WASHINGTON STATE UNIVERSITY
EXTENSION

World Class. Face to Face.

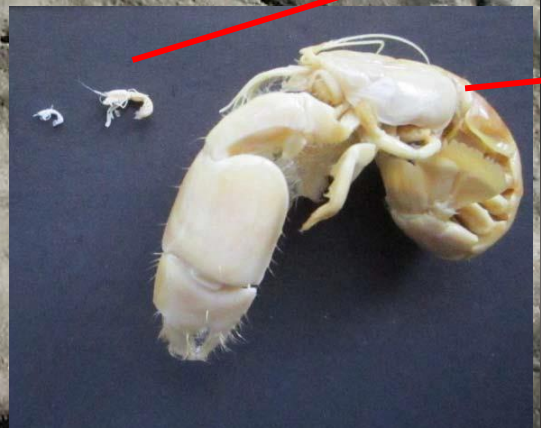
An overview of the research effort to manage invasive eelgrass and burrowing shrimp

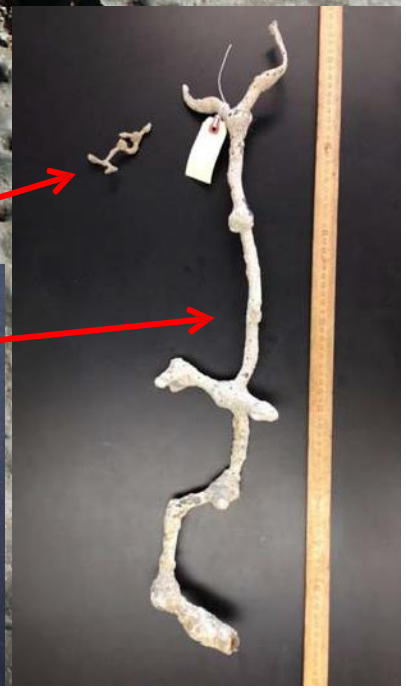
- What has been done
- What is the current status
- What are the impacts

Kim Patten, WSU Extension

Burrowing Shrimp

The problem





The research effort since ~ 2000

Scientists working on burrowing shrimp control and biology since 2000

Universities

WSU: Jim Durfey, Kim Patten, Steve Bollens, Steve Sylvester, Allan Felsot, Vince Hebert, Doug Walsh, Mike Kahn

UW: Chris Grue, Alan Trimble, Miranda Wecker, Brent Vadopalas, Kristine Feldman, Dave Armstrong, John Frew,

University of Idaho: Jim Liou, Thomas Weaver

OSU: John Chapman, Anthony D'Andrea, Katelyn Bosley

University of Oregon: Alan Shanks

San Jose State University: Leslee Parr, Josh Mackie

Federal Agencies

USDA: Brett Dumbauld

EPA: Ted Dewitt

IR4: Keith Dorschner, Rebecca Sisco

Others

Pacific Shellfish Institute: Steve Booth, Dan Cheney, Andrew Suhrbier

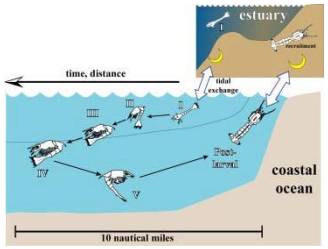
Ag. Development Group: Alan Schreiber

Taylor Resources: Chris Barker, Kurt Johnson

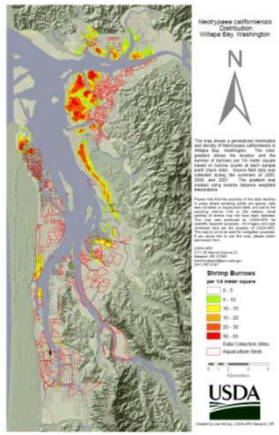
Smith Root: Lisa Harlan

This new research effort had many approaches

Understand basic biology/ecology



Monitor recruitment, map population trends



Burrowing Shrimp IPM

Cultural control

Biological control

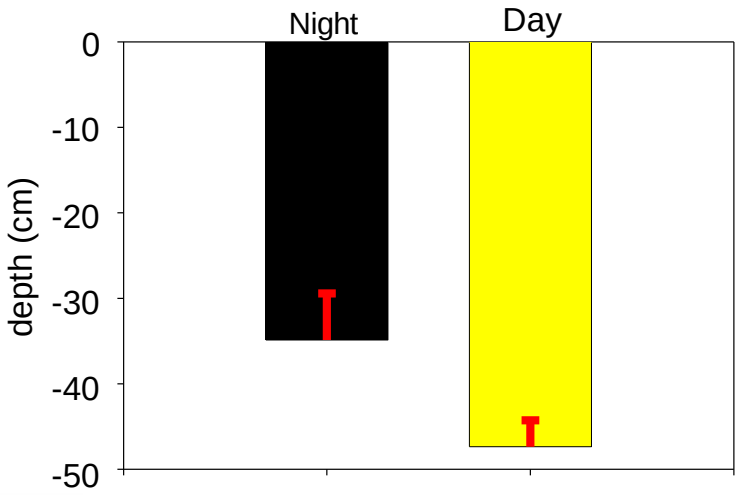
Chemical control

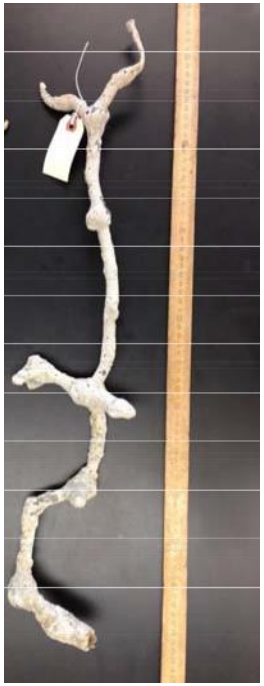
Mechanical / physical management

Mechanical control

- Crushing
- Covering
- Cutting
- Disking
- Electrifying
- Netting
- Heating
- Sound waves

Mean shrimp depth as a function of time of day

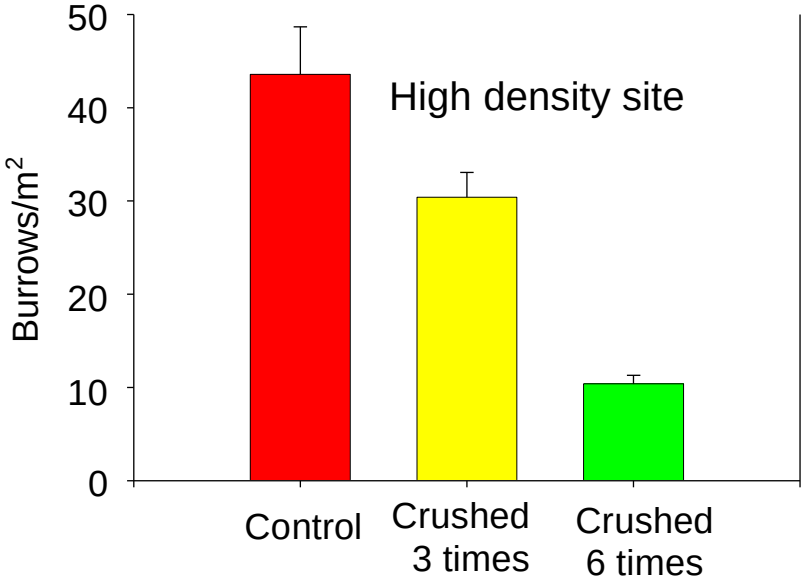




Ghost Shrimp Burrow 1 m deep

Can we target shrimp when they are close to the surface?

Can We Crush Them?



Can we mechanically disrupt and kill them with disking

- not effective on adult shrimp

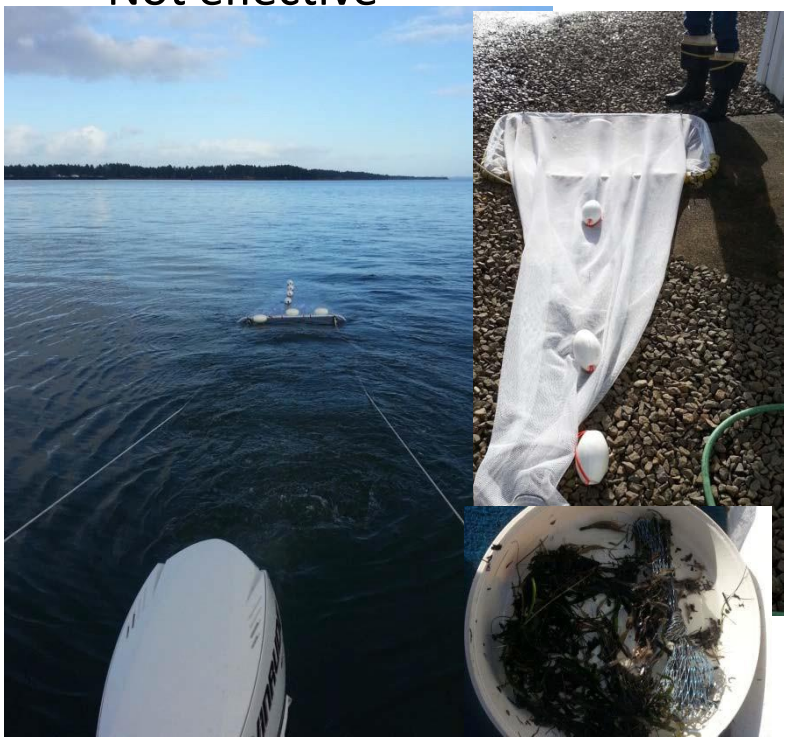
Can we mechanically damage them with high pressure water jets?

High pressure water jets & Taylor water sled

Can we mechanically or electro-shock them into the water column?

Invertebrate tow net with prop wash

– Not effective



Electro-shocking

- Initial research efforts by USDA– not effective

Subsurface suction or subsurface bubbler + tow netting

- Only effective for monitoring

Sound waves

- Not effective to date

Can we kill them with heat or concussive force?

Heat via 4 minutes of torching/m^2
- Not effective

Explosion via propane – oxygen injection into burrows

- Not effective

Can we cover and smother them?

Thin layer of cement

Plastic tarp for 5 days

Mechanical options have not worked to date

- The environment
- Their depth
- Their tolerance to O_2
- Their life cycle

Biological control

- Parasites
- Habitat competition
- Predation
- Habitat modification with invasive species

Parasites

Non-native Isopods for Biological Control of Burrowing Shrimp

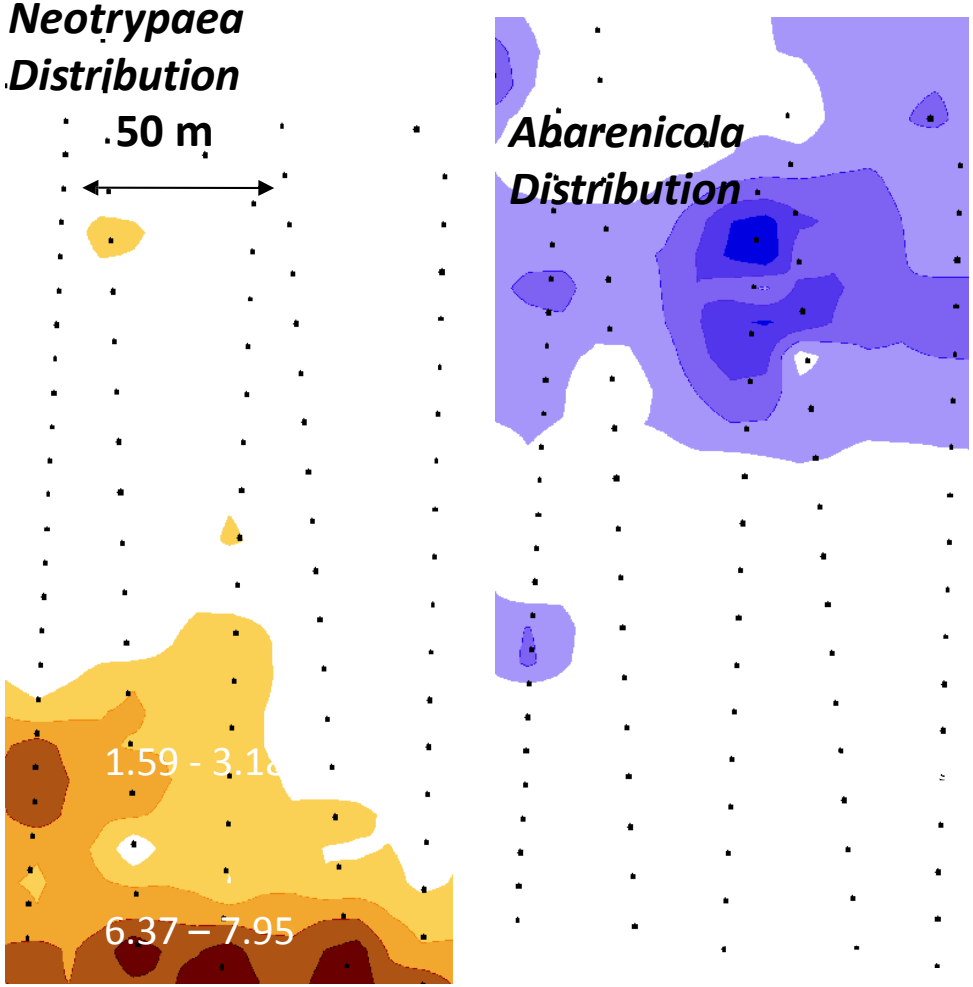
- Caused near extinction of mud shrimp
- No effect on ghost shrimp

Habitat competition

Lugworm

***Neotrypaea* Distribution**

50 m

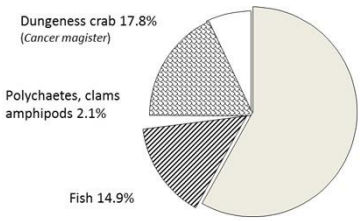


***Abarenicola* Distribution**

Predation

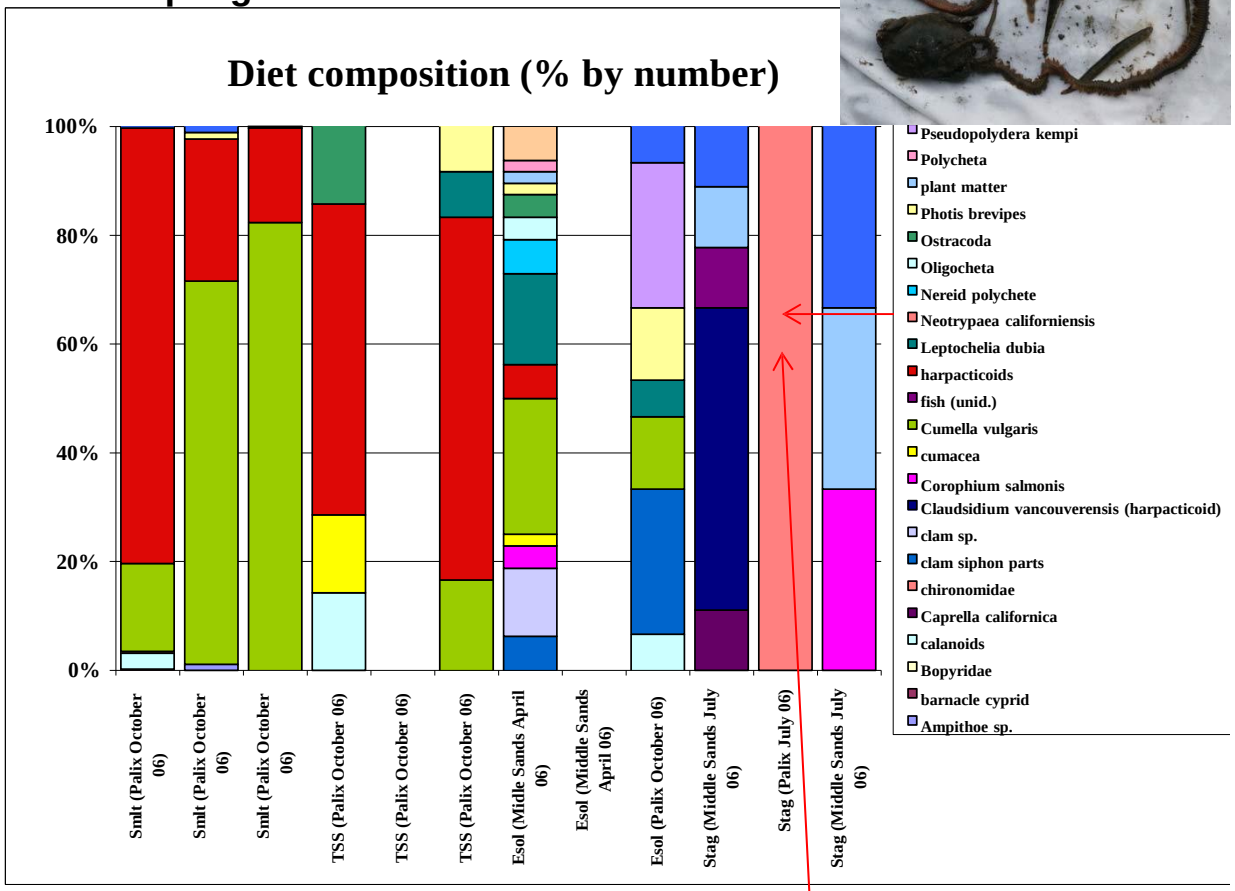
Green sturgeon

Crangonid shrimp 7.1%



Sturgeon do consume burrowing shrimp, but?

Willapa Bay Forage Fish Predator Sampling Counts



Only sculpins at one site consumed ghost shrimp

Habitat modification with invasive species

Invasive *Polychaeta:*
Pseudopolydora paucibranchiata

At high densities (3-5/ cm^2) *Pseudopolydora*– could firm sediment and possibly slow oysters from sinking.

But at what cost?

Biological control options have not worked to date

- Not selective
- Not effective
- Not manageable
- Not legal

Cultural methods / alternative production systems

- Off-bottom culture
- Site selection

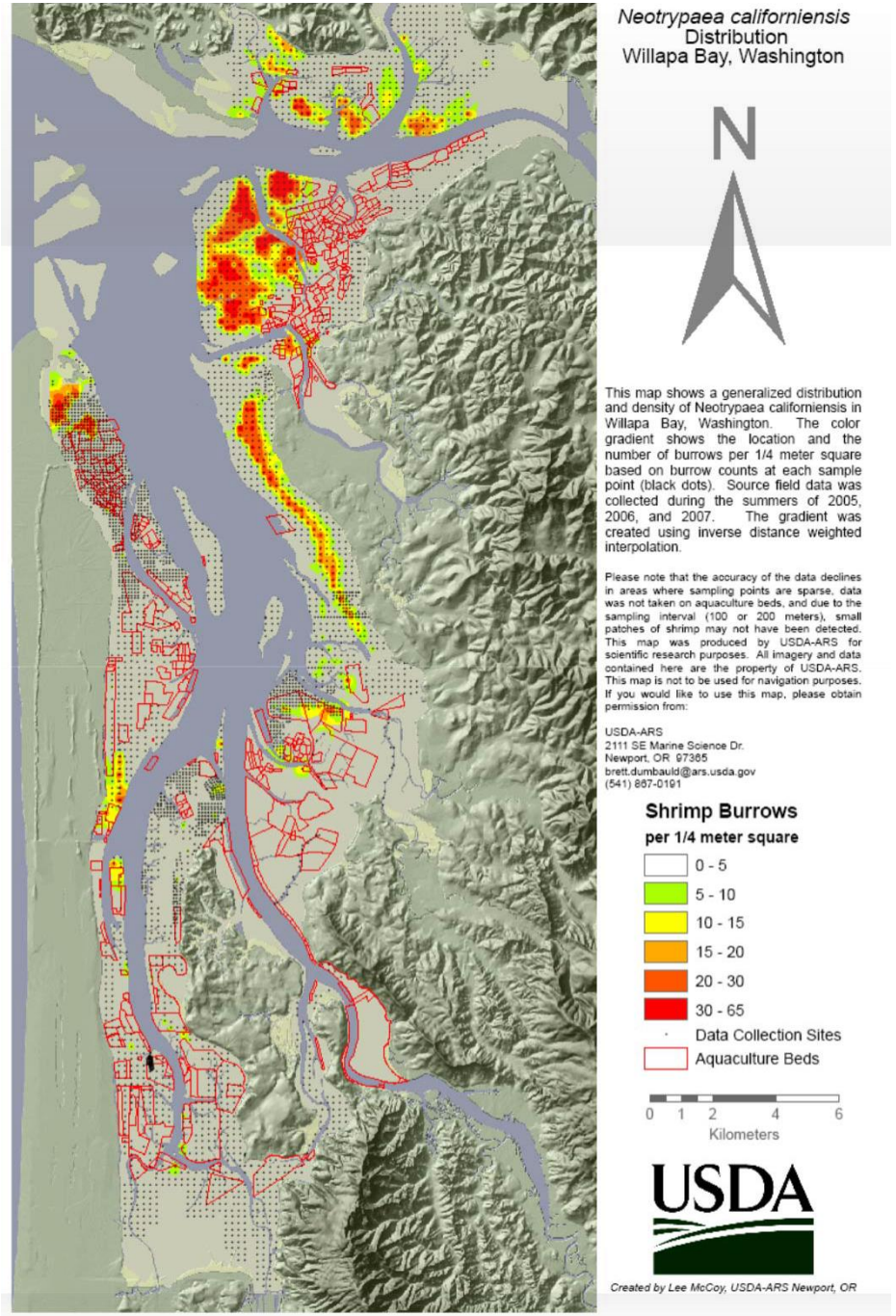
Off-bottom culture won't work if burrowing shrimp populations are too high

Destroyed long-line farm in less than 6 months

Off-bottom culture is only an option is protected areas. Most growers don't have protected sites.

Population dynamic

- How long do they live? (up to 12 years)
- Do adults move? (no)
- Recruitment – location and rate? (Recent uptick in numberS)



Cultural methods

- Alternative system won't work if shrimp populations are too high, and new recruitment numbers are a cause for concern.
- Willapa Bay is 95% bottom culture. Any switch to off-bottom culture is very problematic. Limited options due to market and bed ownership.

Chemical control

- Chemical screening
- Application methods
- Assessments of nontarget impact
- Permitting

Chemistries evaluated

- **Does it work at rates that are viable?**
- **Is the product registerable ?**
-

Essential plant oils
- •clove oil
- •cinnamon oil
- • citronella oil
- • cedar oil
- • linseed oil
- • garlic oil
- • geranium oil
- • peppermint oil
- • rosemary oil
- • thyme oil
- • neem oil

Other compounds
- • bleach
- • $KMnO_4$
- • 2-phenethyl propionate
- • potassium sorbate
- • super oxygenated water
- • fresh water

Fertilizers or minerals
- •sulfur
- • NaCl
- •MgCl
- •KCl
- • lime
- • copper
- • urea ammonium nitrate
- • aqua ammonium
- • ammonium thiosulfate
- • Kyrocide
- • ammonium sulfate

Plant extracts or "natural" insecticides
- • crushed chrysanthemums
- • naturally extracted pyrethrum
- • mustard seed meal
- • habanero pepper extract
- • yucca extract
- • sabadilla
- • white pepper
- • geranial
- • citric acid
- • malic acid
- • hydrogen peroxide
- • potassium salts of fatty acids
- • SeaKlean

Insecticide
- • carbaryl
- •Spectrus
- •Belay (clothianidin)
- • Esteem (pyriproxyfen)
- • Methoprene
- •synthetic pyrethrums
  - •Deltaguard (deltamethrin)
  - •Bigrade (bifenthrin)
  - •zeta-cypermethrin)
- •imidacloprid

Chemistries evaluated to date: 2003 to 2016 data

Essential plant oils
- clove oil
- cinnamon oil
- citronella oil
- cedar oil
- linseed oil
- garlic oil
- geranium oil
- peppermint oil
- rosemary oil
- thyme oil
- neem oil

Other compounds
- bleach
- $KMnO_4$
- 2-phenethyl propionate
- potassium sorbate
- super oxygenated water
- fresh water

Fertilizers or minerals
- sulfur
- NaCl
- MgCl
- KCl
- Lime
- copper
- urea ammonium nitrate
- aqua ammonium
- ammonium thiosulfate
- Kryocide
- ammonium sulfate

Plant extracts or "natural" insecticides
- crushed chrysanthemums
- naturally extracted pyrethrum
- mustard seed meal
- habanero pepper extract
- yucca extract
- sabadilla
- white pepper
- geranial
- citric acid
- malic acid
- hydrogen peroxide
- potassium salts of fatty acids
- SeaKlean

Insecticide
- carbaryl
- Spectrus
- Belay (clothianidin)
- Esteem (pyriproxyfen)
- Methoprene
- synthetic pyrethrums
  - Deltaguard (deltamethrin)
  - Bigrade (bifenthrin)
  - zeta-cypermethrin)
- **imidacloprid**

Chemical screening

After >15 years of work only one compound, imidacloprid, had the three key components to be a suitable alternative to carbaryl.

- It had reasonable efficacy, at a reasonable rate.
- It had the potential for minimal non-target impacts.
- It had a viable pathway towards registration.

Going from screening to registration

- Efficacy
  - Formulation and application method
  - Small-scale plots to commercial scale trials
- Registration package and NPDES
  - Fate and persistence in environment
  - Nontarget impacts: megafauna and infauna
  - Lab studies, small field trials, large commercial trials

Subsurface injection from a barge with shanks and harrows

Subsurface injection from ground using spikewheels

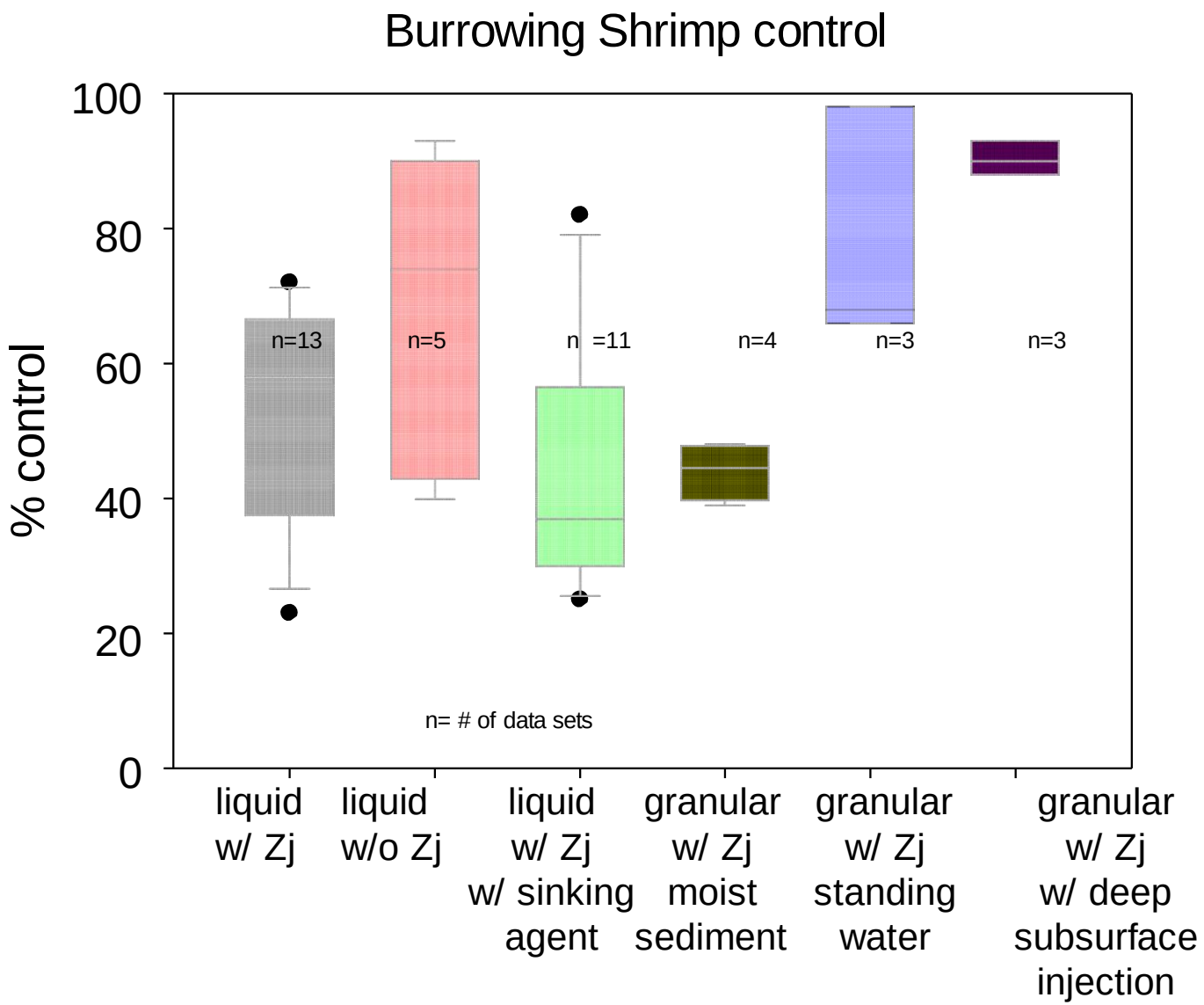

ARCTIC CAT

Subsurface injection from a barge with spikewheels

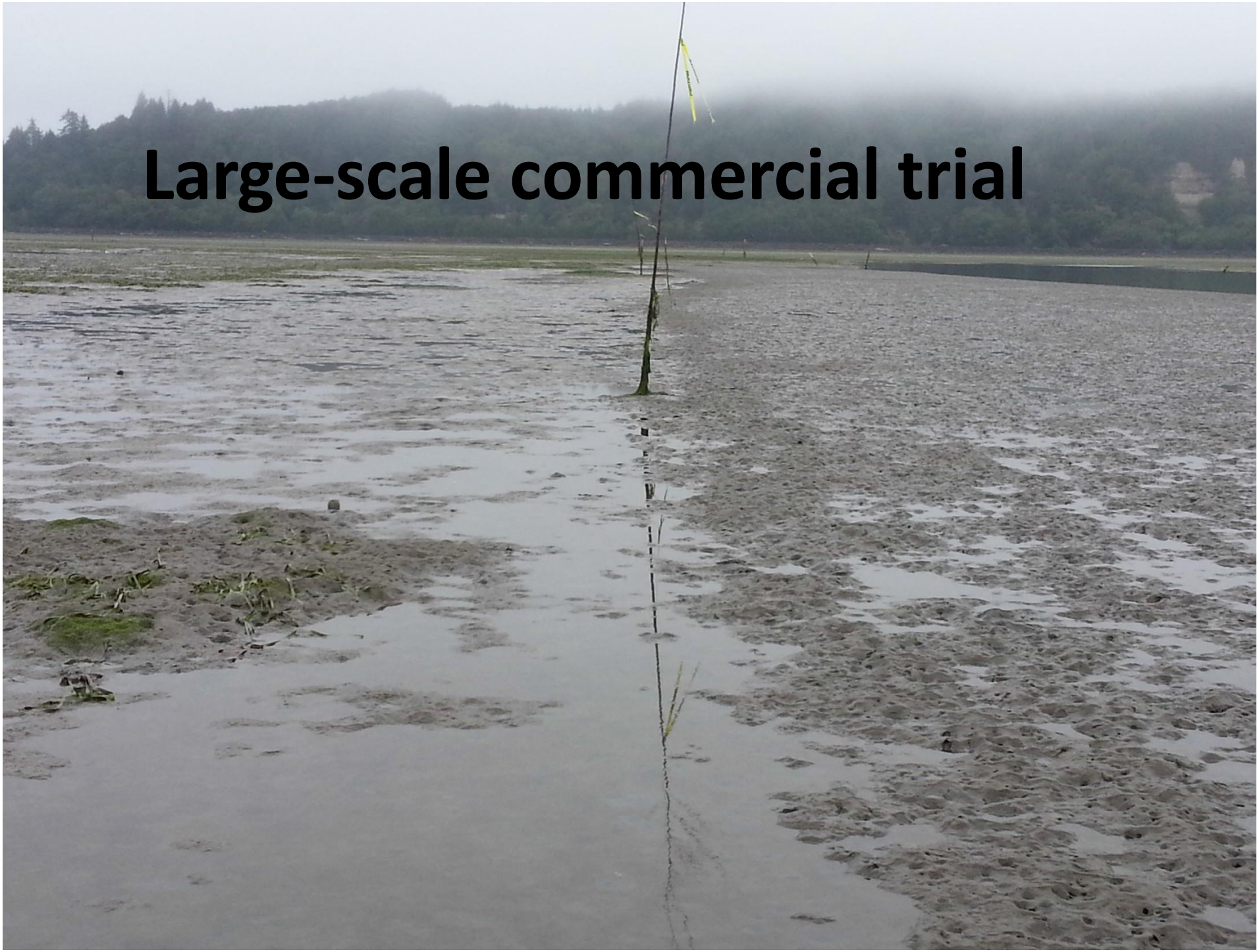
Granular applications by ground

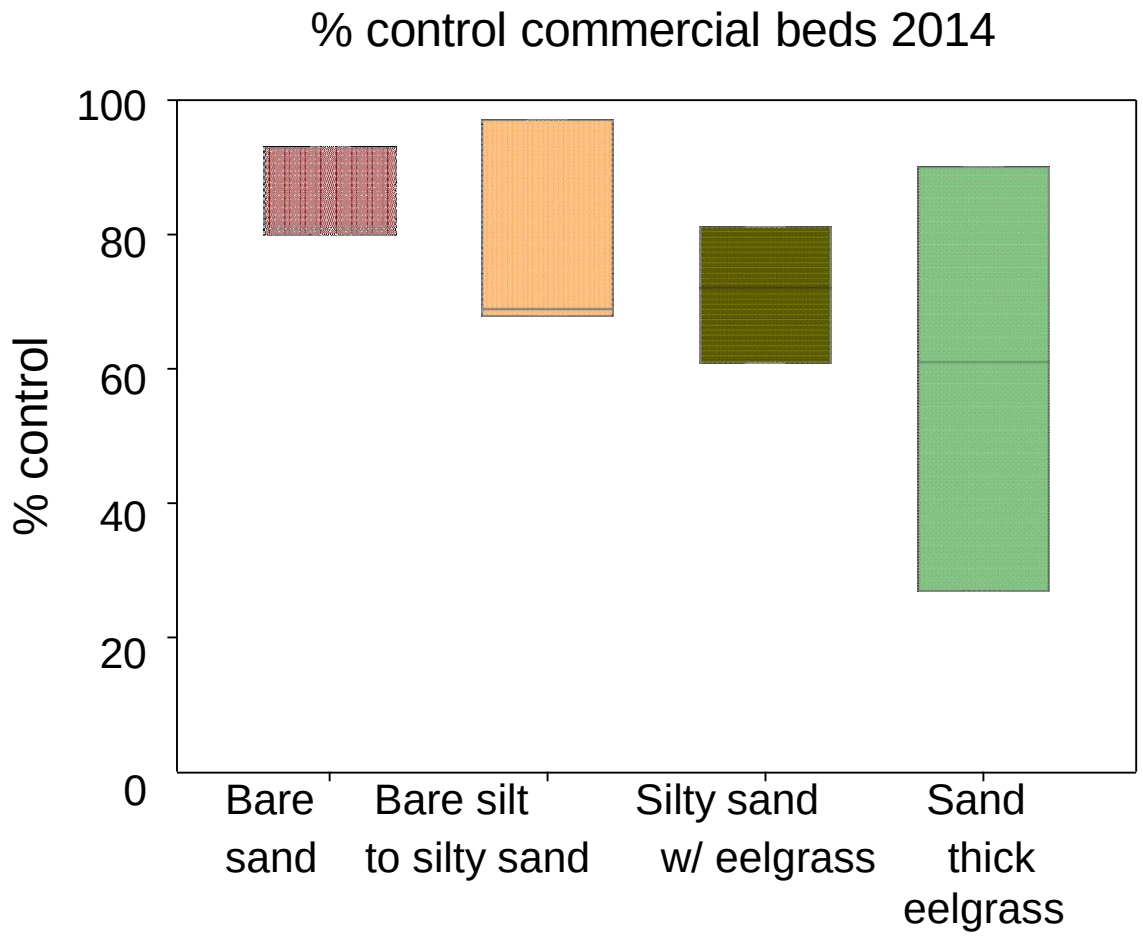
Granular applications by air

Granular applications by sea



2014 research data


Large-scale commercial trial



- ***Efficacy highly variable, and some sites are very problematic.***
- ***Suppresses populations of burrowing shrimp, but it is not carbaryl.***

Summary of efficacy

- Imidacloprid @ 0.5 lbs ai/ac is not carbaryl @ 8 lbs ai/ac
- Efficacy is variable and affected by numerous conditions
- Application methods and formulations can be used to improve efficacy
- It is going to take more trial and error to obtain consistent efficacy.

Fate and persistence of imidacloprid in environment

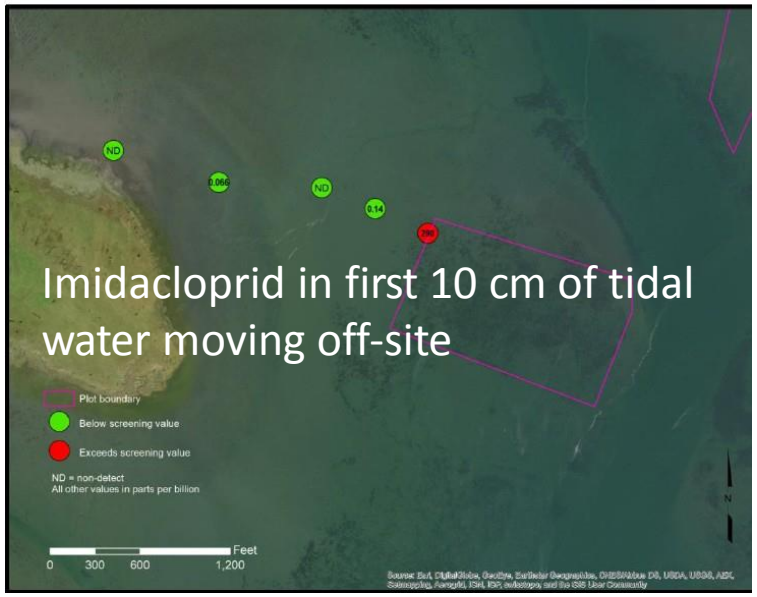
From 2010 to 2014

- **13 large-scale (10 to 100 acres) applications to monitor nontarget impacts, movement, persistence of imidacloprid and its metabolites.**
- **Comparisons were made to matched untreated control sites**

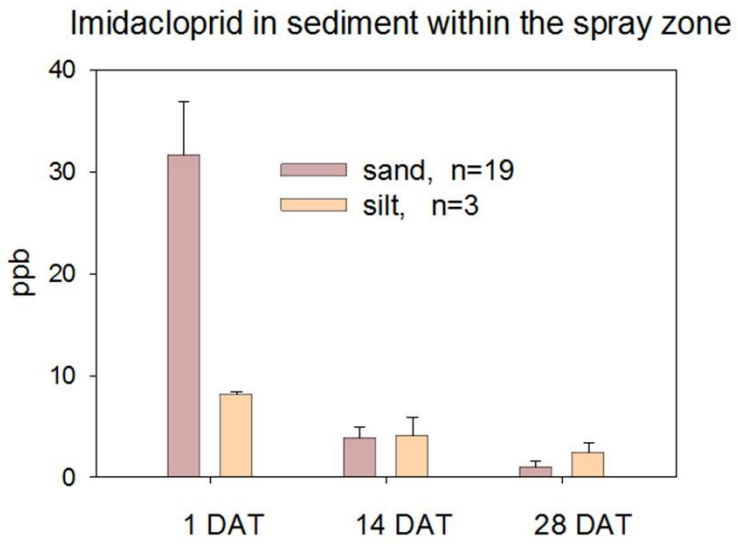
No imidacloprid residue in product

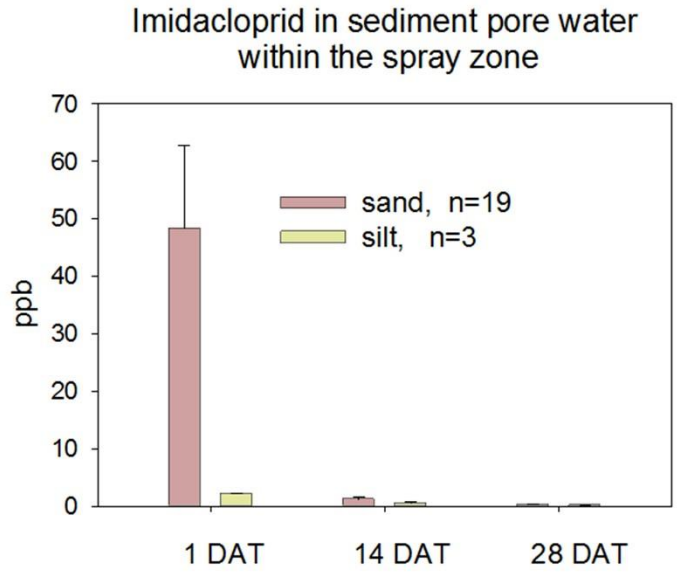
Zero residue of imidacloprid and/or its metabolites in shucked meat at 30 day after treatment at 4X label rate

Rapid dilution in tidal column



Short persistence in sediment– exponential decay





Minimal impact to megafauna

Direct over-spray of caged crab

Brain and blood assays of fish

Post-treatment field survey for affected megafauna

Infauna - abundance and diversity

- Pretreatment vs 14 and 28 days post-treatment
- Proportional to untreated control site
  - Some occasional minor 14 day effects
  - No significant 28 day impacts
  - Treatment only accounts for a very minor part of the variability of infauna

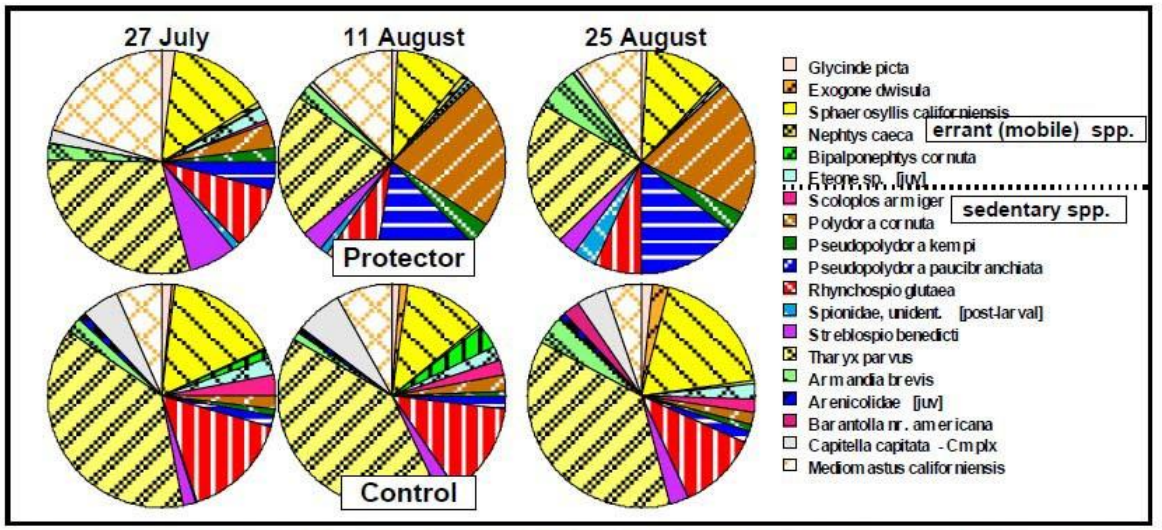


Figure 12 – Proportional abundance of 19 of 54 polychaetes at the Protector-treated and control plots before treatment (July 27) and at 14 and 28 days after treatment (11 August, 25 August)

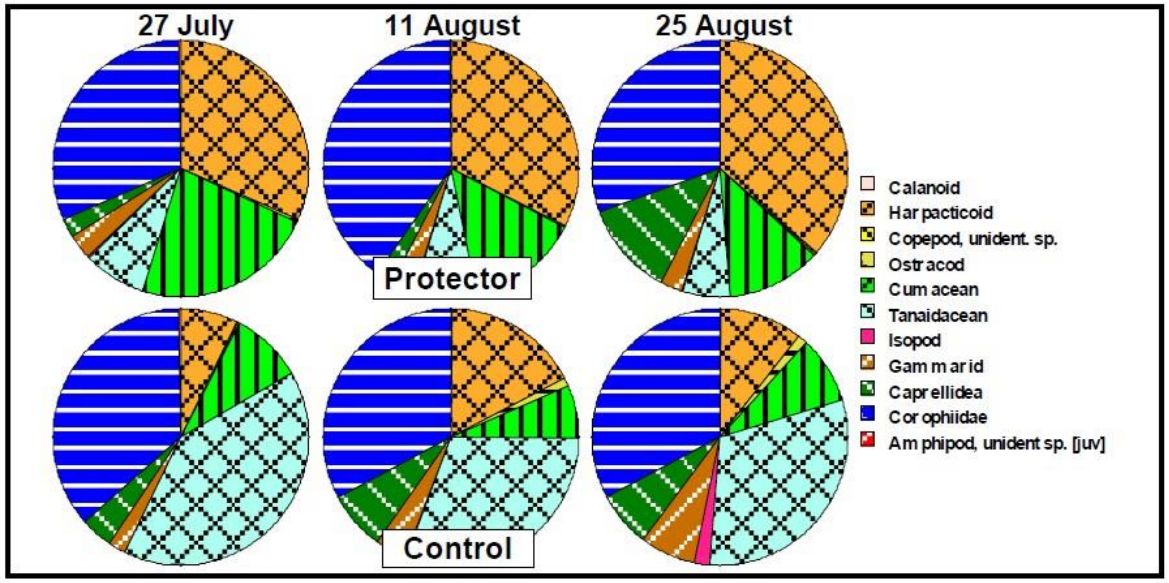


Figure 18 – Proportional abundance of 11 of 14 crustaceans at Protector-treated and control plots before treatment (27 July) and at 14 and 28 days after treatment (11 August, 25 August)

After extensive field testing: label and NPDES for imidacloprid

GROUP 4A INSECTICIDE

PROTECTOR 2F

NOT FOR SALE TO ANY PERSON OTHER THAN A MEMBER OF THE WILLAPA-GRAYS HARBOR OYSTER GROWERS ASSOCIATION

ACTIVE INGREDIENT:
Imidacloprid: 1-[(6-Chloro-3-pyridinyl)methyl]-N-nitro-2-imidazolidinimine..... 21.4%
OTHER INGREDIENTS:..... 78.6%
TOTAL:..... 100.0%

Contains 2 pounds of imidacloprid per gallon.

KEEP OUT OF REACH OF CHILDREN
CAUTION-CAUCION

Si usted no entiende la etiqueta, busque a alguien para que se la explique a usted en detalle.
(If you do not understand the label, find someone to explain it to you in detail.)

EPA Reg. No. 86867-2
EPA EST #226-IL-002

SHAKE WELL BEFORE USING

Net Contents: 2.5 Gal. (9.46 L)

DEPARTMENT OF ECOLOGY
State of Washington

Page 1 of 28
Permit No. WA0039781

Issuance Date: April 16, 2015
Effective Date: May 16, 2015
Expiration Date: May 15, 2020

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM
WASTE DISCHARGE PERMIT NO. WA0039781

State of Washington
DEPARTMENT OF ECOLOGY
Olympia, Washington 98504-7775

In compliance with the provisions of
Chapter 90.48 Revised Code of Washington
(State of Washington Water Pollution Control Act)
and
Title 33 United States Code, Section 1251 et seq.
The Federal Water Pollution Control Act (The Clean Water Act)

The Willapa Grays Harbor Oyster Growers Association
P.O. Box 3
Ocean Park, Washington 98640

Final Environmental Impact Statement Control of Burrowing Shrimp using Imidacloprid on Commercial Oyster and Clam Beds in Willapa Bay and Grays Harbor, Washington

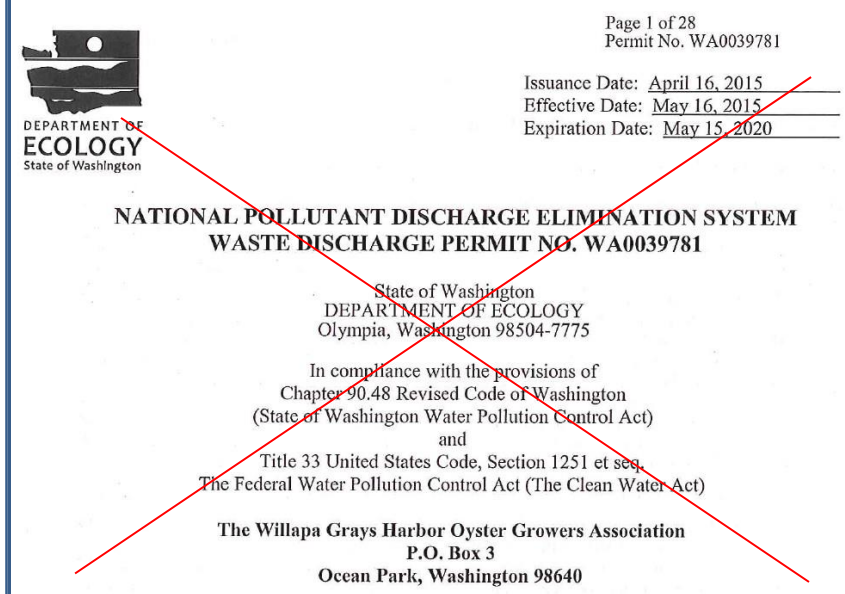
DEPARTMENT OF ECOLOGY
State of Washington

Water Quality Program
Washington State Department of Ecology
Olympia, Washington
April 9, 2015
Publication no. 15-10-013

Issues voiced by WDFW in comment letter on NPDES

Issue	Research findings
Dungeness crab	No large-scale impacts on Dungeness have been noted (1 to 2 orders of magnitude less than carbaryl) Minor 1-2 day post- treatment forage by gulls noted Spatial / temporal safety factor for larval crab and tropic effects
Finfish	No additional information has been collected Temporal safety factor
Drift from aerial spray	None noted to date; new permit won't include aerial

NPDES withdrawn prior to its use in 2015



Page 1 of 28
Permit No. WA0039781

DEPARTMENT OF ECOLOGY
State of Washington

Issuance Date: April 16, 2015
Effective Date: May 16, 2015
Expiration Date: May 15, 2020

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM
WASTE DISCHARGE PERMIT NO. WA0039781

State of Washington
DEPARTMENT OF ECOLOGY
Olympia, Washington 98504-7775

In compliance with the provisions of
Chapter 90.48 Revised Code of Washington
(State of Washington Water Pollution Control Act)
and
Title 33 United States Code, Section 1251 et seq.
The Federal Water Pollution Control Act (The Clean Water Act)

The Willapa Grays Harbor Oyster Growers Association
P.O. Box 3
Ocean Park, Washington 98640

Request for new NPDES resubmitted January 2016

- 500 instead of 2000 acres
- No aerial spraying
- Permit not likely to be granted in time for use in 2016

Summary of the research effort to develop a control for burrowing shrimp.

- Very extensive and costly effort.
- Science behind the program is solid and it has been very well vetted .
- Minor nontarget impacts and off-site movement issues.

Zostera japonica – non-native eelgrass

3/29/09

9/2/09

Japanese eelgrass in Willapa Bay

•It currently covers much of the upper intertidal mudflats in Willapa (10,000+ acres).

•Clam growers treated ~ 300 acres of *Z. japonica* with imazamox in 2014 and 300 acres in 2015.

Why is it so controversial?

- It is an eelgrass with important perceived ecological value
  - Waterfowl and shorebirds
  - Net production and biomass
  - CO_2 absorption (ocean acidification)
  - Habitat for benthic infauna, epifauna, and megafauna
- Control requires a herbicide
  - Potential for off-site nontarget impact

What does the new data say about *Z. japonica*?

- No studies to date have been in estuaries where *Z. japonica* dominates the ecosystem, such as Willapa Bay
- Use of imazamox in Willapa Bay provided research opportunities to look at impacts at the ecosystem-level

Does it really cause crop loss?

- Crop loss for Manila Clam
  - For age class 1 to 3 yrs – 15% reduction in growth/yr with *Z. japonica*
  - *For a harvest cycle of 3 to 5 yrs~ 45% crop reduction*
  - 18,000 lbs/ac @ $1.50/# net X 50 ac/yr

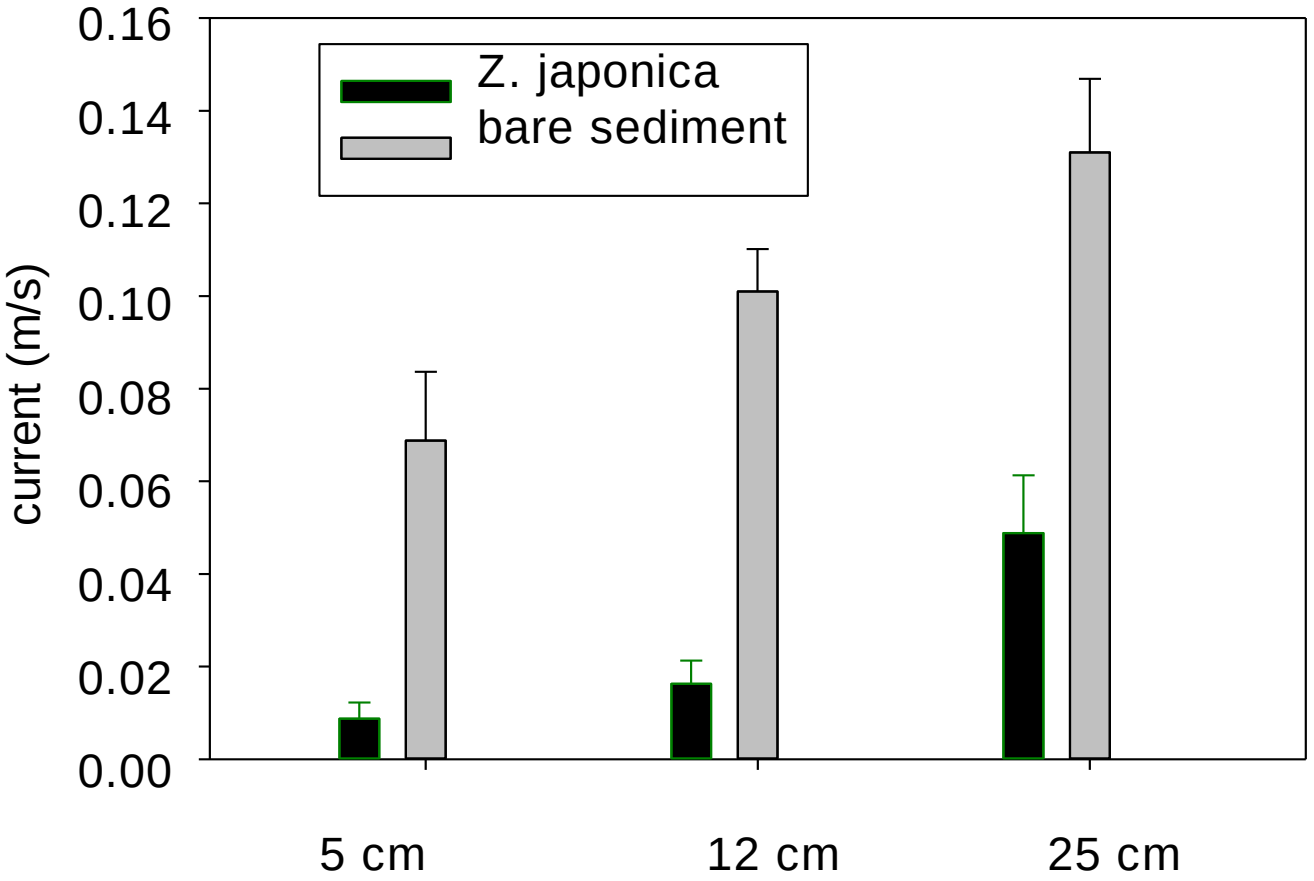
    > $1 M/yr crop loss in Willapa

Why does it cause crop loss?

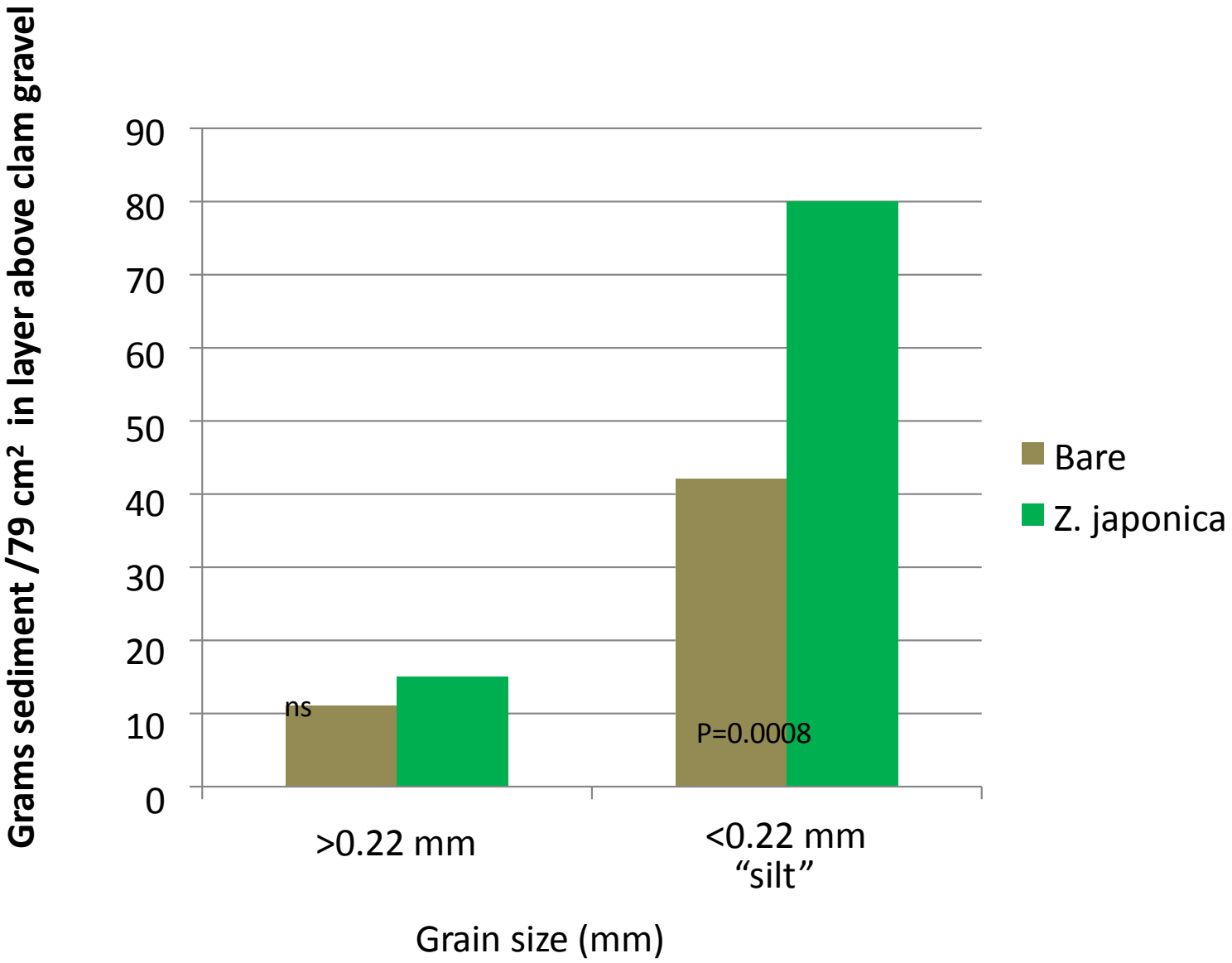
- Access to food
- Accretion of silt
- Increased predation

Reduction in access to food

Effect of *Z. japonica* removal on current above the sediment floor

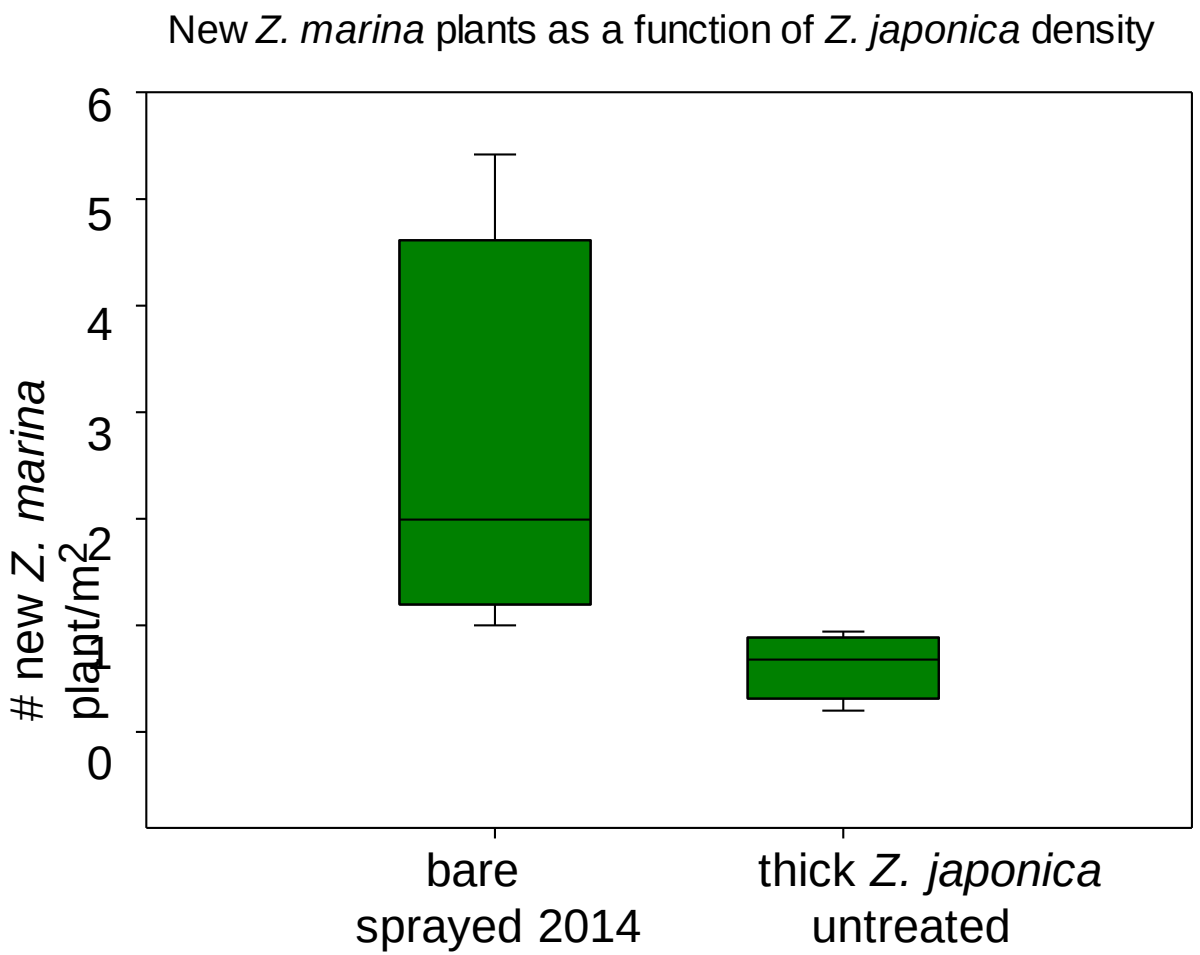


Eelgrass – increases silt accretion over gravel

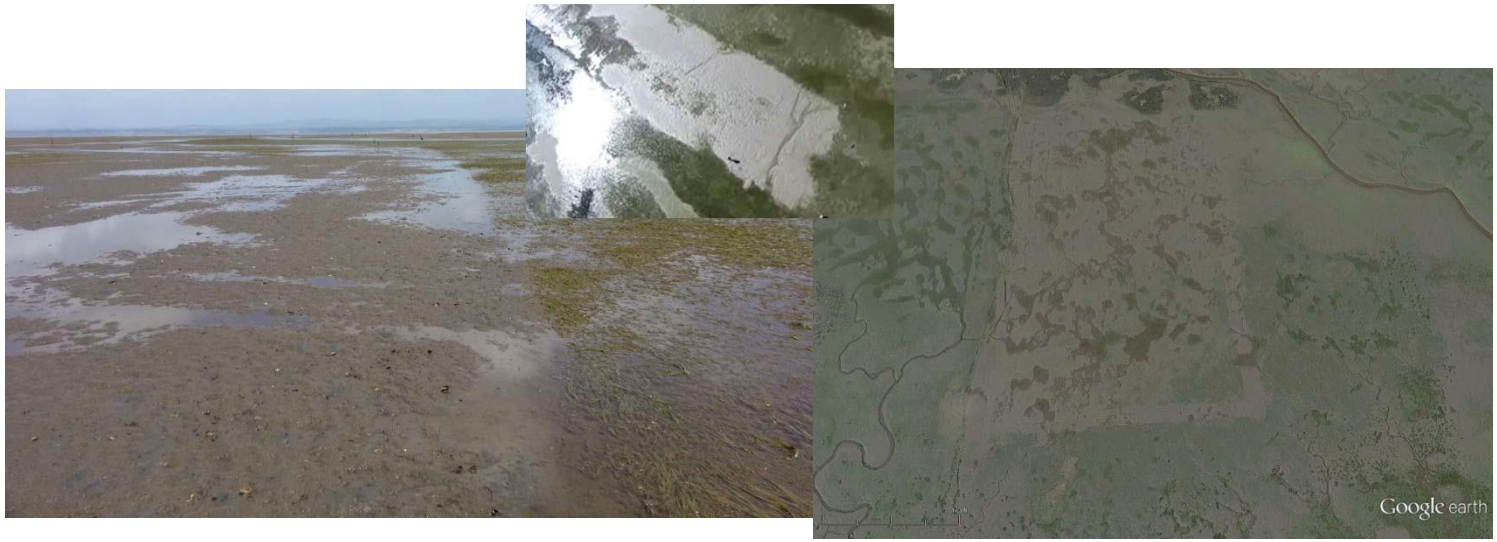


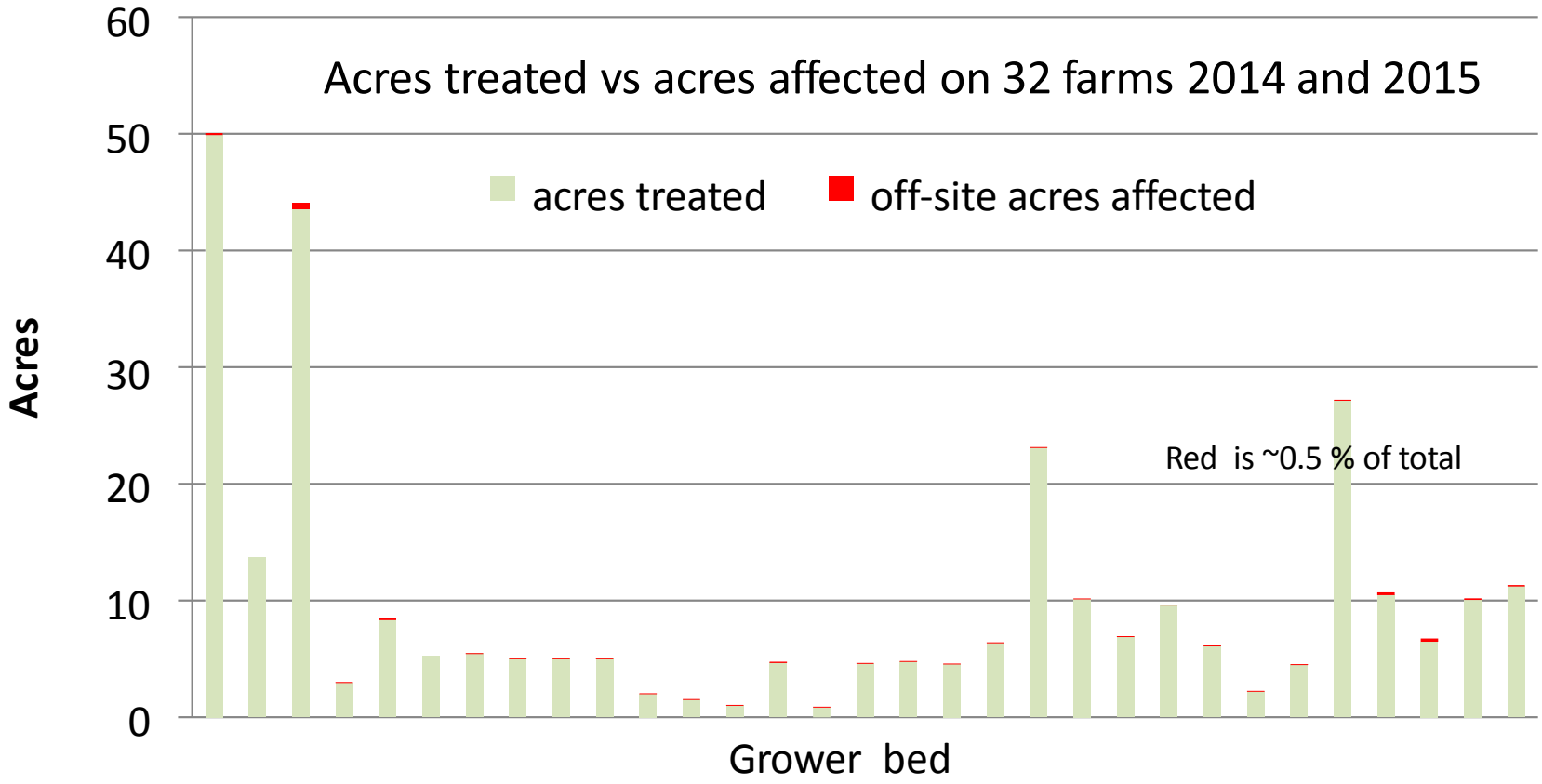
What do we see following a treatment with imazamox?

Does spraying affect the subsequent population of *Z. marina* in treated beds?

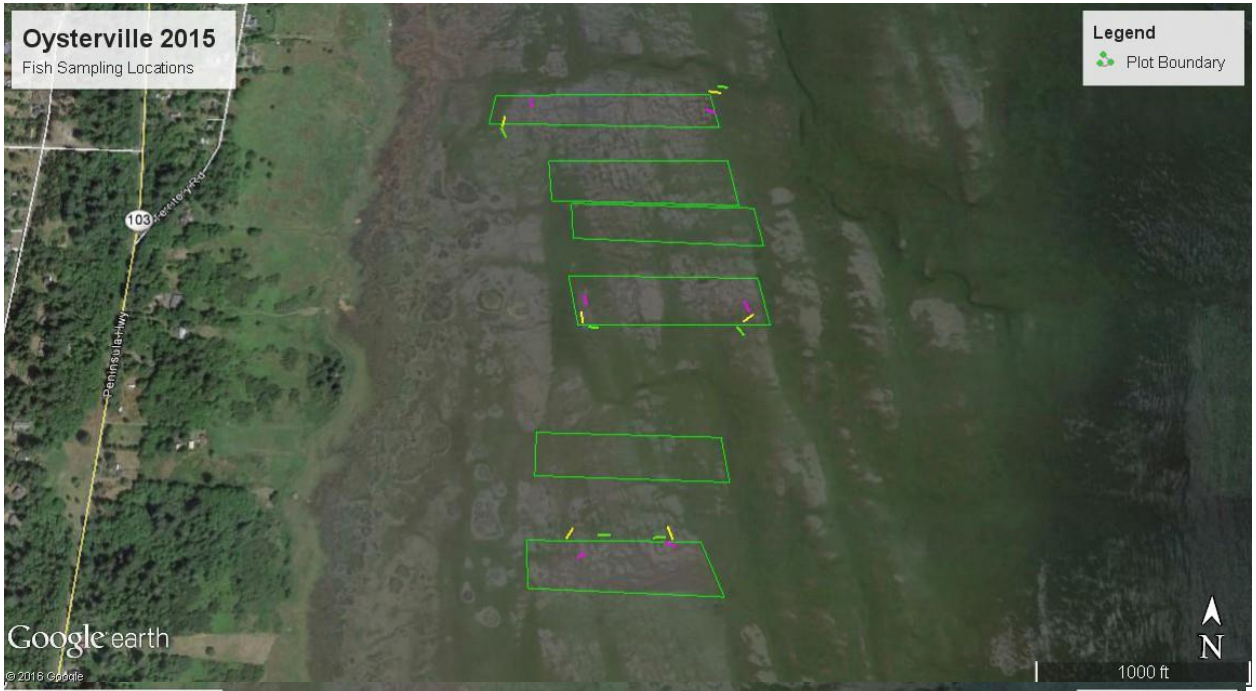


Are there off-site impacts from grower treatment?

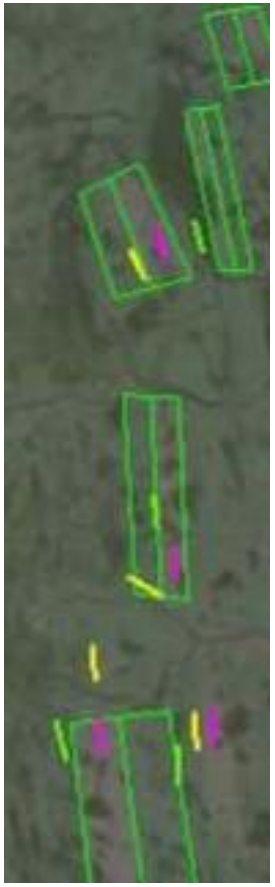




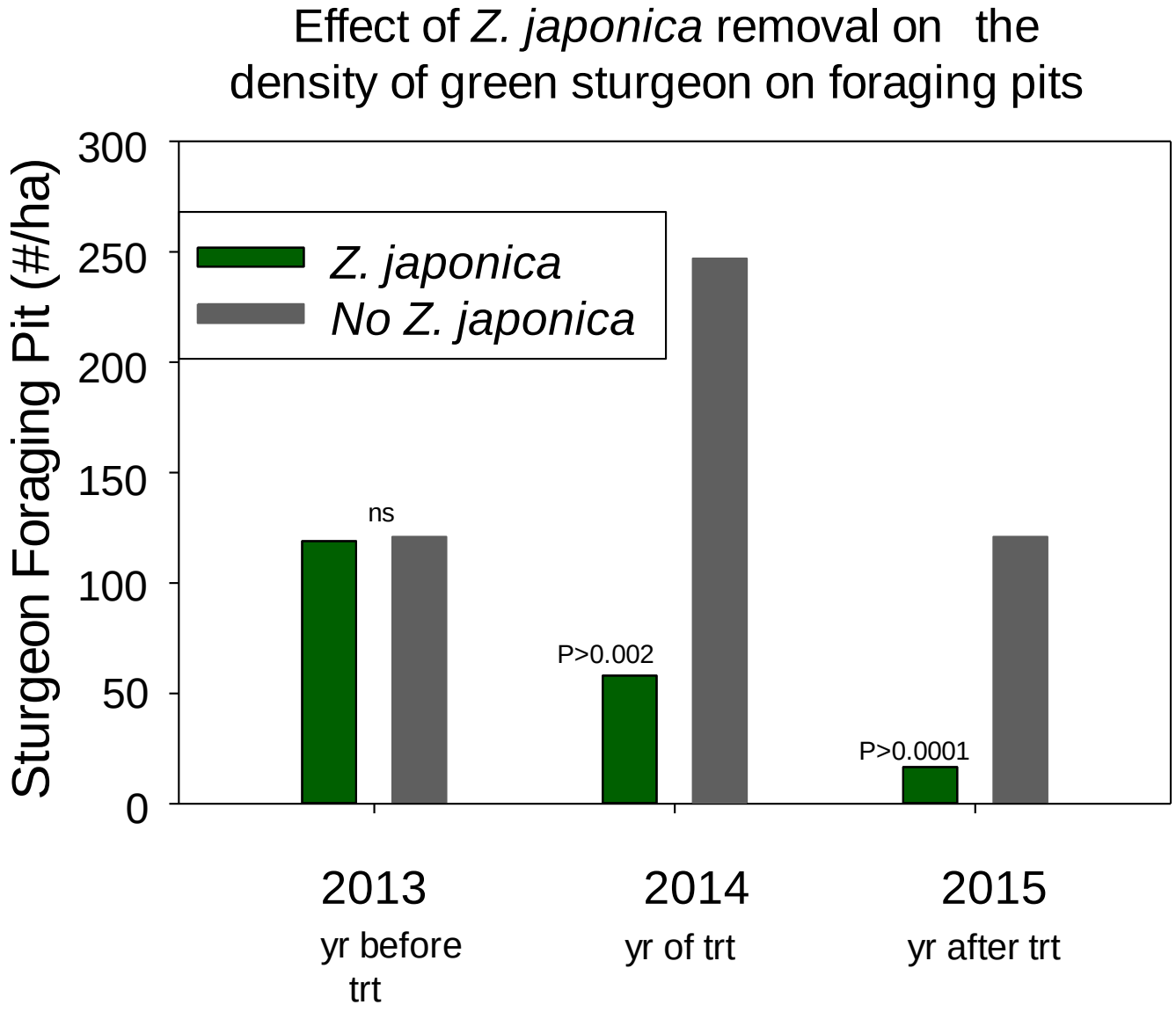

Paired plots for sturgeon and bird usage: 2013 to 2016
Google earth
© 2016 Google



Fish Transects
Bare
Z. Japonica
Z. marina

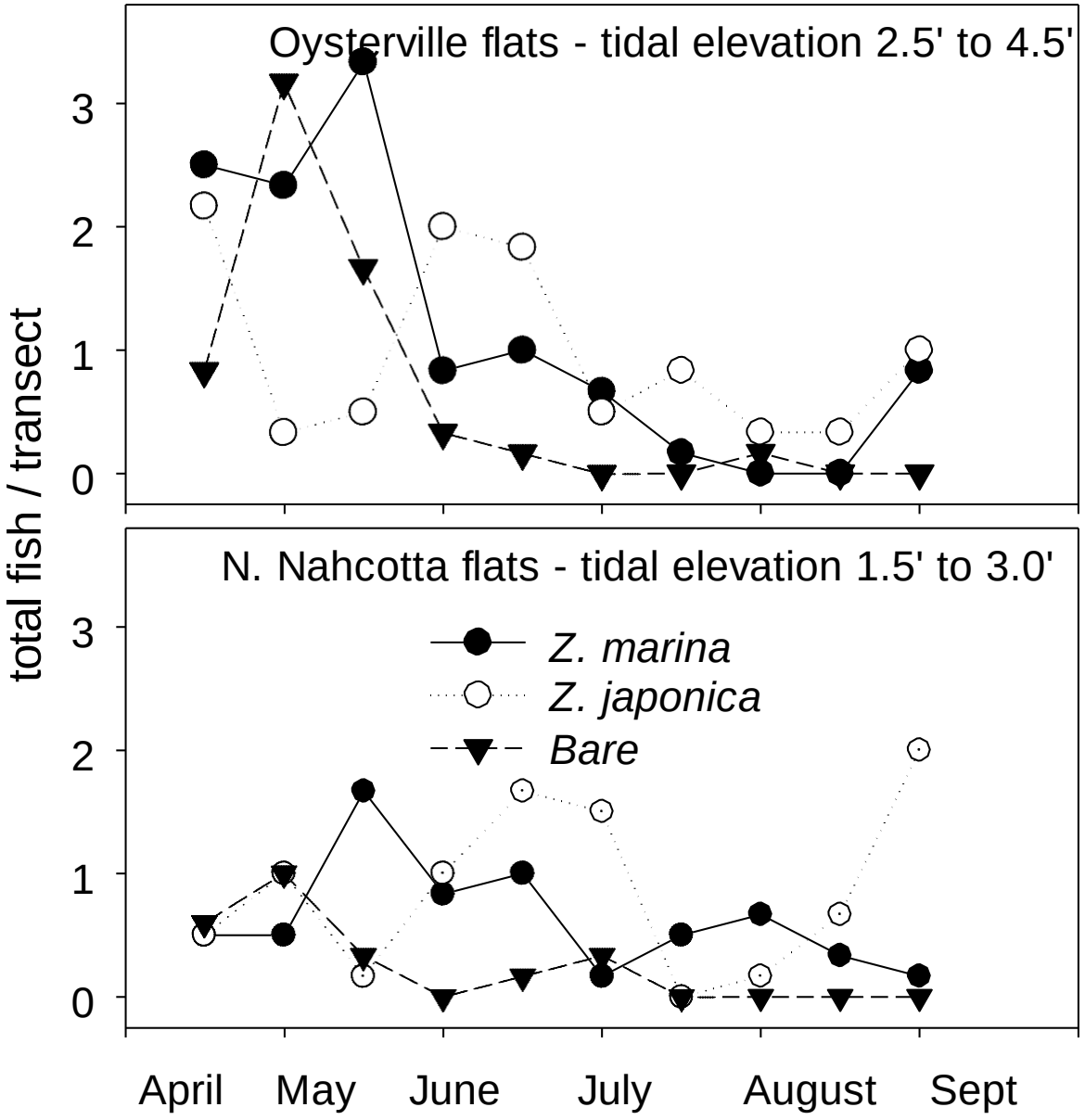


Green sturgeon impacts?

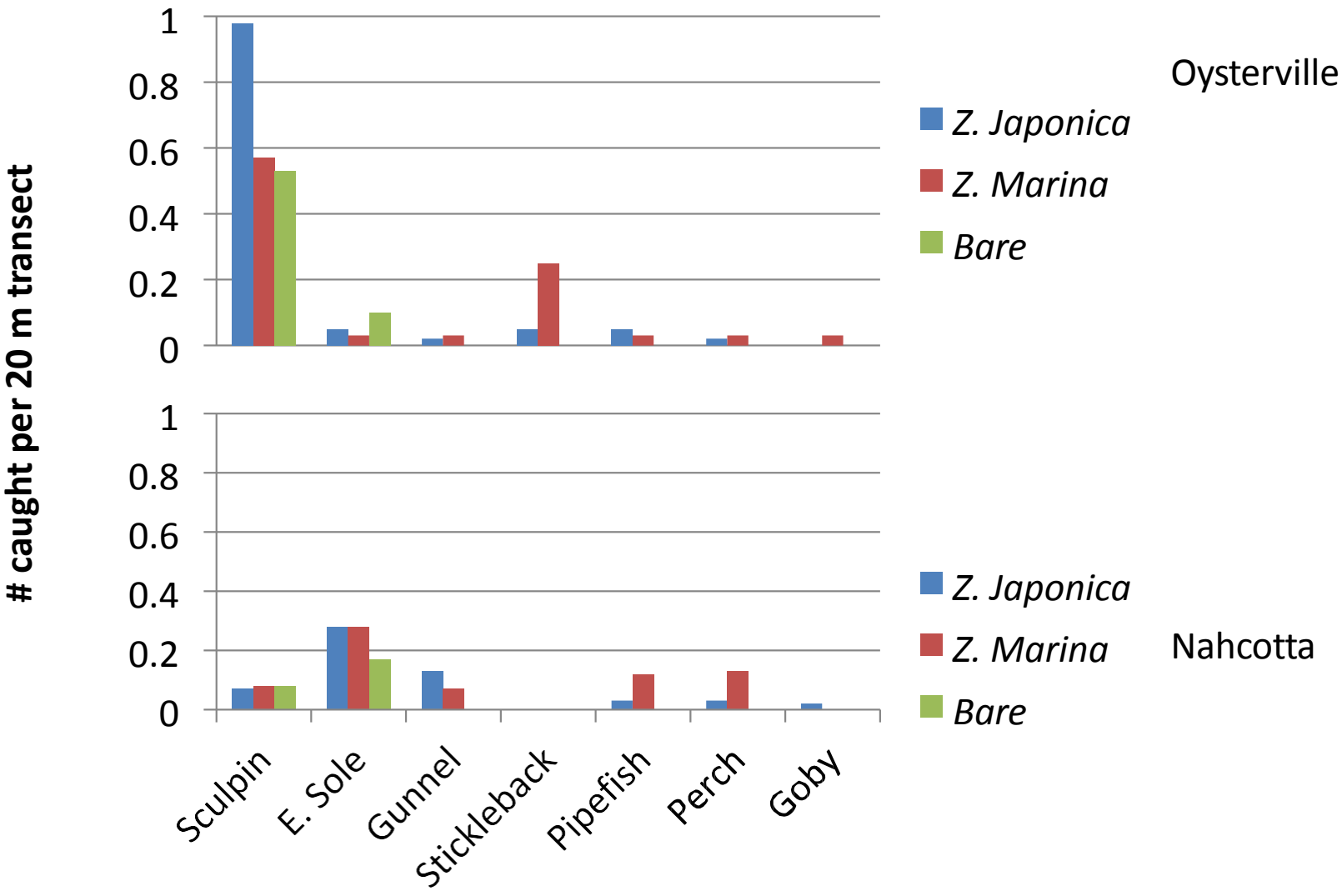


Forage fish impacts?

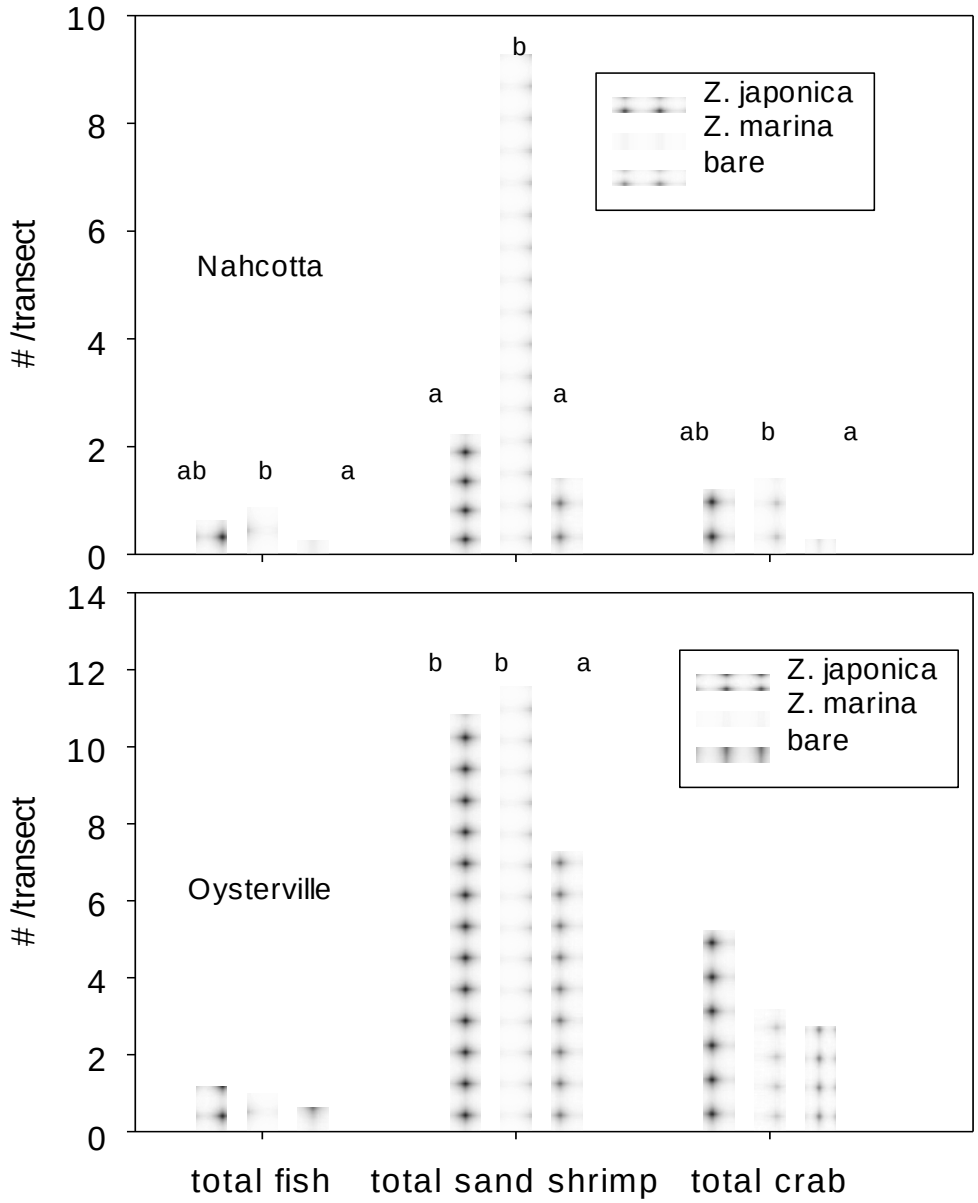
Species by location by time interaction



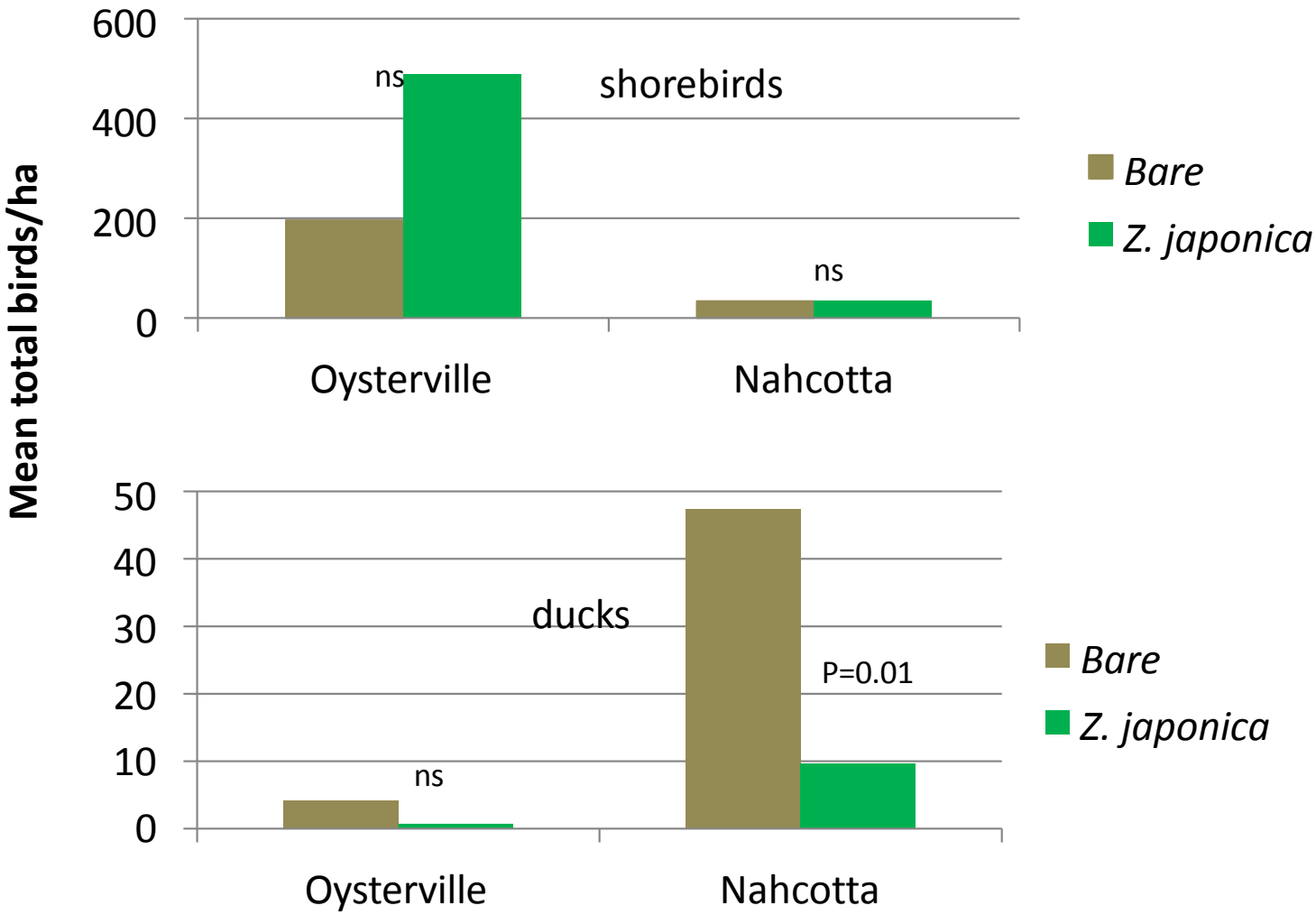
Forage fish impacts?



Forage fish, crangon shrimp and crab impacts?



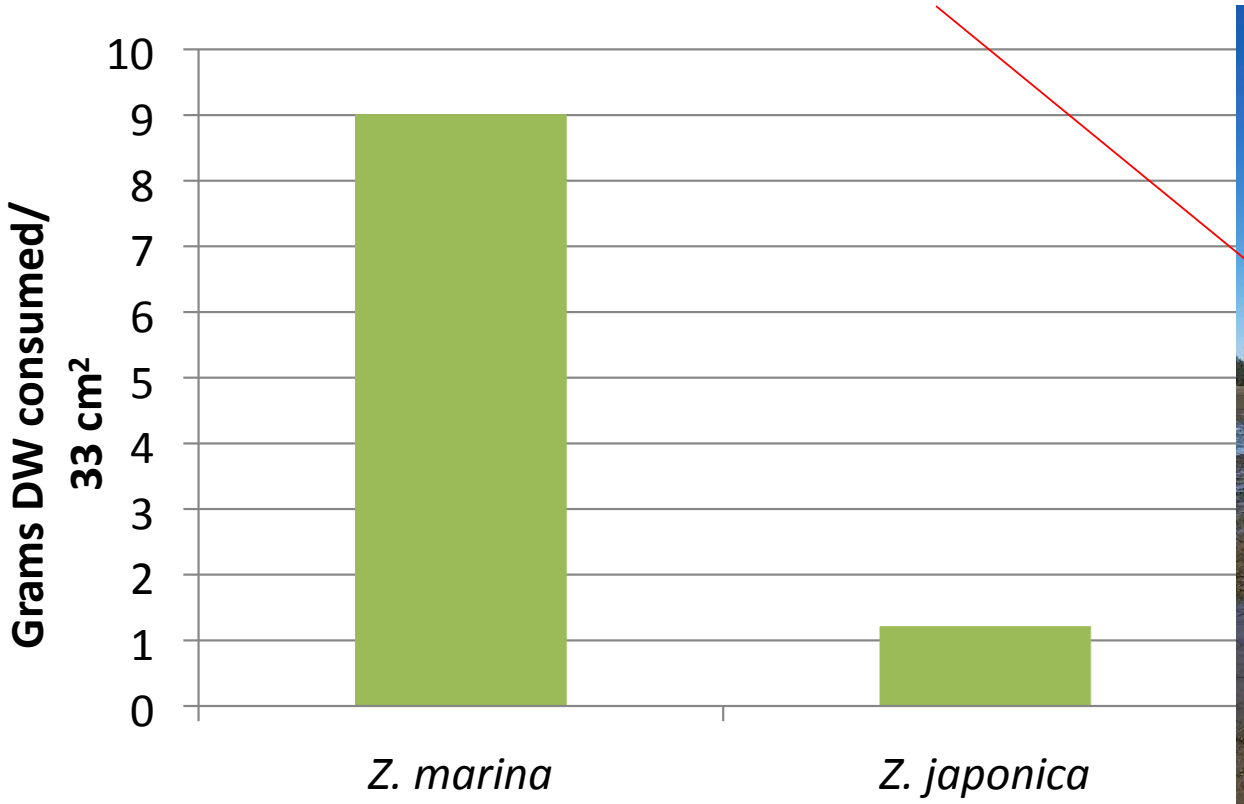
Water fowl and shorebird impacts?



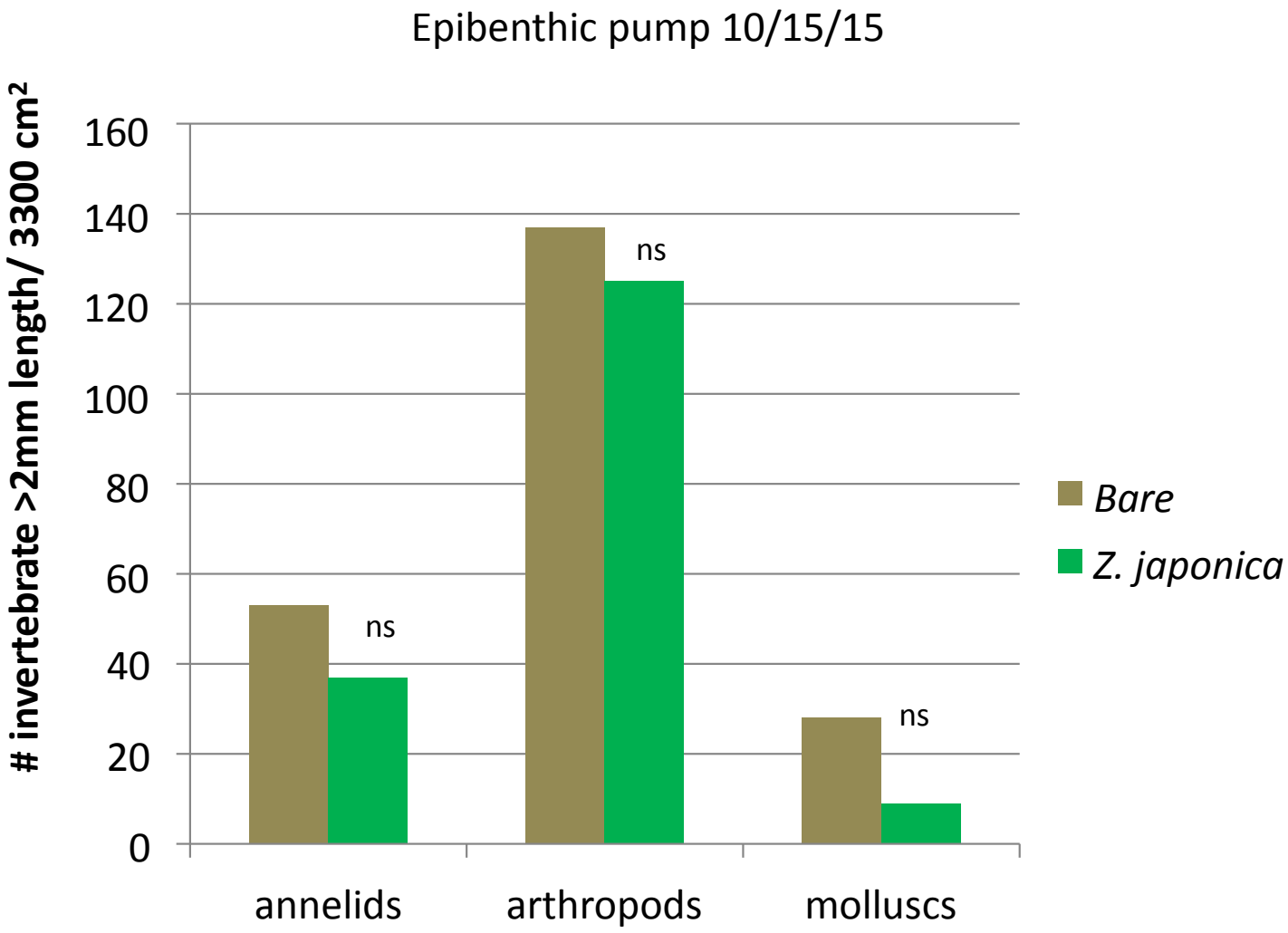
Brant impacts?

3/28/16

Foraging study of brant in Willapa Bay, mixed eelgrass site early spring

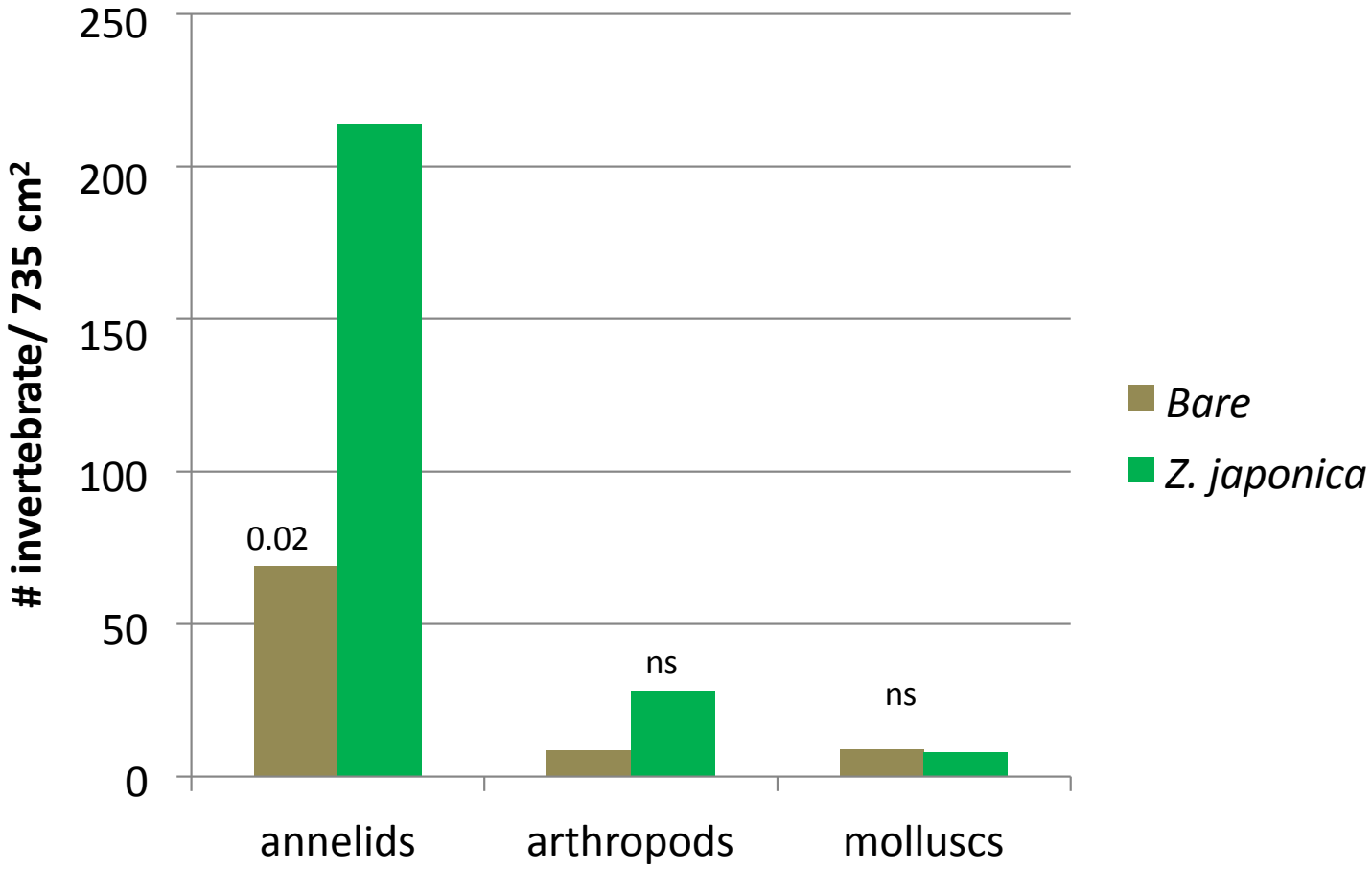


Infauna impacts?



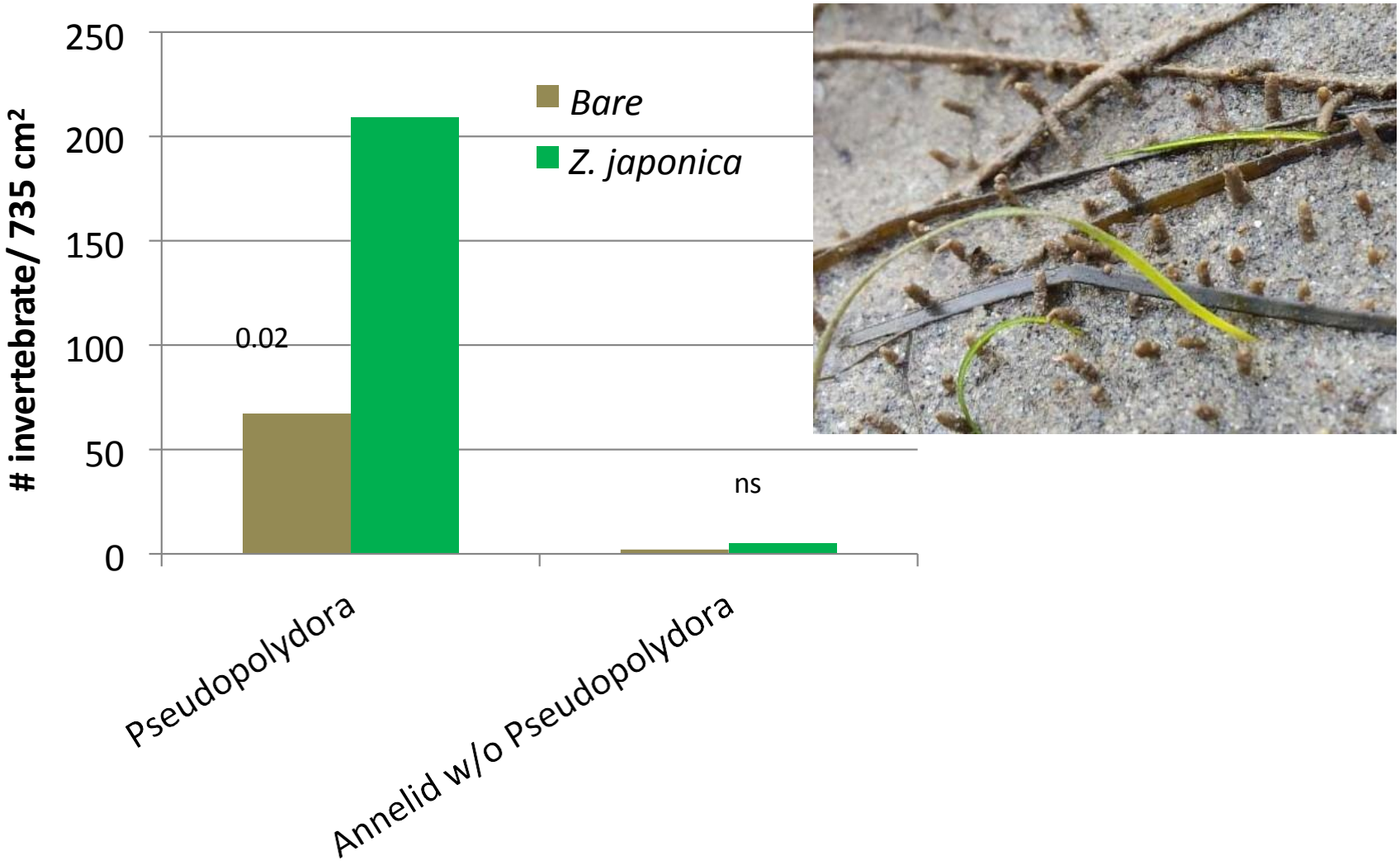
Infauna impacts?

Across all grower beds - sediment cores 0 to 10 cm May 2015

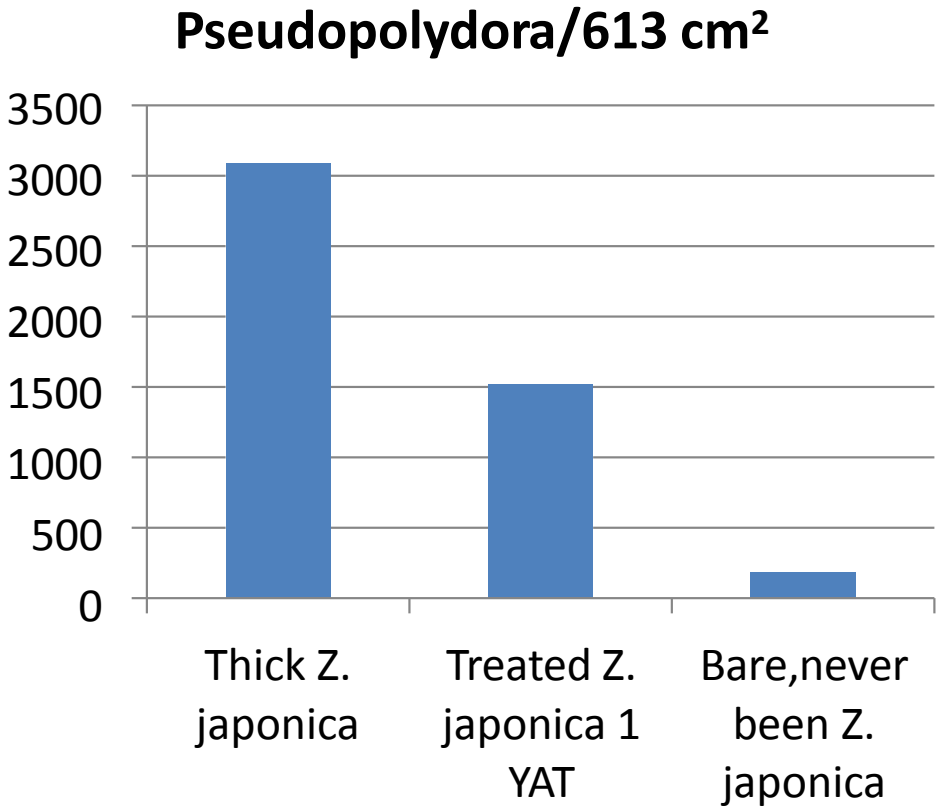


Infauna impacts?

Across all grower beds -sediment cores 0 to 10 cm May 2015

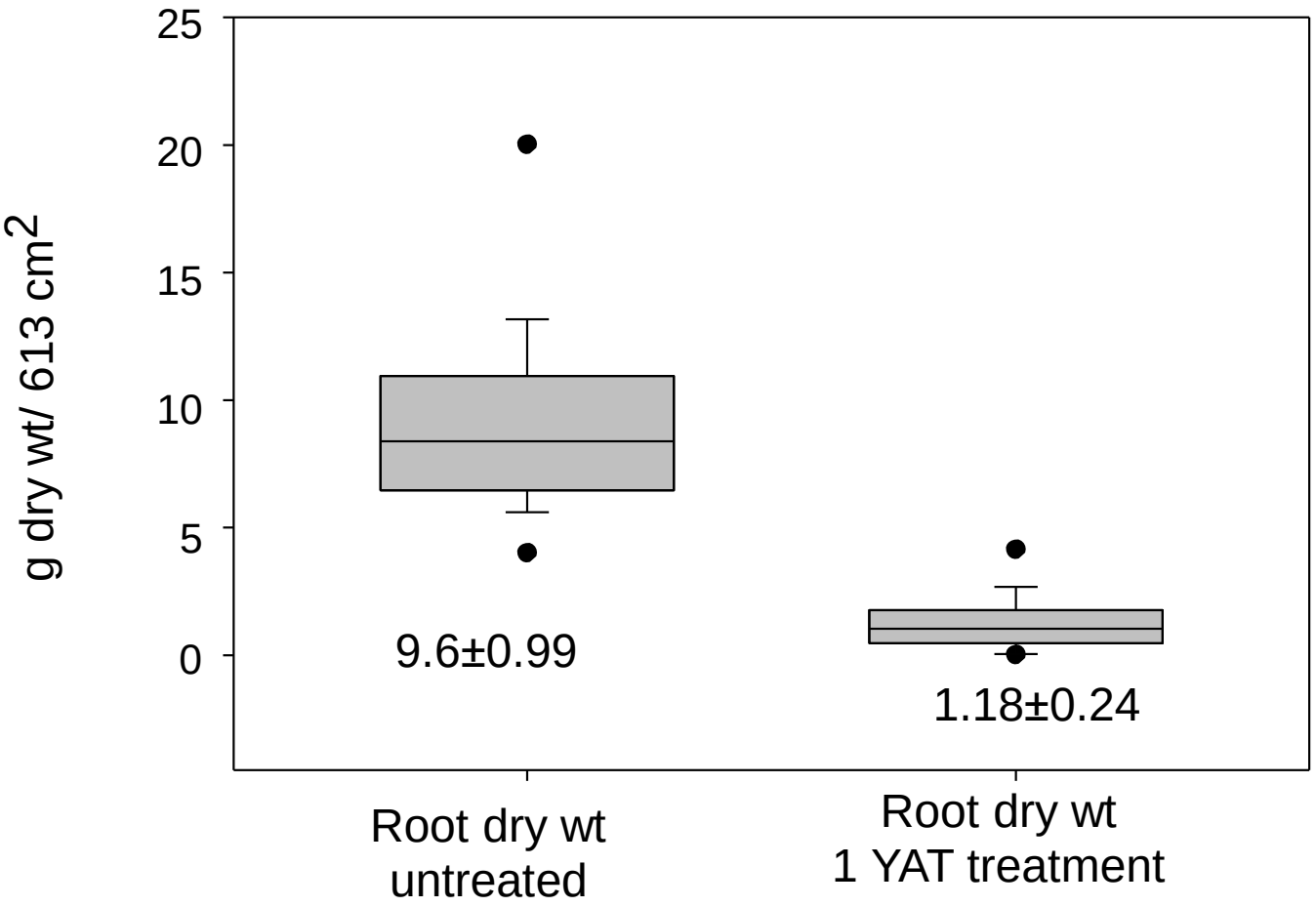


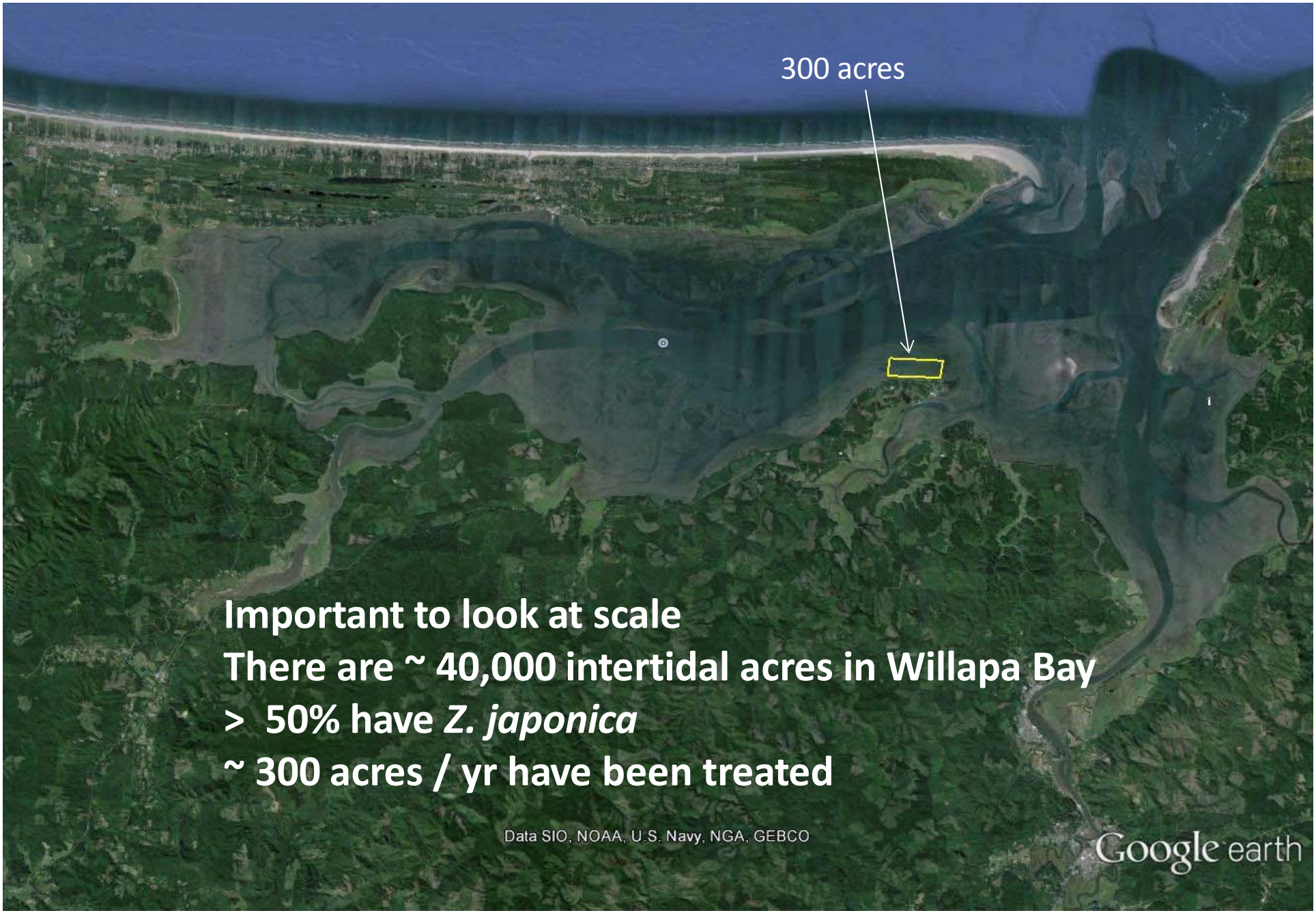
Infauna impacts?



Carbon storage?

Z. japonica root dry wt on treated and untreated sites one year after treatment (n=15 pair sites)




300 acres
Important to look at scale
There are ~ 40,000 intertidal acres in Willapa Bay
> 50% have *Z. japonica*
~ 300 acres / yr have been treated
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth

Issues voiced by WDFW in comment letter

Issue	Research findings
Monitoring in subsequent years for effects on *Z. marina*	Two years monitoring as per permit, third year planned. No unexpected findings reported.
Winter waterfowl - carrying capacity	Minor reduction in duck foraging in areas w/o *Z. japonica*. Forage value of *Z. japonica* in Willapa for brant – appears minor. Treatment of commercial clam beds not likely to be ecologically important.
Drift effects on adjacent marsh species and native eelgrass	No effect on native marsh noted Very minor off-site movement and effect on *Z. marina* (well within the bonds of permit)
Overlapping sprays of imazamox with imidacloprid	None to date, but spatially and temporally they will be separated

Summary of Japanese eelgrass control program

- It has been a very well-vetted scientific and regulatory process to get to where we are
- Science behind the program is solid and it indicates that there is minimal risk
- There is no evidence of off-site impacts
- Monitoring steps will be in place to assure no unforeseen consequences
- *Z. japonica* ecological impacts - mixed
    - Big negative impact on green sturgeon
    - Minor positive impact on ducks (one site only)
    - No impact on shorebirds
    - Forage fish and crab – mixed weak impact that is temporal and spatial
    - Infauna - minor impact, except for increased population of invasive Pseudopolydora

Funds for these projects:

- **Washington State Department of Fish and Wildlife**
- **Washington State Commission for Pesticide Registration**
- **Washington State Legislative Proviso to WSU**
- **USDA**