Z. japonica – effects on shellfish aquaculture

Kim Patten – WSU Long Beach

WASHINGTON STATE UNIVERSITY
EXTENSION

World Class. Face to Face.

- Recruitment
- Post-recruitment survival
- Growth rate and condition index
- Other production issues
  - disease & parasites
  - sediment health
  - predation
  - HAB
  - bio-fouling
  - harvesting

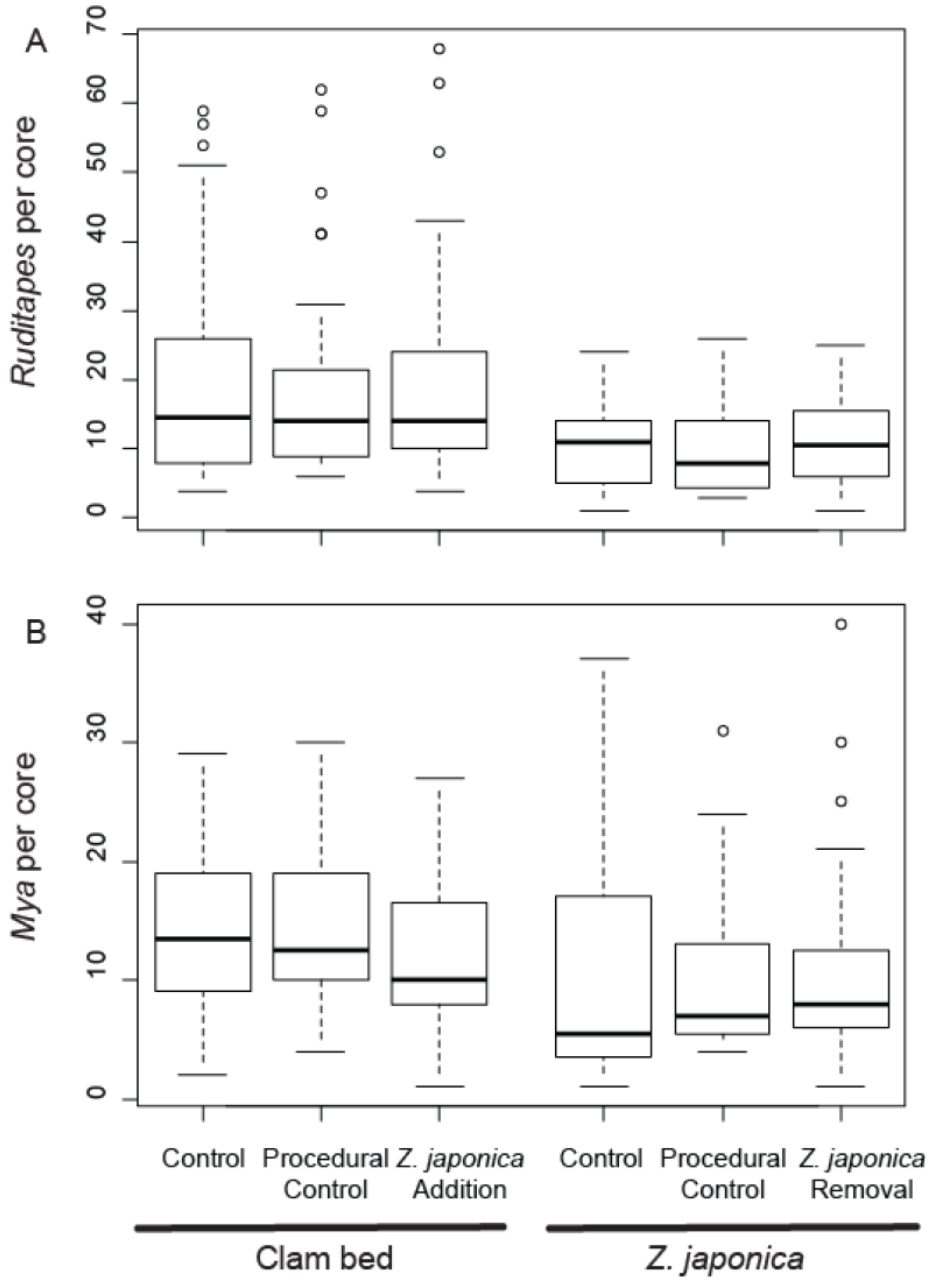
- Recruitment

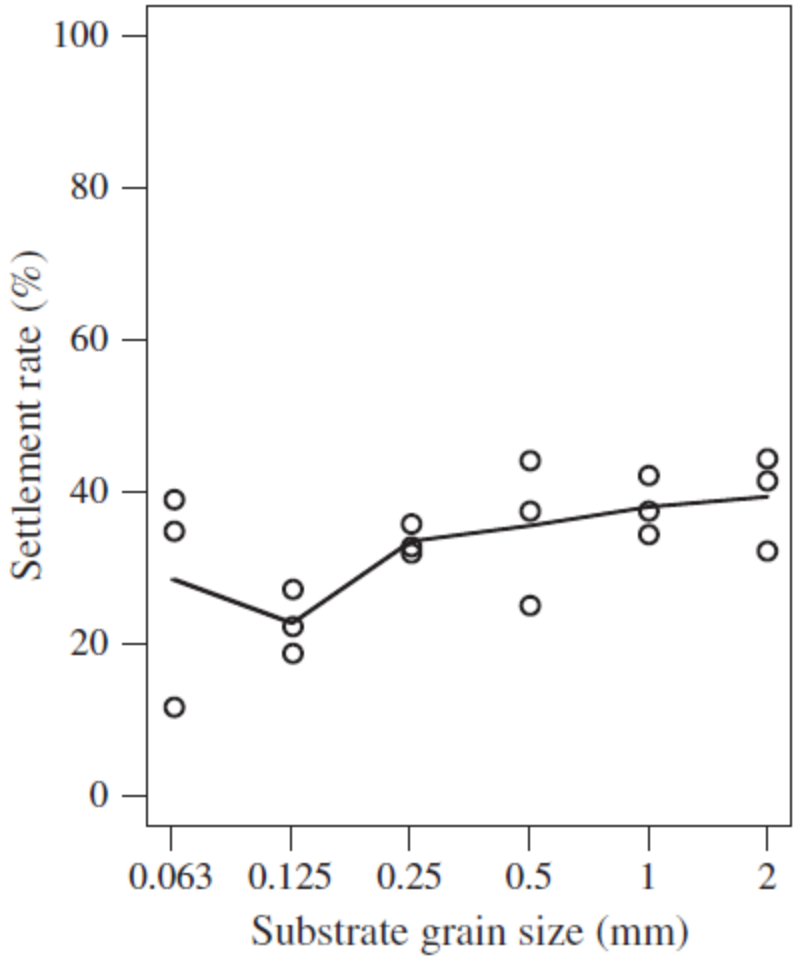
Ruesink et al.
in review

Manila and softshell clams

Recruitment (#/core)

No treatment effect





Tezuka et al. 2013
Manila clam recruitment vs. sediment size

No treatment effect of grain size

Fig. 3. Relationship between larval settlement rate and substrate grain size. The solid line indicates the mean value. A statistically significant difference was no by grain size (Tukey HSD test, $p > 0.05$).

Journal of Experimental Marine Biology and Ecology 439 (2013) 108–112

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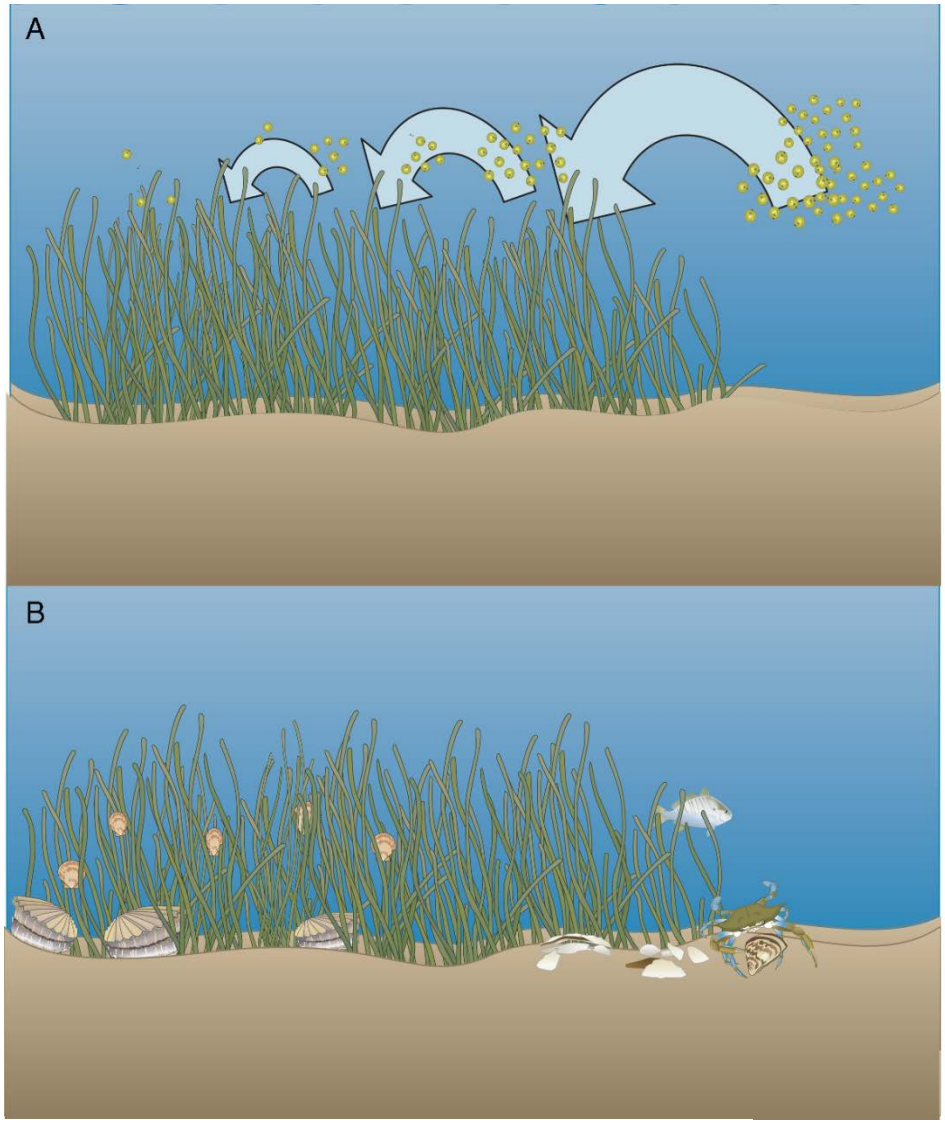
journal homepage: www.elsevier.com/locate/jembe

Effect of salinity and substrate grain size on larval settlement of the asari clam (Manila clam, *Ruditapes philippinarum*)

Naoaki Tezuka [a,*], Masaei Kanematsu [a], Kimio Asami [a], Kazutaka Sakiyama [a], Masami Hamaguchi [a], Hironori Usuki [b]



Carroll et al. 2012.
Bay scallops – in *Z. marina*
enhanced recruitment via edge effects

Ecology, 93(7), 2012, pp. 1637–1647
© 2012 by the Ecological Society of America

Balancing the edge effects budget: bay scallop settlement and loss along a seagrass edge

John M. Carroll,[1,3] Bradley T. Furman,[1] Stephen T. Tettelbach,[2] and Bradley J. Peterson[1]

[1]*School of Marine and Atmospheric Sciences, Stony Brook University, 239 Montauk Highway, Southampton, New York 11968 USA*
[2]*Department of Biology, Long Island University, CW Post Campus, Brookville, New York 11548 USA*

Gribben & Wright 2006

Sea Scallop – Australia

Recruitment better @ intermediate density of Caulerpa compared to heavy or none

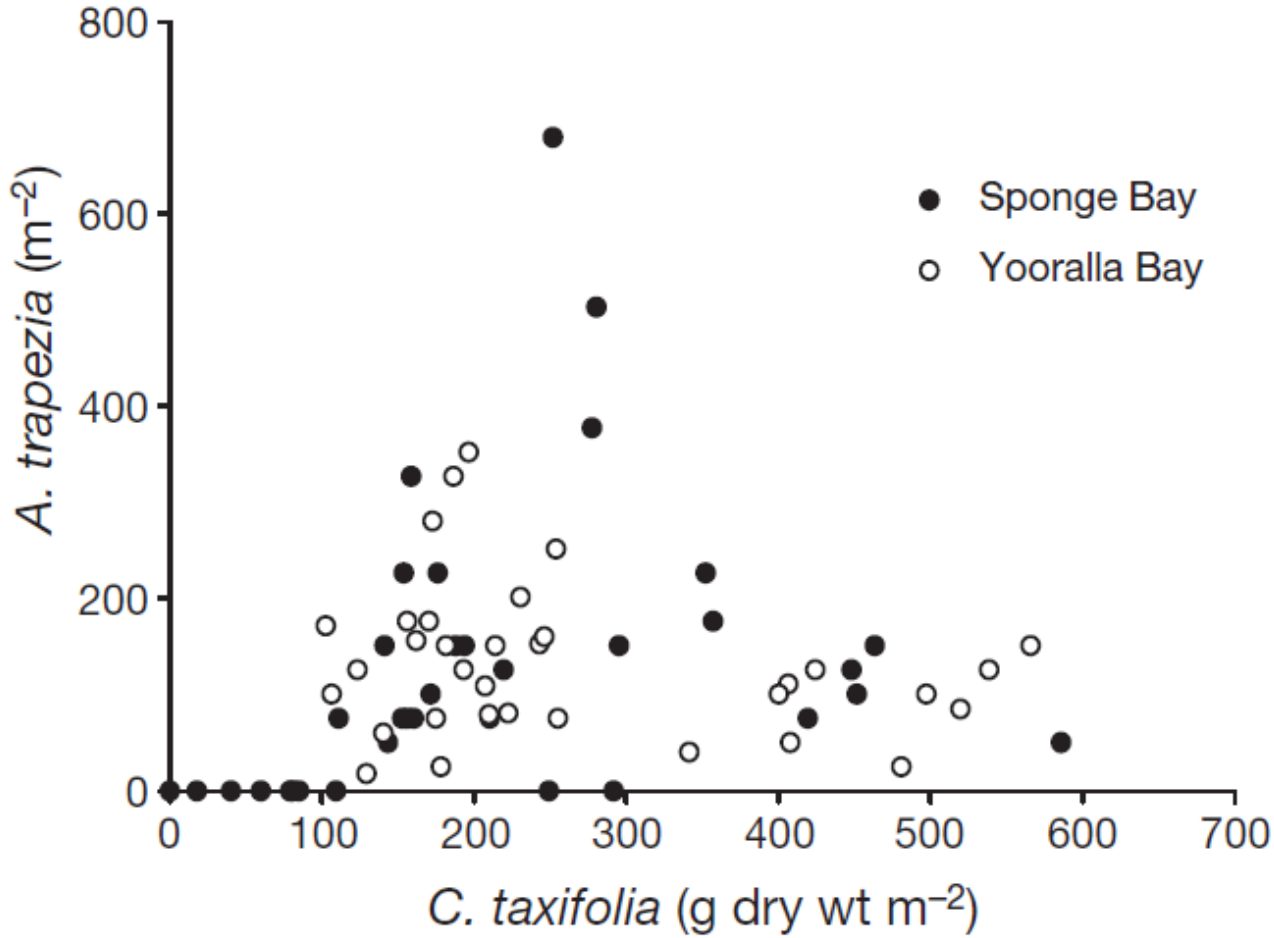


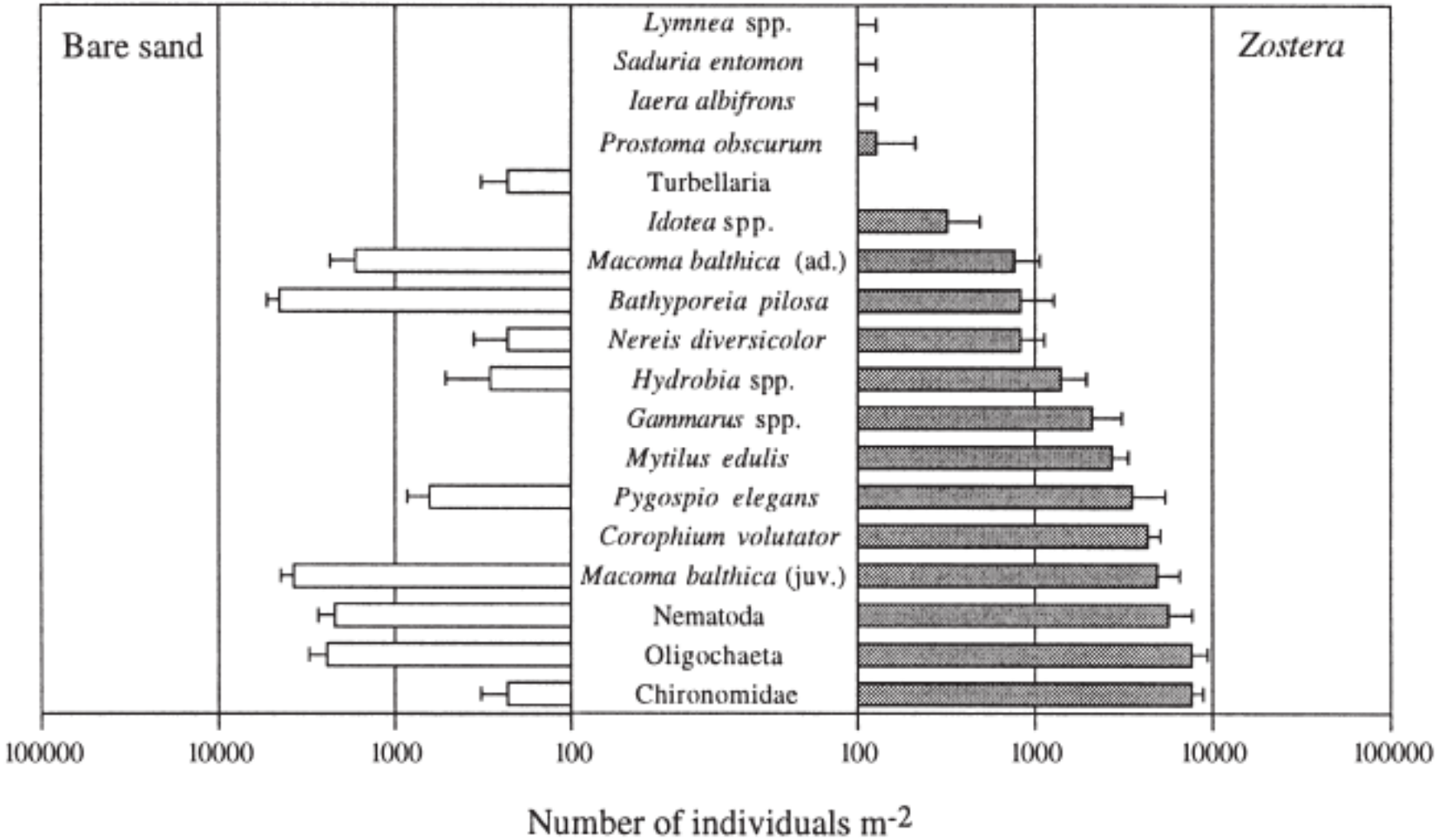
Fig. 2. *Anadara trapezia*. Number of recruits (m^{-2}) versus biomass of *Caulerpa taxifolia* (g dry wt m^{-2}) at Sponge Bay and Yooralla Bay

Vol. 318: 177–185, 2006 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published August 3

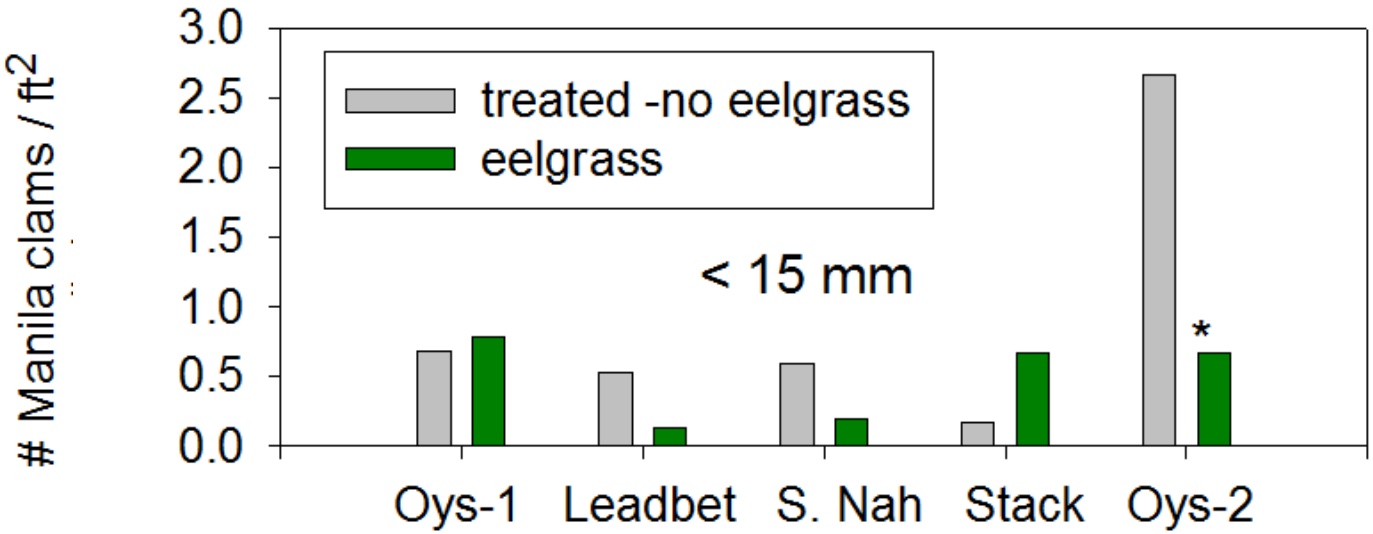
Invasive seaweed enhances recruitment of a native bivalve: roles of refuge from predation and the habitat choice of recruits

Paul E. Gribben[1,*], Jeffrey T. Wright[2]

Bostrom & Bonsdorff, 2000
infaunal community



- Post-recruitment survival



* Significant @ 5% level

Patten 2012

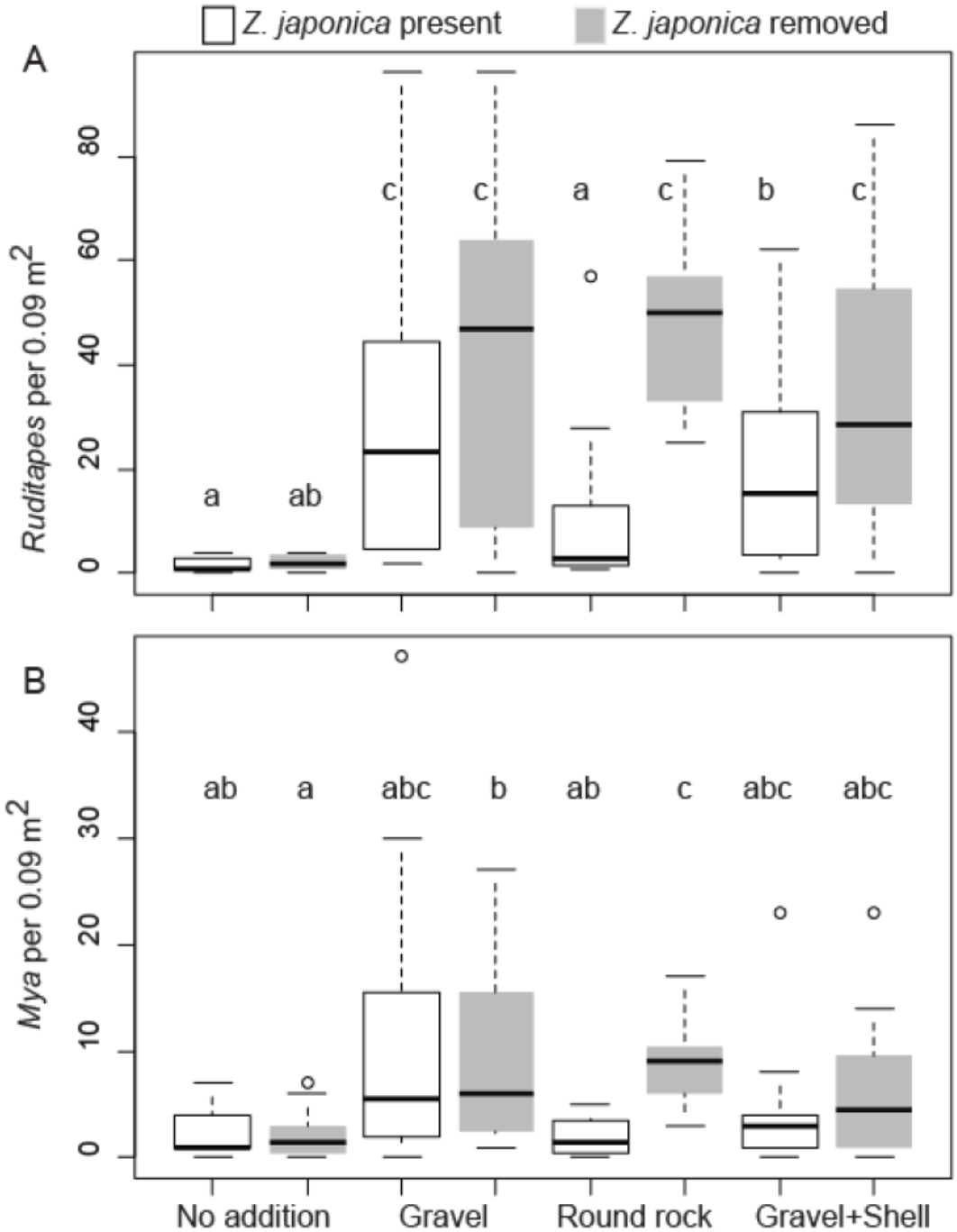
Juvenile clams on sites with and without *Z. japonica* removal (# clams < 15 mm /ft^2 1 YAT)

Treatment effect at one site, but other sites had densities too low to be of value

Ruesink et al.
in review

Manila and soft shell
Clams (#/core 1 YAT)

Z. japonica removal
enhanced recruitment /
survival of clams <20 mm size
on some substrate types



Fredriksen et al 2010

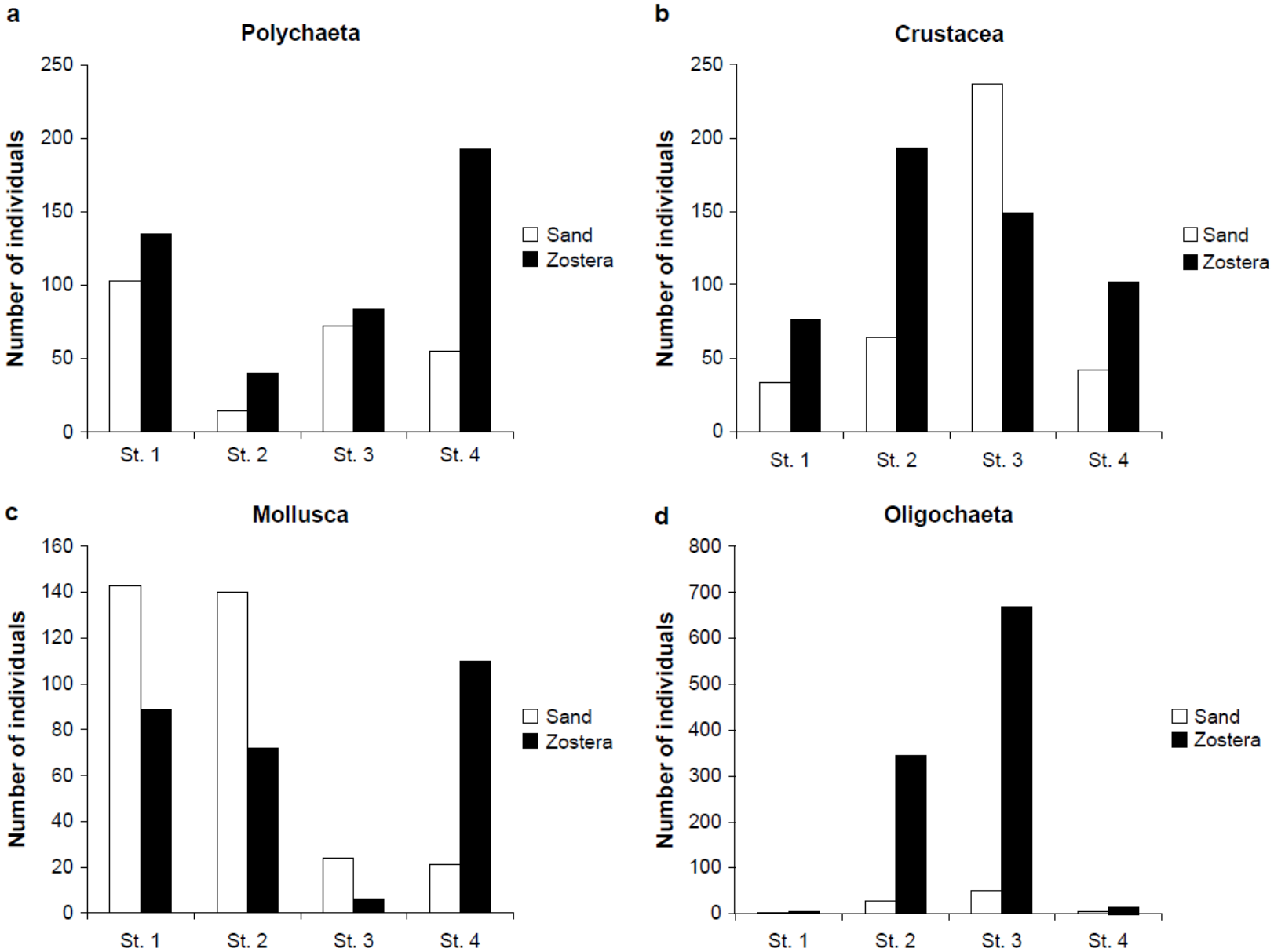


Figure 4. Total number of individuals found in sand and *Zostera marina* habitats at the different sites (St.). (a) Polychaeta; (b) Crustacea; (c) Mollusca; (d) Oligochaeta.

Tu Do et al. 2012

Change in benthic and epifauna populations in a French estuary during the expansion of Dwarf eelgrass (*Z. noltii*) 2005 to 2009

All bivalve species decreased in rank and abundance with colonization (Manila rank and abundance went from 7th to 27th, and 53 to 7, respectively)

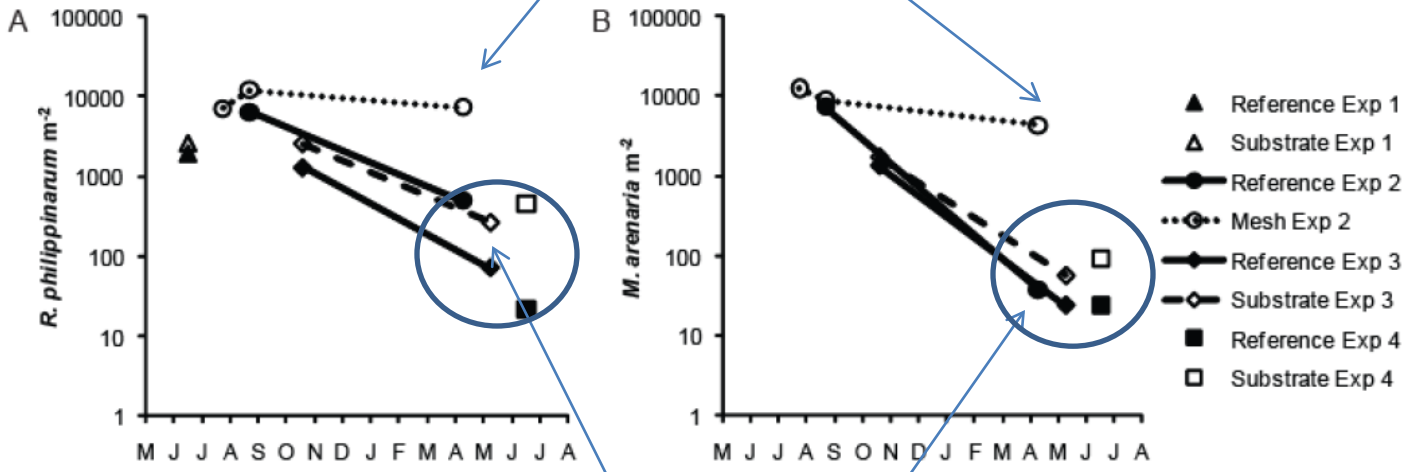
List of species with mean abundance >50 ind.m^{-2} in at least one of three habitats. (G): gastropod; (B): bivalve; (O): oligochaete; (P): polychaete; (Op): ophiuroid; (A): amphipod; (D): decapod; (Ma): malacostraca; (N): nemert. Epifauna species are in bold.

Species	Sand (2005–2009)		*Z. noltii* (2005–2006)		*Z. noltii* (2009)	
	Rank	Mean	Rank	Mean	Rank	Mean
***Hydrobia ulvae* (G)**	**1**	**3964**	**1**	**13607**	**9**	**407**
Notomastus latericeus (P)	2	397	4	607	3	2400
Heteromastus filiformis (P)	3	366	2	754	1	3385
Cerastoderma edule (B)	4	206	5	307	–	0
Ampelisca brevicornis (A)	5	74	31	6	–	0
Scrobicularia plana (B)	6	58	16	89	–	0
Ruditapes philippinarum (B)	7	53	12	133	27	7
***Cyclope neritea* (G)**	**8**	**50**	**22**	**31**	–	**0**
Abra segmentum (B)	9	49	8	222	25	37
Prionospio sp. (P)	10	46	13	126	20	67
Nemertina (N)	11	28	19	59	13	163
Glycera spp. (P)	12	27	20	39	18	96
Euclymene oerstedii (P)	13	27	20	39	11	281
Poecilochaetus serpens (P)	14	15	26	19	19	81
***Nassarius reticulatus* (G)**	**15**	**13**	**14**	**120**	**22**	**59**
Aphelochaeta marioni (P)	16	12	3	687	2	2526
Tubificoides benedii (O)	17	12	15	115	12	222
Melinna palmata (P)	18	9	23	30	10	385
***Bittium reticulatum* (G)**	**19**	**4**	**7**	**224**	**5**	**874**
***Littorina littorea* (G)**	**19**	**4**	**9**	**187**	**15**	**133**
Euclymene collaris (P)	19	4	24	30	14	148
Pseudopolydora spp. (P)	19	4	25	24	20	67
Capitella capitata (P)	23	3	11	139	–	0
***Mytilus edulis* (B)**	**24**	**1**	**6**	**304**	–	**0**
***Gammarus* sp. (A)**	**24**	**1**	**18**	**61**	**4**	**2363**
Microdeutopus gryllotalpa (A)	24	1	26	19	7	652
***Platynereis dumerilii* (P)**	–	**0**	**10**	**150**	**26**	**15**
Aonides oxycephala (P)	–	0	17	76	17	111
***Gibbula umbilicalis* (G)**	–	**0**	**26**	**19**	**24**	**52**
Melita palmata	–	0	29	9	6	844
***Ophiura* sp. (Op)**	–	**0**	**30**	**6**	**15**	**133**
***Gammarella fucicola* (A)**	–	**0**	–	**0**	**8**	**511**
***Nebalia strausi* (Ma)**	–	**0**	–	**0**	**23**	**52**

Cockle

Manila clam

Screened against predation



Not screened against predation

Ruesink et al.
in review

Manila and softshell
clams

Decoupling of recruitment density with juvenile density
due to winter losses (predation?)

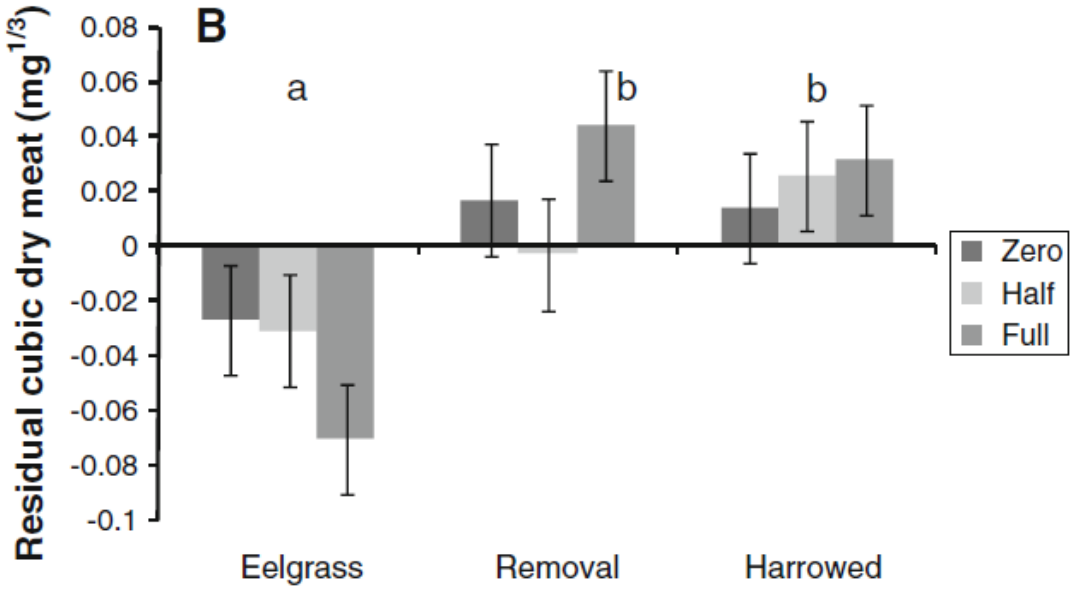
Summary – Recruitment and post-recruitment survival

- Recruitment process does not appear to be affected by *Z. japonica*
- Post-recruitment survival likely to be reduced by *Z. japonica,* but results are site-specific

- Growth and fitness

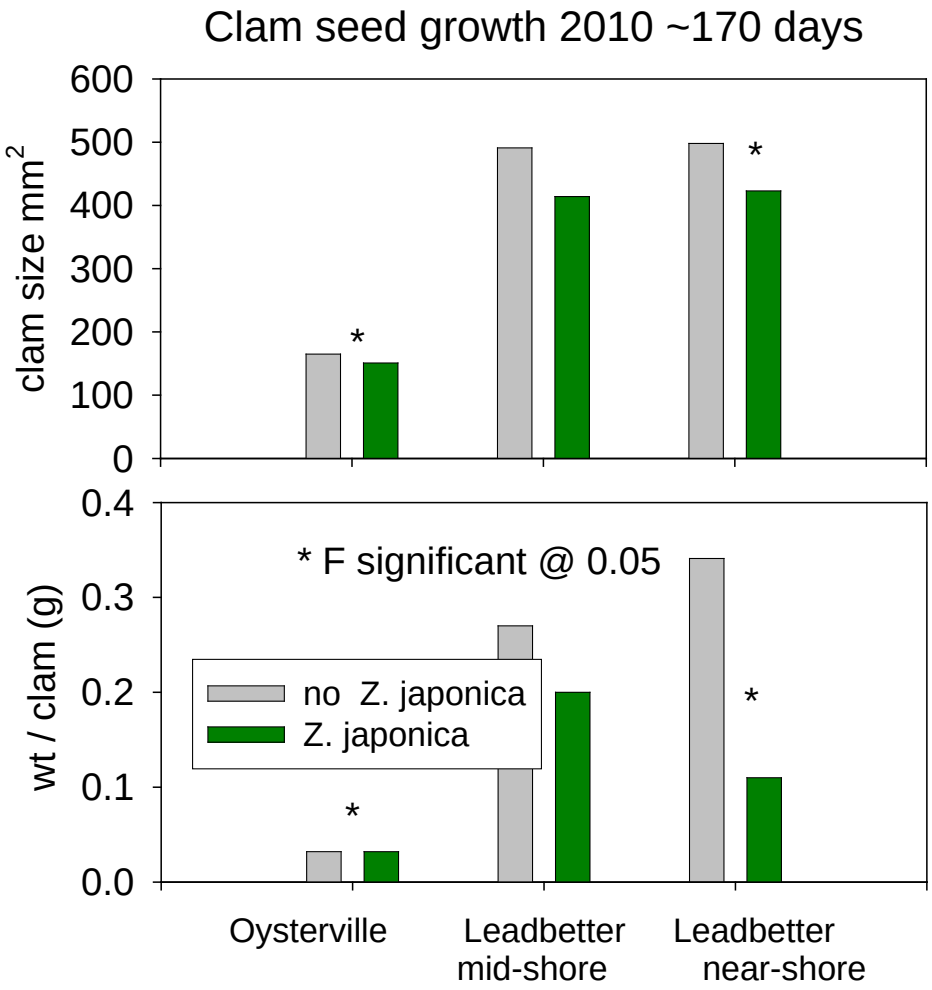
Tsai et al. 2010

Interactions between two introduced species: *Zostera japonica* (dwarf eelgrass) facilitates itself and reduces condition of *Ruditapes philippinarum* (Manila clam) on intertidal flats

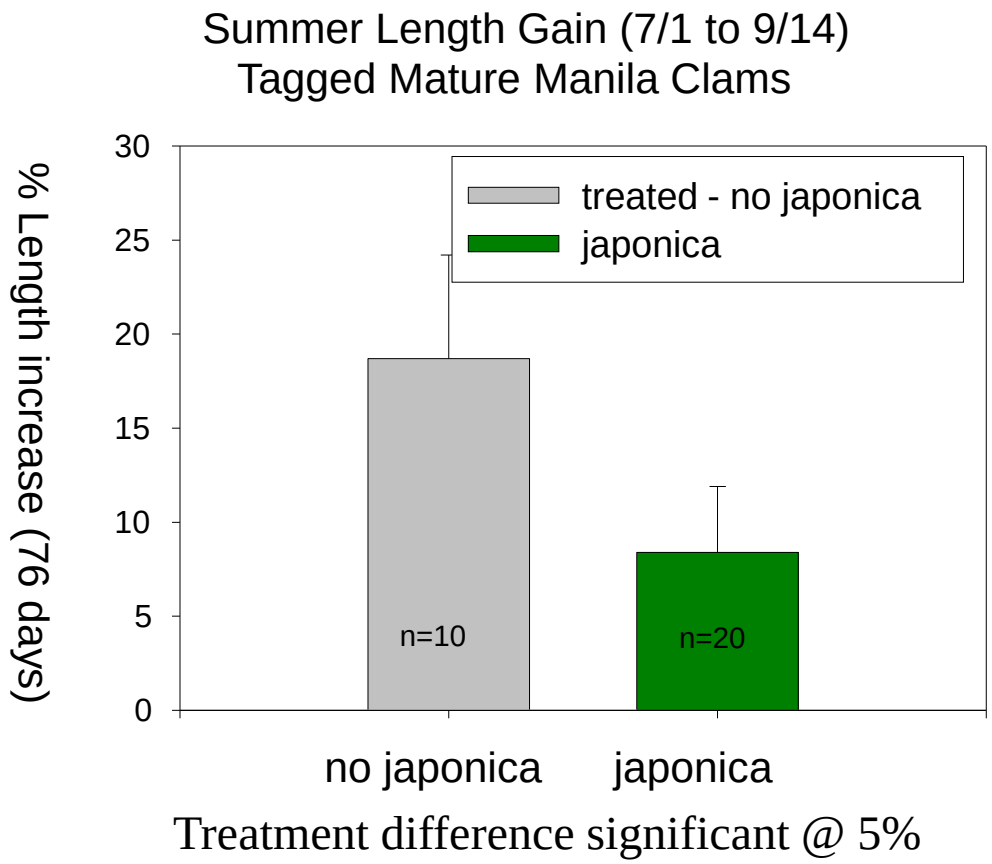


Clam density
0, 250 or 500m^2

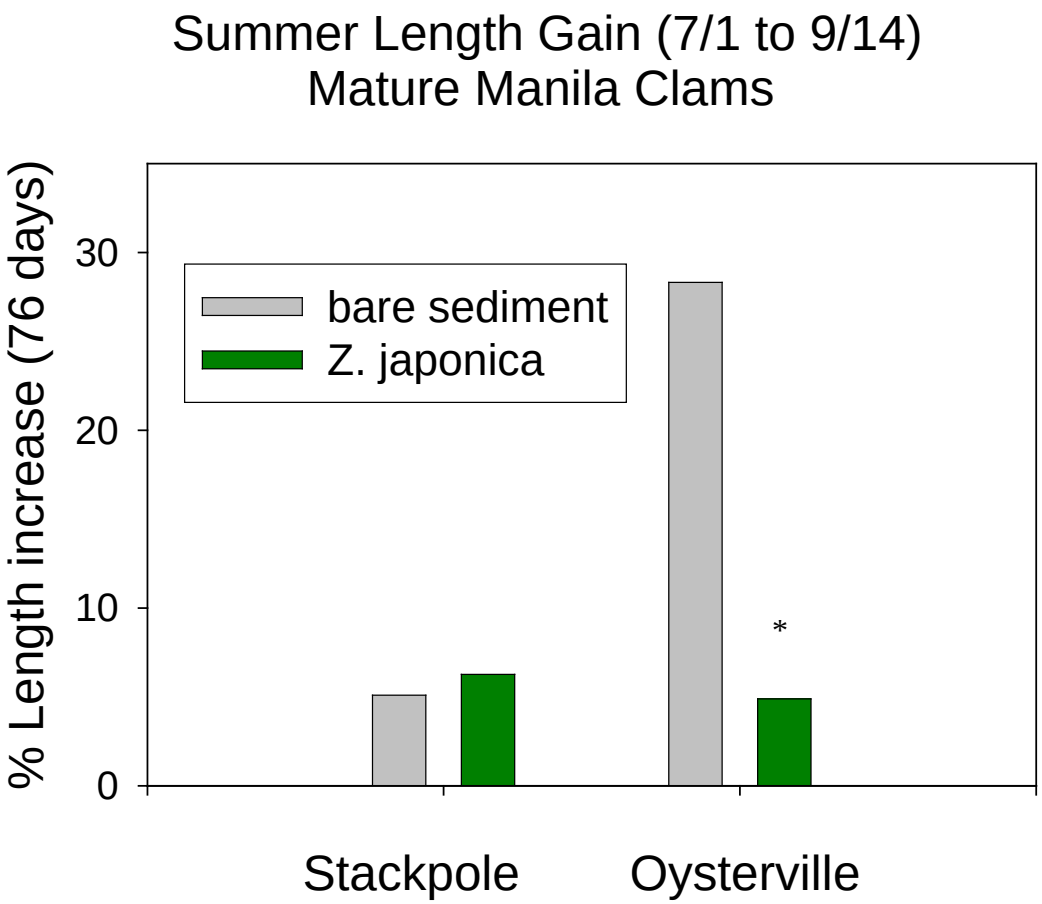
b Dry meat weight as the residual from the linear relationship between cubic meat weight and shell length at end of experiment. Values are from least *square* means; *error bars* show SE. *Letters* above



Patten et al. 2012



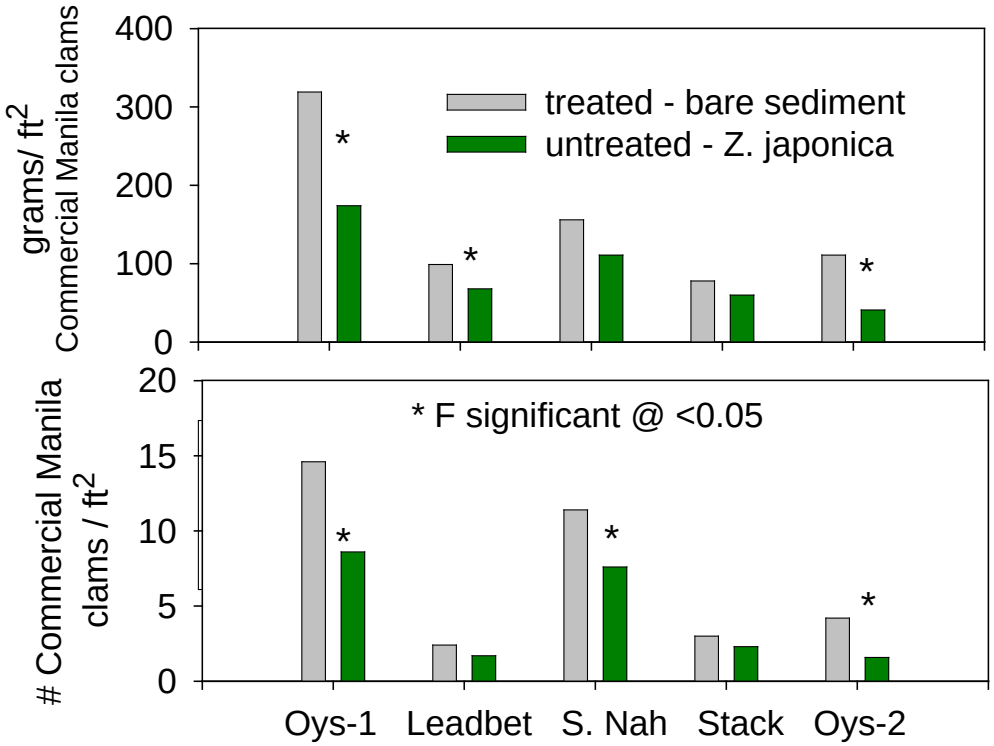
Patten et al. 2012



* Treatment difference significant @ 5%

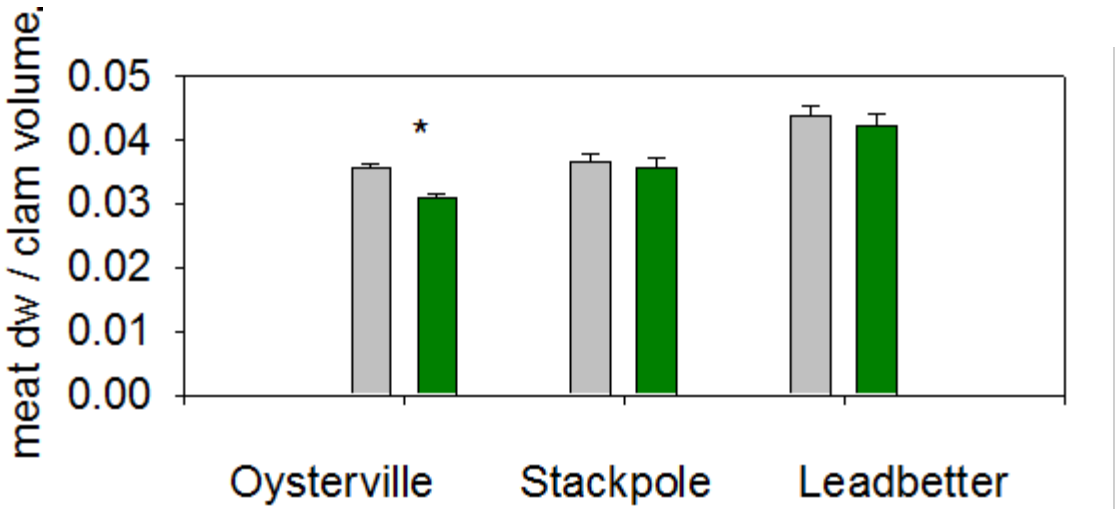
Patten et al. 2012

Production of mature Manila clams



Patten et al. 2012

Condition index of mature Manila clams (clam quality)



* Treatment difference significant @ 5%

Patten et al. 2012

Allen & Williams 2003

Mussel growth vs. *Z. marina*

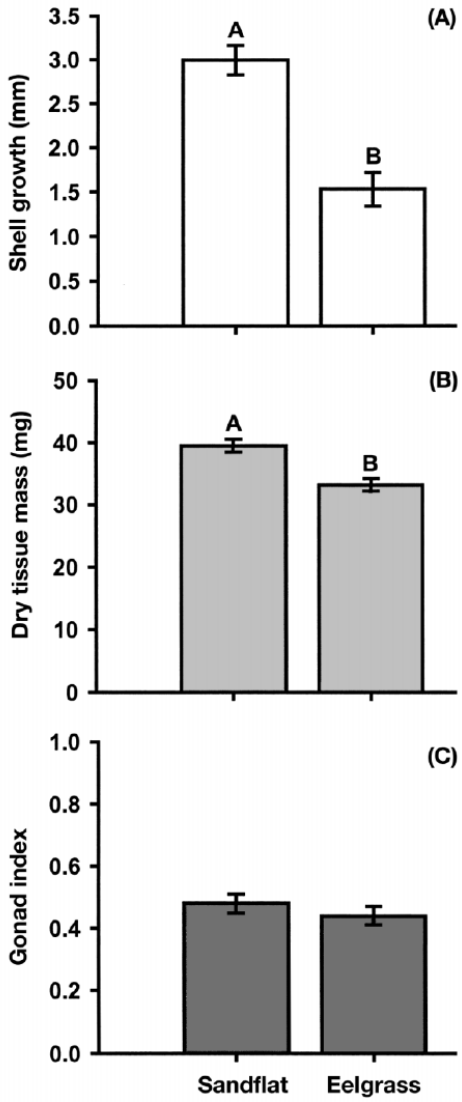
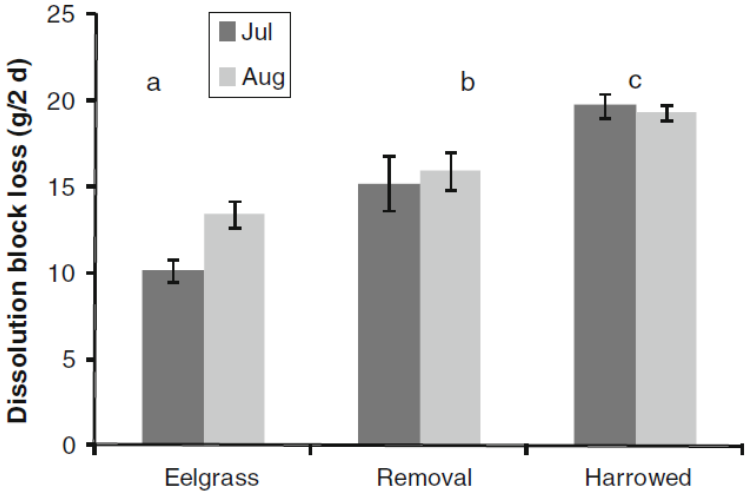


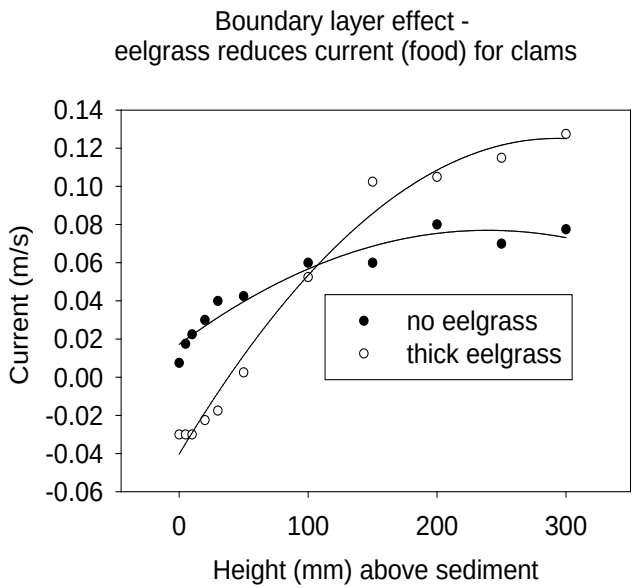
Fig. 5. *Musculista senhousia*. Shell growth (A, white bars) and dry tissue mass (B, light gray bars), and gonad index (C, dark gray bars) of mussels in the eelgrass bed and adjacent unvegetated sand flat at Harbor Island, San Diego Bay (A & B: adjusted means ± SE; C: means ± SE; n = 6 plots). Differing letters indicate significant differences among treatments ($p < 0.05$, Tukey's HSD multiple-comparison method)

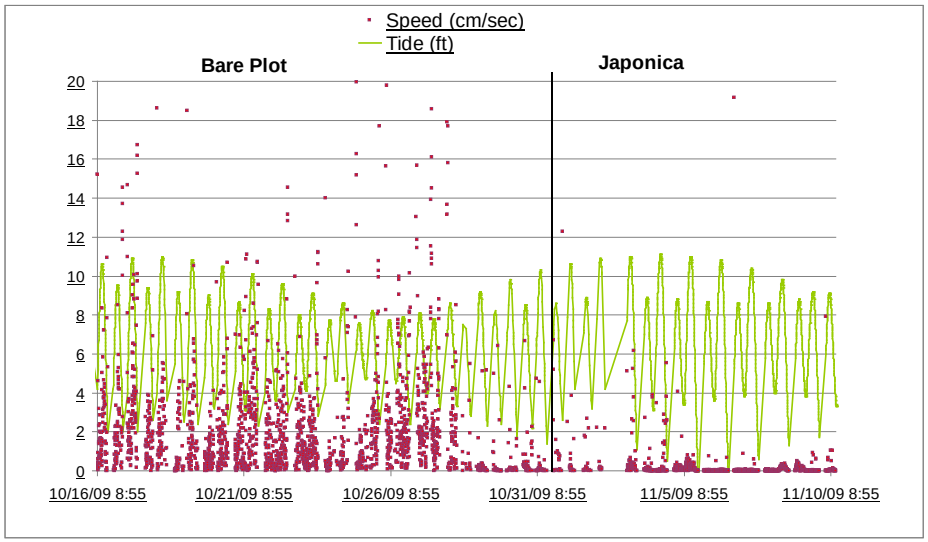
For obligate filter feeders like Manila clams, the more water passing over the siphon the better the growth

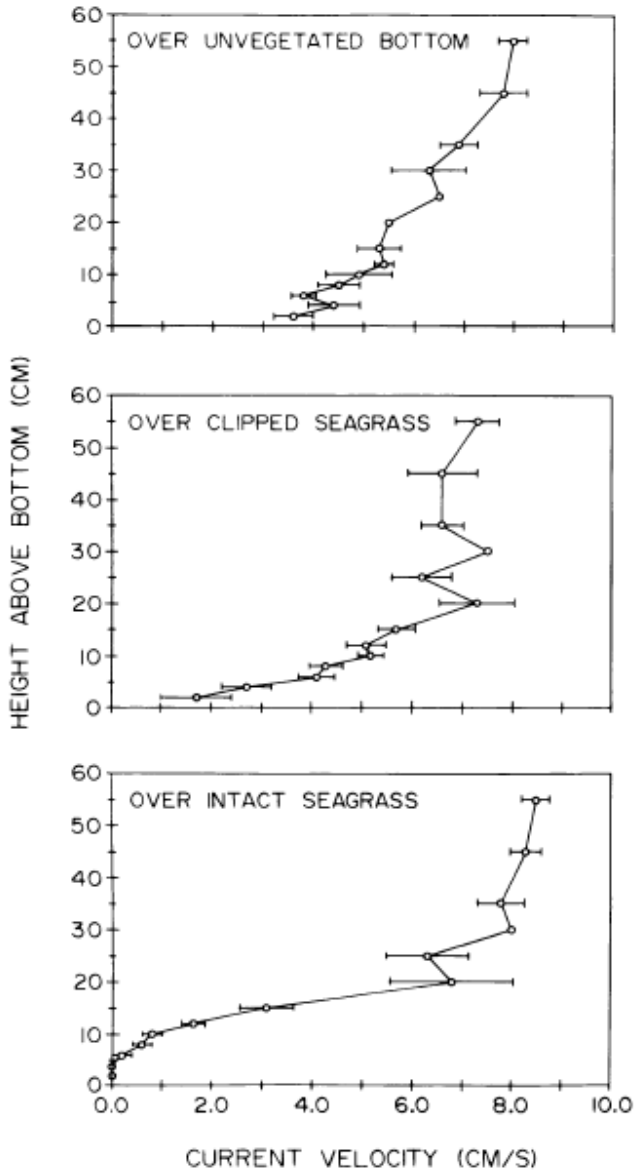
Three data sets for current and *Z. japonica* in Willapa

Patten et al. 2012
Tsai et al. 2010

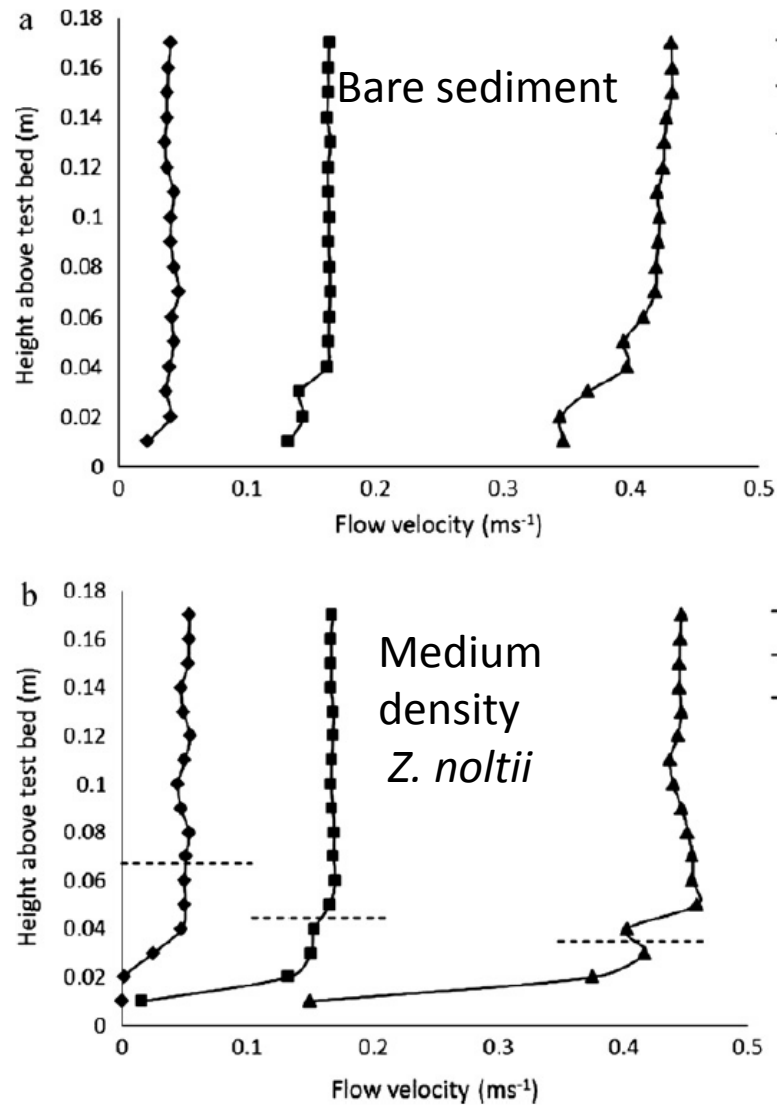








Author(s): E. A. Irlandi and C. H. Peterson
Source: *Oecologia*, Vol. 87, No. 3 (1991), pp. 307-318



Wilke et al. 2012
Z. noltii vs current

Many shellfish species show the opposite response to SAV

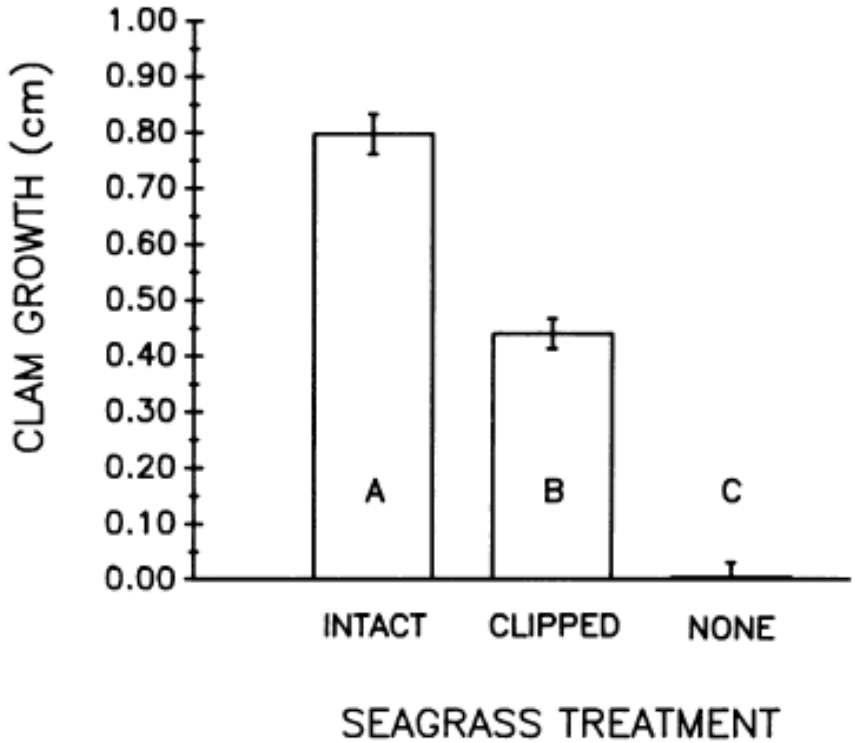


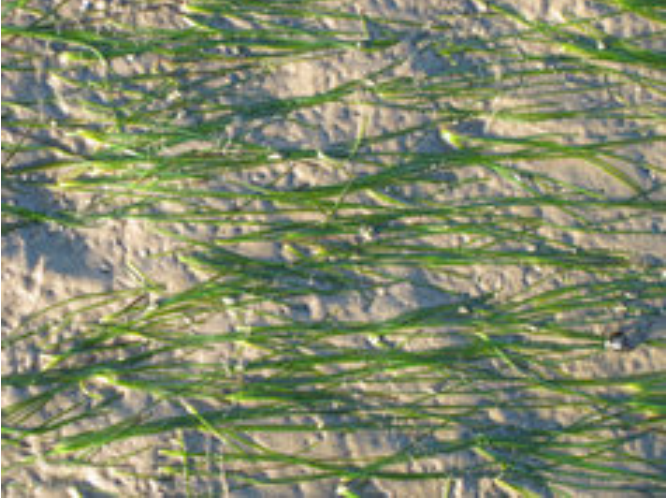
Fig. 5. Mean estimated growth of *Mercenaria* 2.60 cm in initial length averaged over the 8 clipped, the 8 unvegetated, and the 7 intact seagrass treatment plots. Error bars represent ± the standard error. The different letters denote a significant difference between treatments (orthogonal contrasts within the ANOVA, $p < 0.001$; Table 3)

Author(s): E. A. Irlandi and C. H. Peterson
Source: *Oecologia*, Vol. 87, No. 3 (1991), pp. 307-318

Summary – growth and fitness

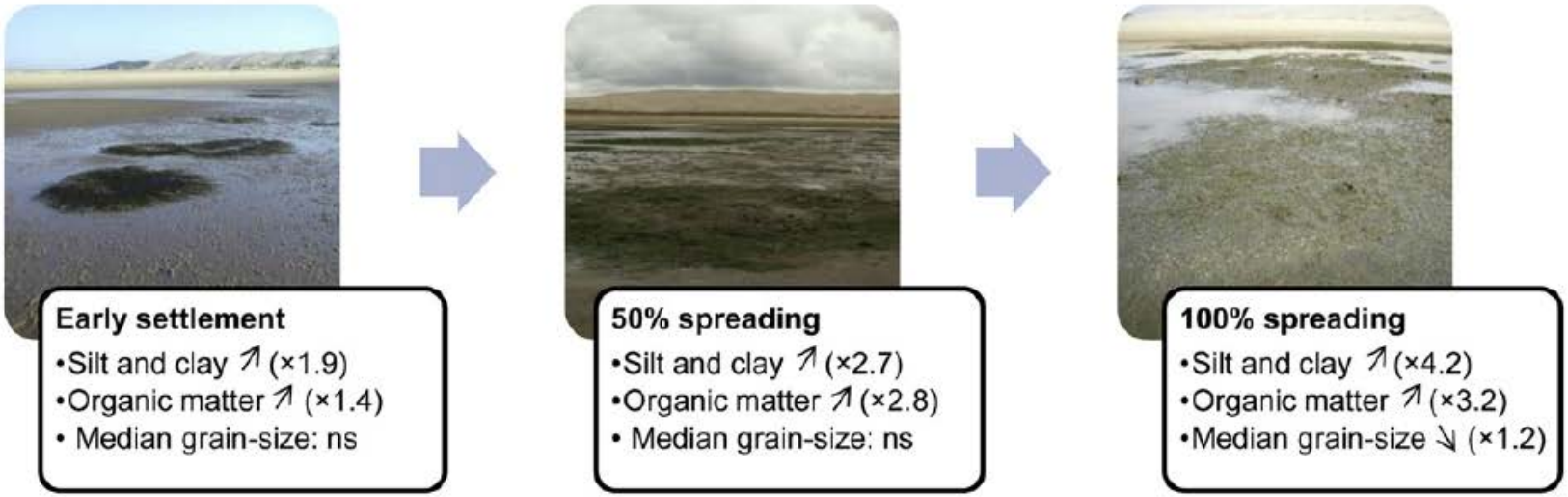
- Manila clam growth rate and condition is reduced by *Z. japonica*
- Other shellfish species may show a positive or negative response to SAV

- sediment health



Dwarf eelgrass – *Z. noltii in France, monitor changes with colonization over 5 years*

V. Tu Do et al. / Estuarine, Coastal and Shelf Science 95 (2011) 458–469



Posey 1988

Mean particle size reduced with *Z. japonica, especially @ site with oldest infestation of* Z japonica.

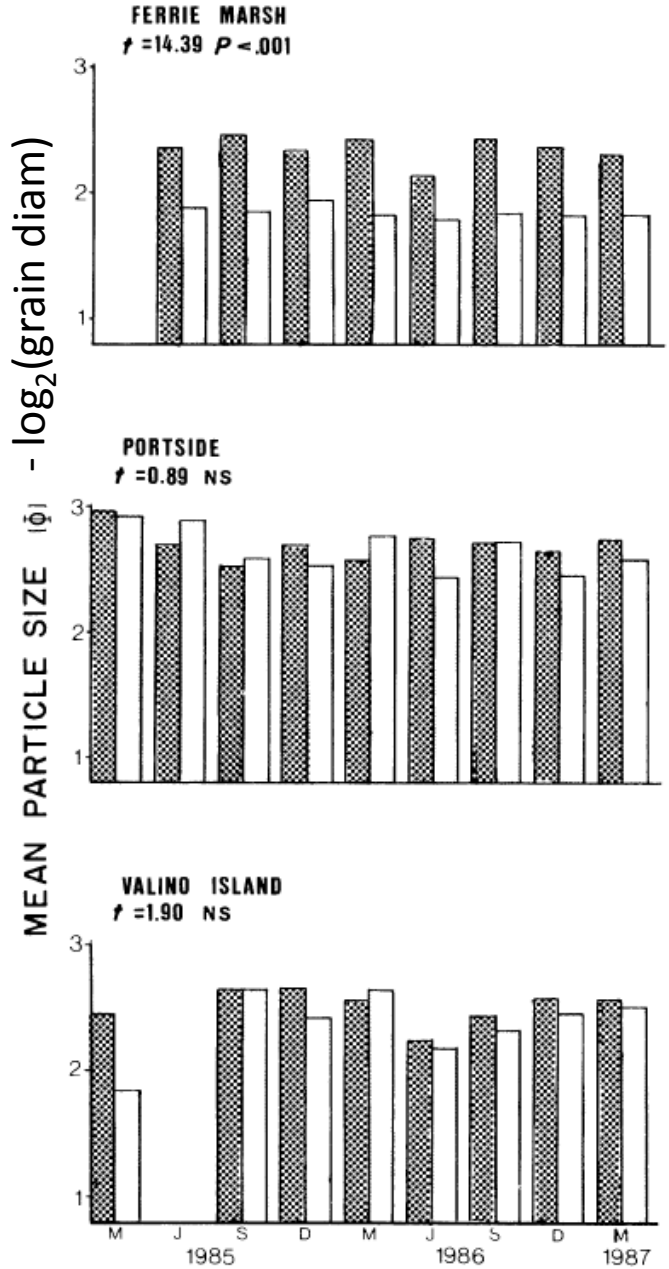
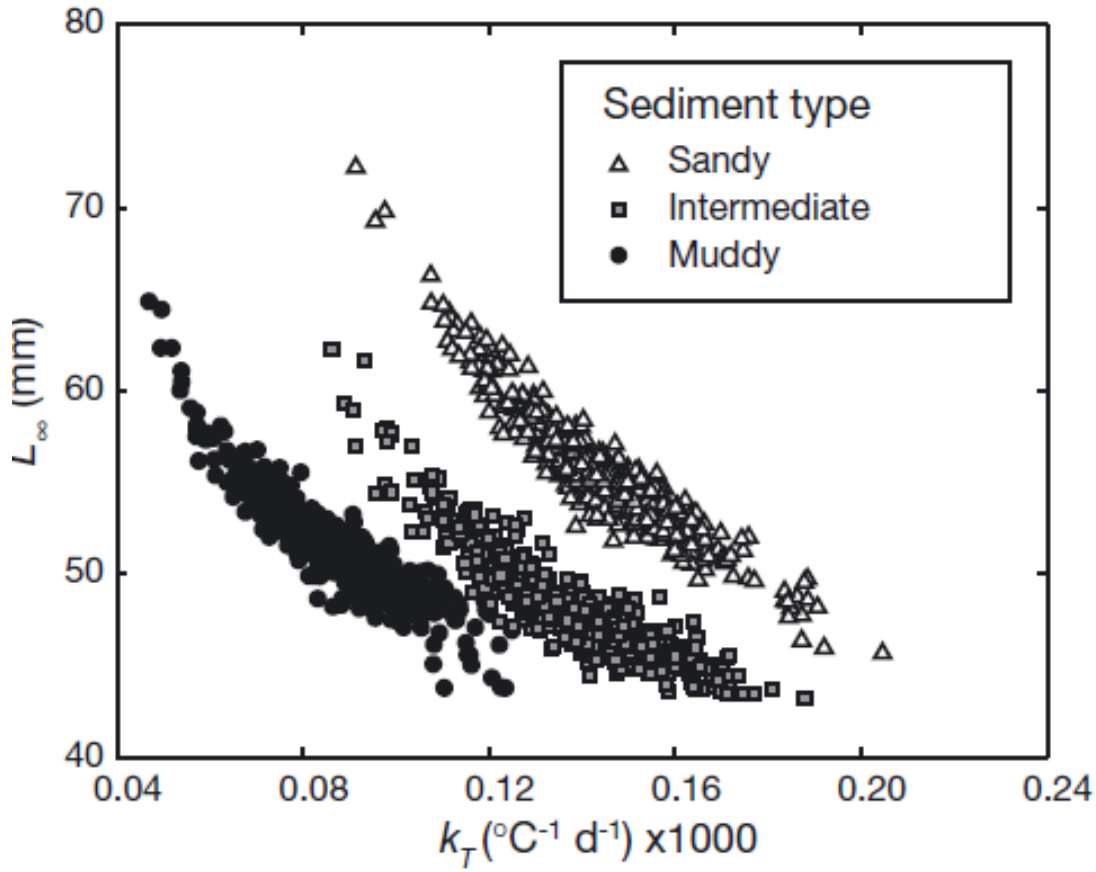


FIG. 2. Mean sediment grain size within and outside nat-
lly established *Zostera japonica* patches. Dark stippling:
hin seagrass patches; light stippling: unvegetated areas.
= −log₂[grain diameter]).

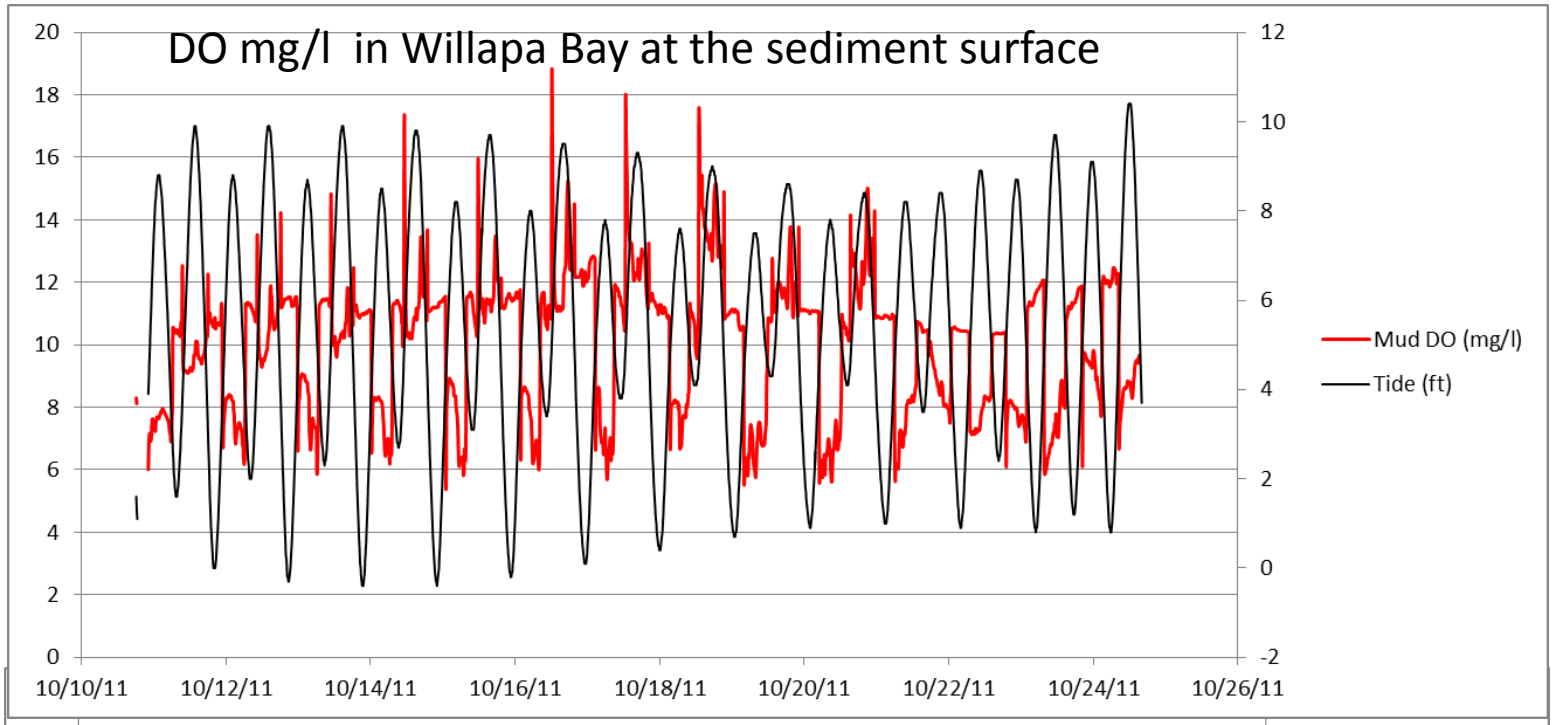
Melia et al. 2004

Clam growth vs. Sediment type

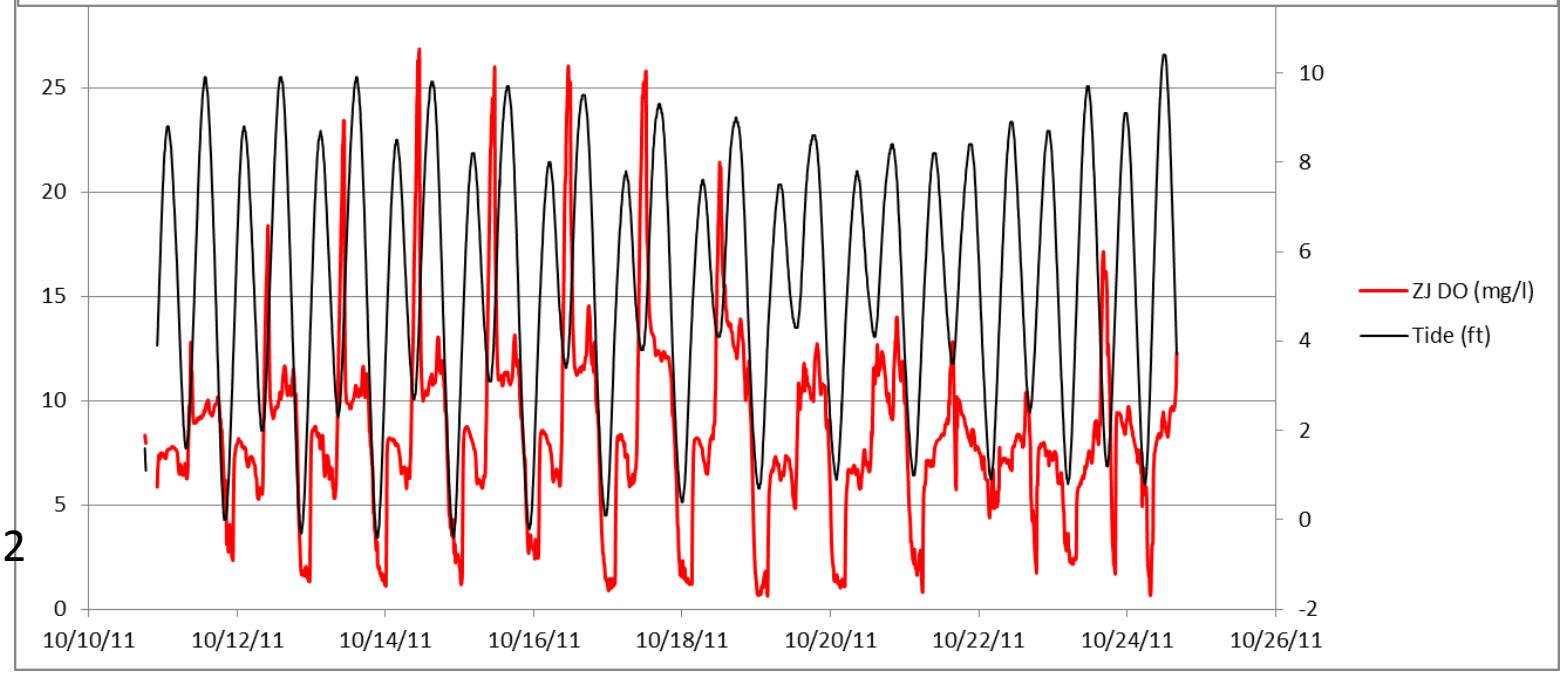


'ig. 4. *Tapes philippinarum*. Distribution of bootstrap repli-ates of L_∞ (asymptotic mean size) and k_T (proportionality oefficient between Brody growth constant and temperature, ee Eq. (3)) for the 3 growth models, corresponding to different sediment types (sandy, intermediate and muddy)

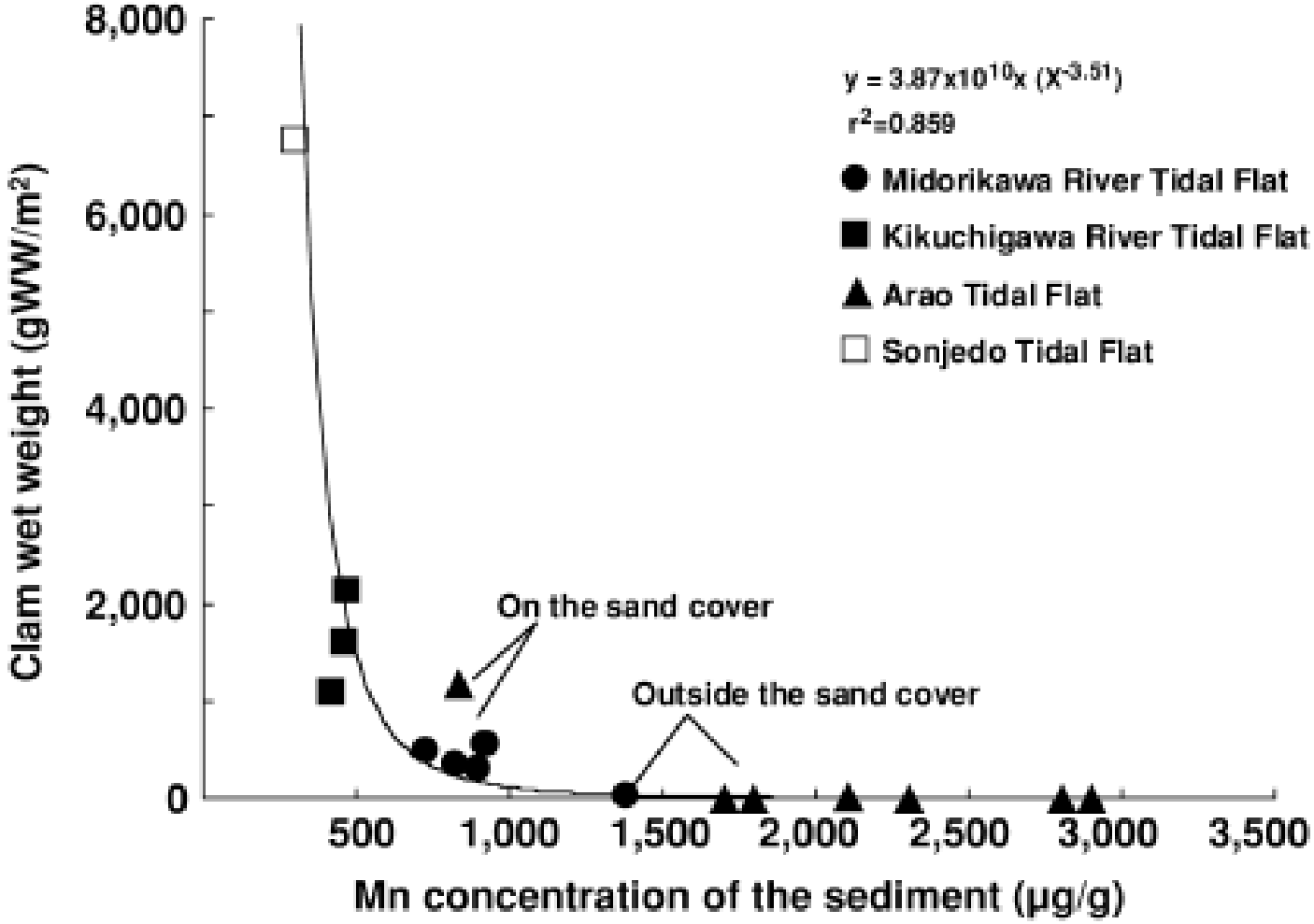
Bare sediment
DO never
< 5.5 mg/l



Z japonica
DO <2 mg/l
nightly 1-2 hrs

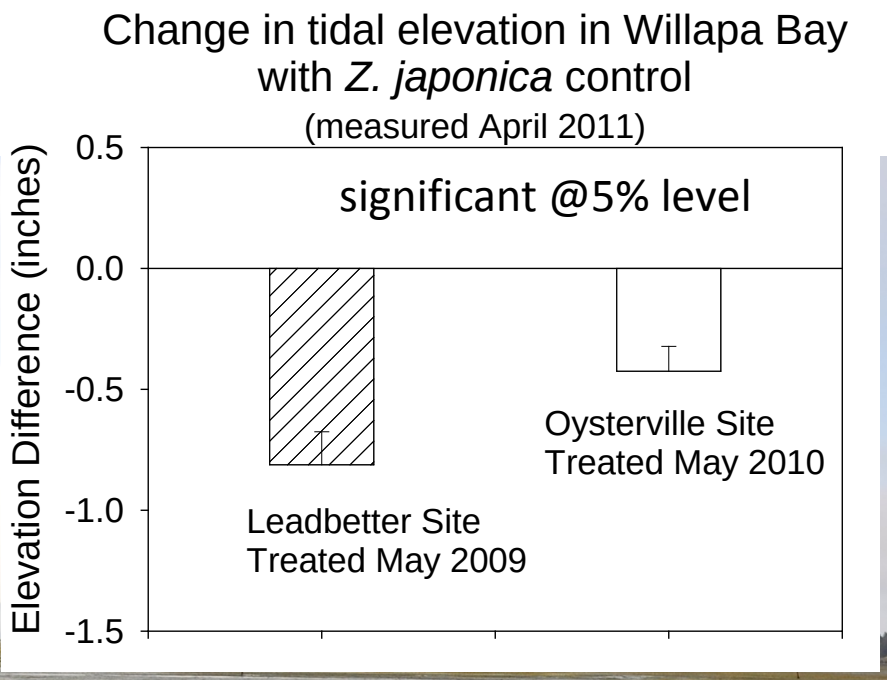


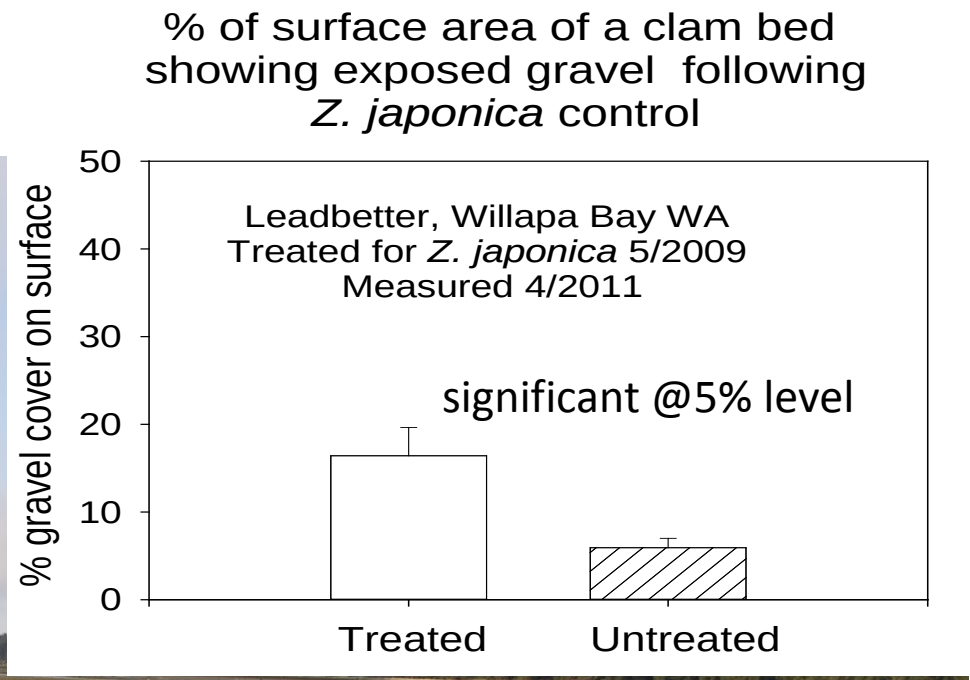
Patten et al 2012



Tsutsumi 2006

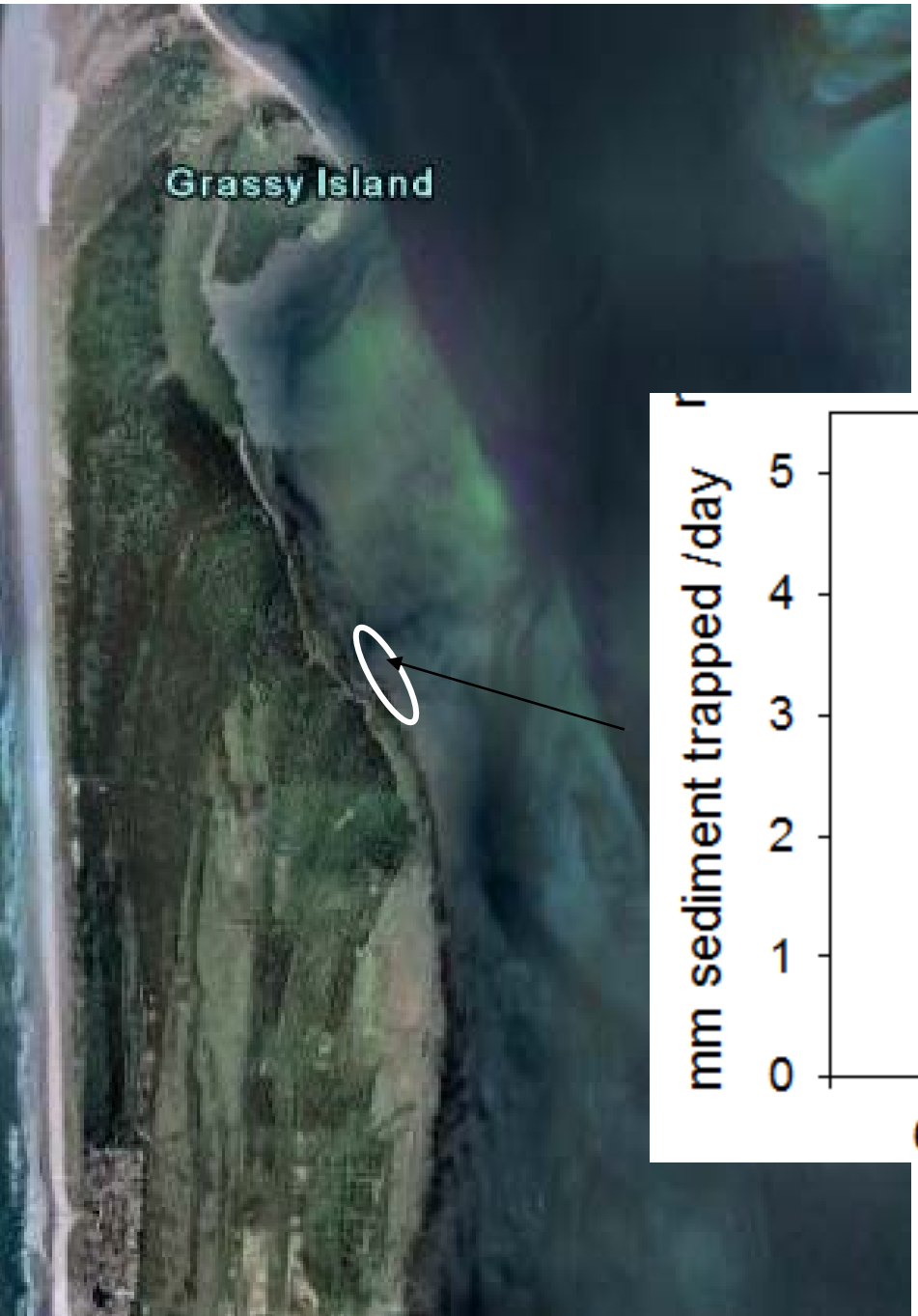
Critical events in the Ariake Bay ecosystem: Clam population collapse, red tides, and hypoxic bottom water

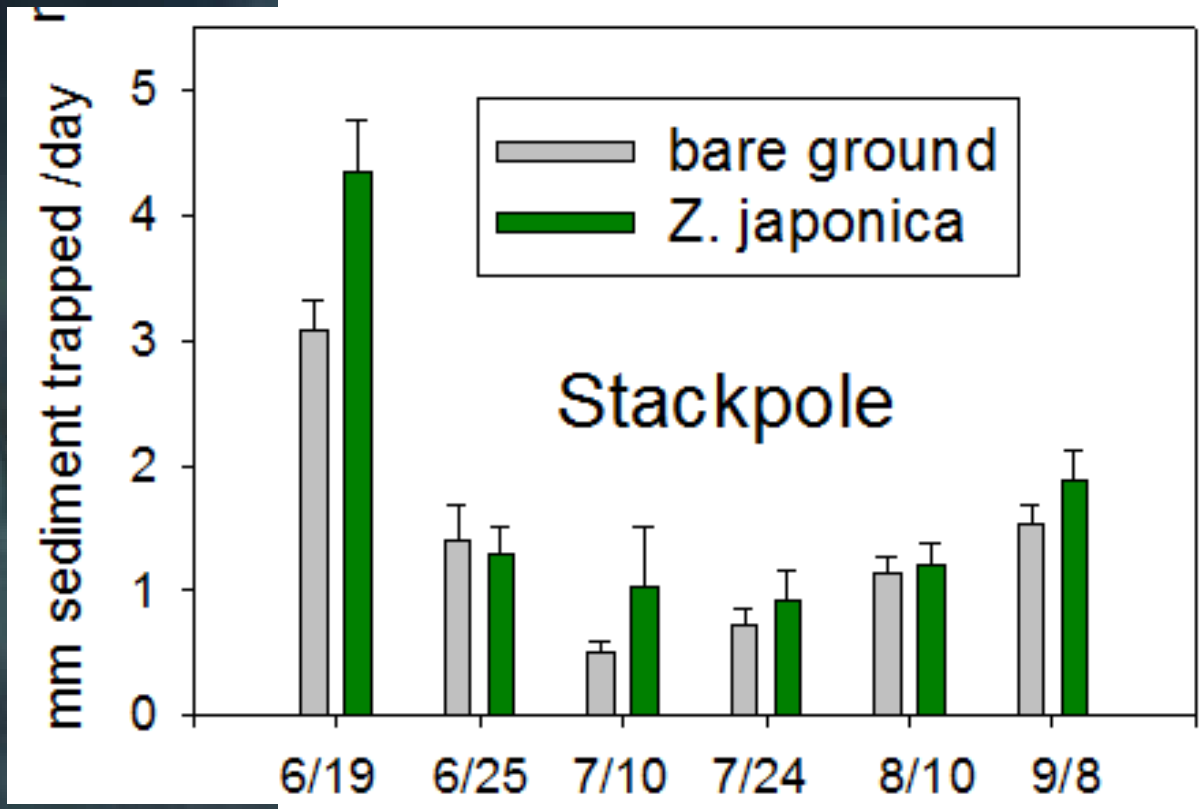

Change in tidal elevation in Willapa Bay
with *Z. japonica* control
(measured April 2011)
Elevation Difference (inches)
0.5
0.0
-0.5
-1.0
-1.5
significant @5% level
Oysterville Site
Treated May 2010
Leadbetter Site
Treated May 2009

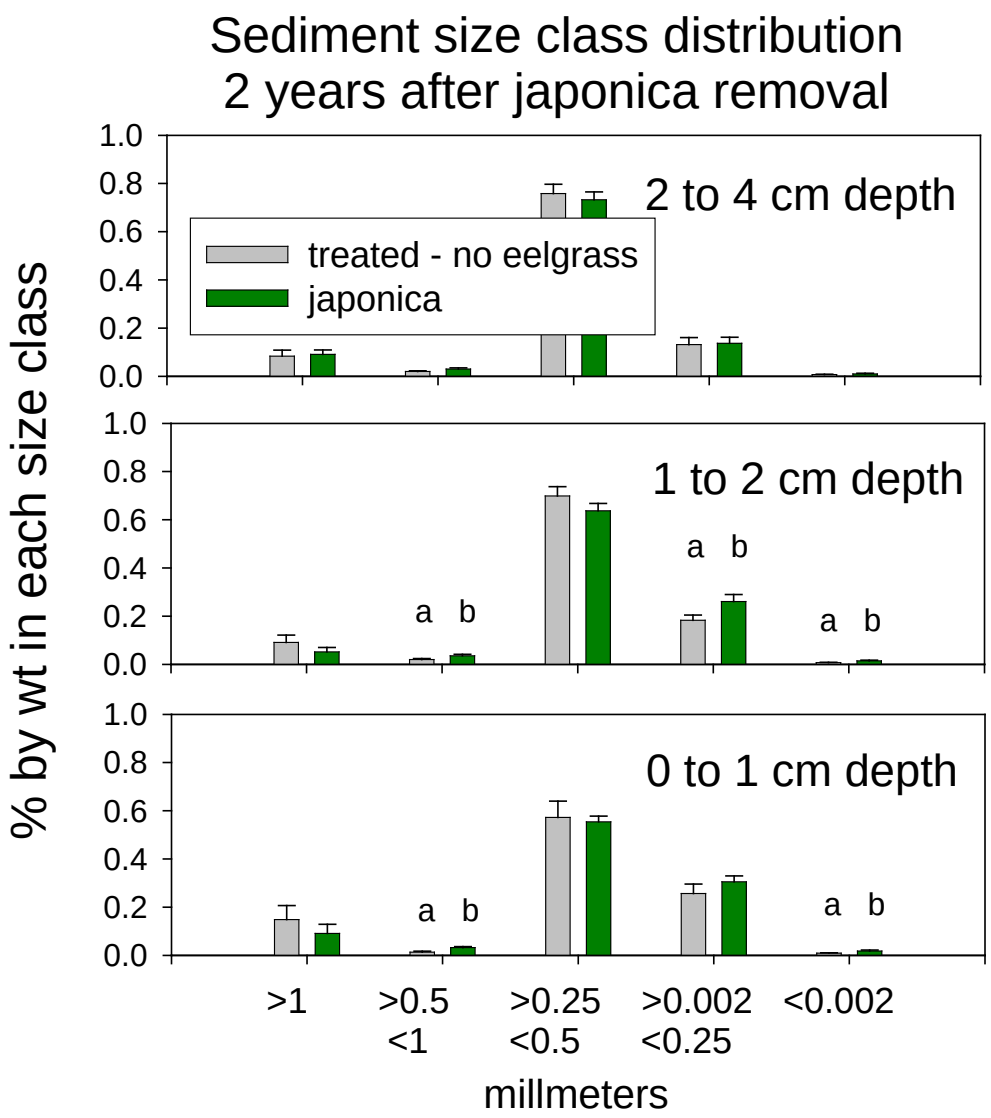

% of surface area of a clam bed
showing exposed gravel following
Z. japonica control
% gravel cover on surface
50
40
30
20
10
0
Leadbetter, Willapa Bay WA
Treated for *Z. japonica* 5/2009
Measured 4/2011
significant @5% level
Treated
Untreated

Patten et al. 2012

Sedimentation studies







Patten et al. 2012

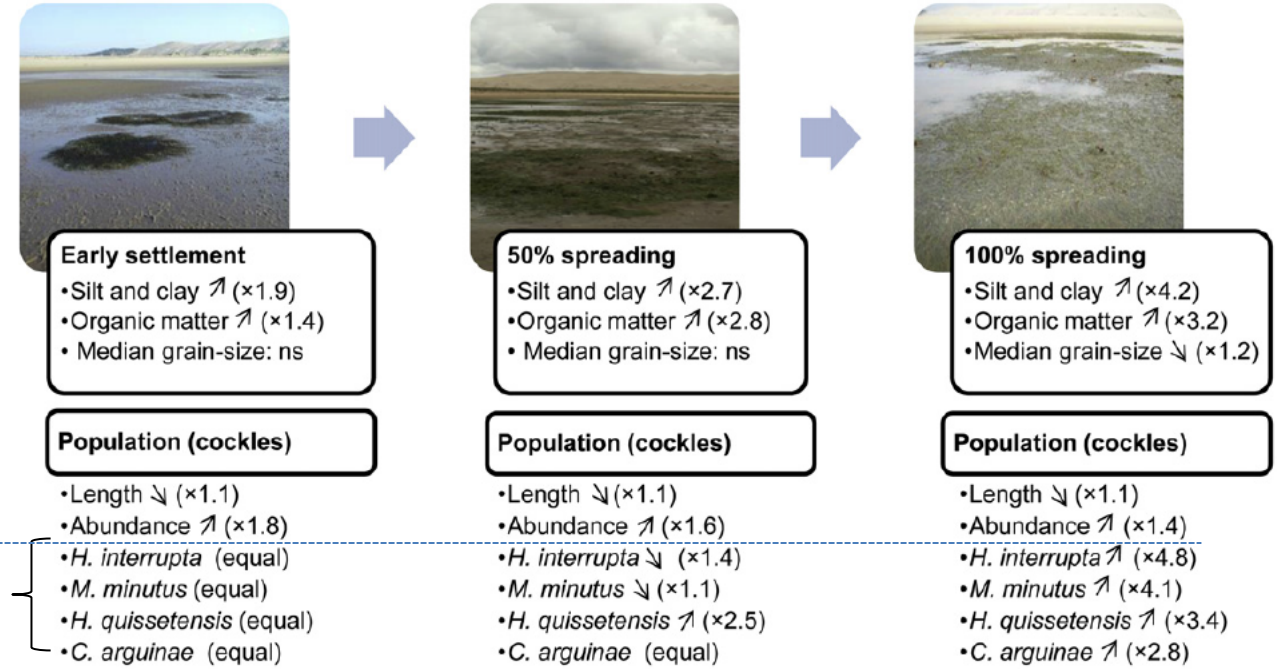
Summary – sediment/water health

- *Z. japonica* affects sediment texture, organic matter, surface gravel, and short-term night-time anoxia
  - These changes may negatively affect Manila clam survival, growth rate and/or condition
  - Level of impact is dependent on the level of colonization
  - Some of these variables are transitory and disappear during the winter.
  - Some of these variables could have lasting impacts

- Disease and parasites

Dwarf eelgrass – *Z. noltii in France, monitor changes with colonization over 5 years*
Tu Do et al. 2011

V. Tu Do et al. / Estuarine, Coastal and Shelf Science 95 (2011) 458–469



Cockle parasites

Shellfish disease – no data on relationship with *Z. Japonica* or other eelgrass or SAV

Enzootic parasites

- Prokaryotes (rickettsia-like and chlamydia-like)- not associated w/ diseases
- Gregarines in gills
- Sphenophrya-like ciliates in gills and palp surfaces
- Trichondina – chilates on gills and siphon
- Tubellaria
- Trematodes
- Mytilicola

Exotic pathogens

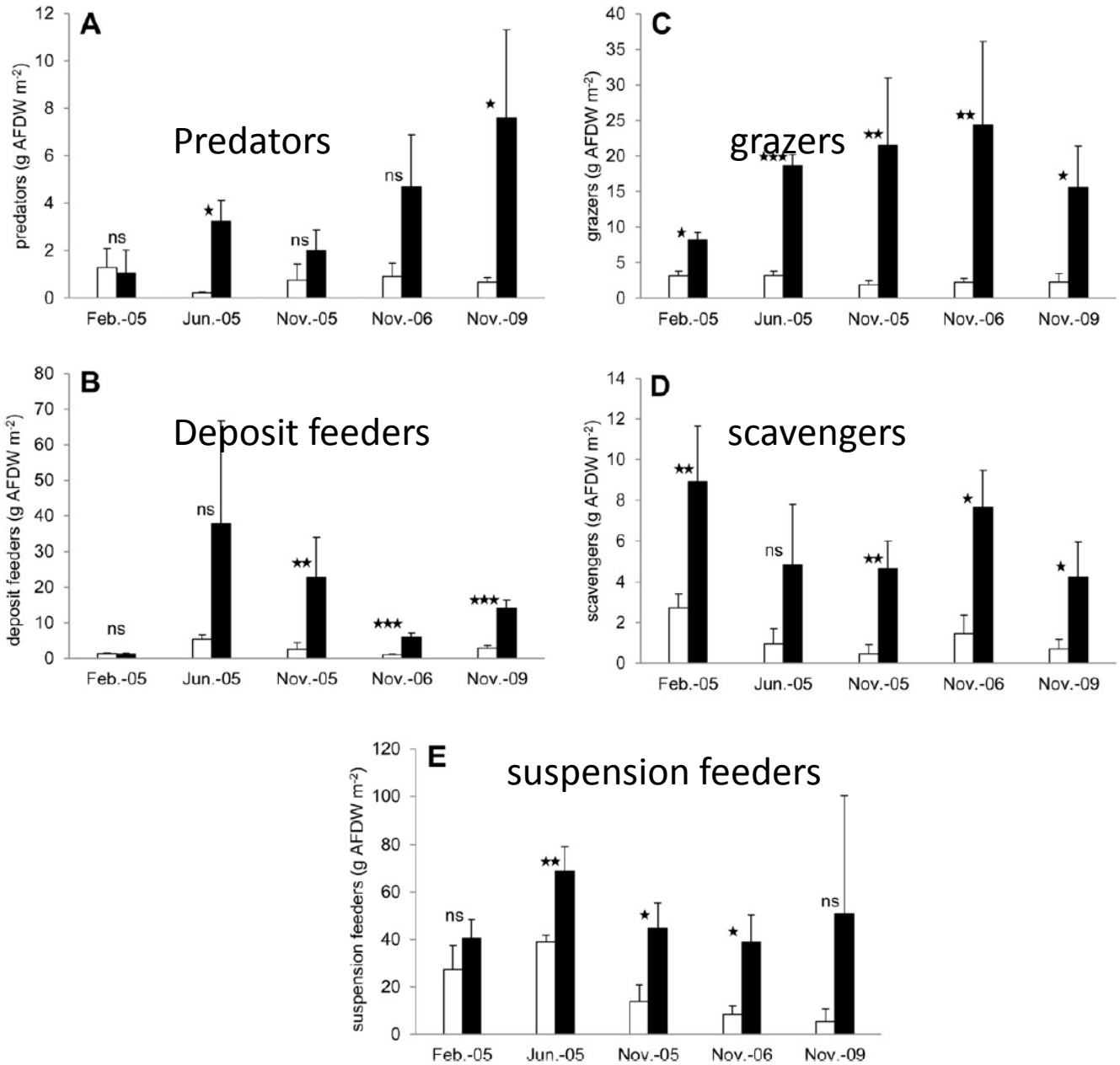
- Herpes-like viral infection – (France)
- Vibrio tapetis (brown ring disease – France)
- Protozoa – Perkinsis olseni

Exotic parasite

- Haplosporidian
- Marteillia

- Predation

Tu Do et al 2012
mean biomass
of trophic groups
as a function of Z. noltii
colonization over 5 yrs
in France



White – sand, black - eelgrass

Munari and Mistri
2011 Adriatic lagoon

Whelk prey preference following–24 hr short term hypoxia w/single prey or 3 prey offered together

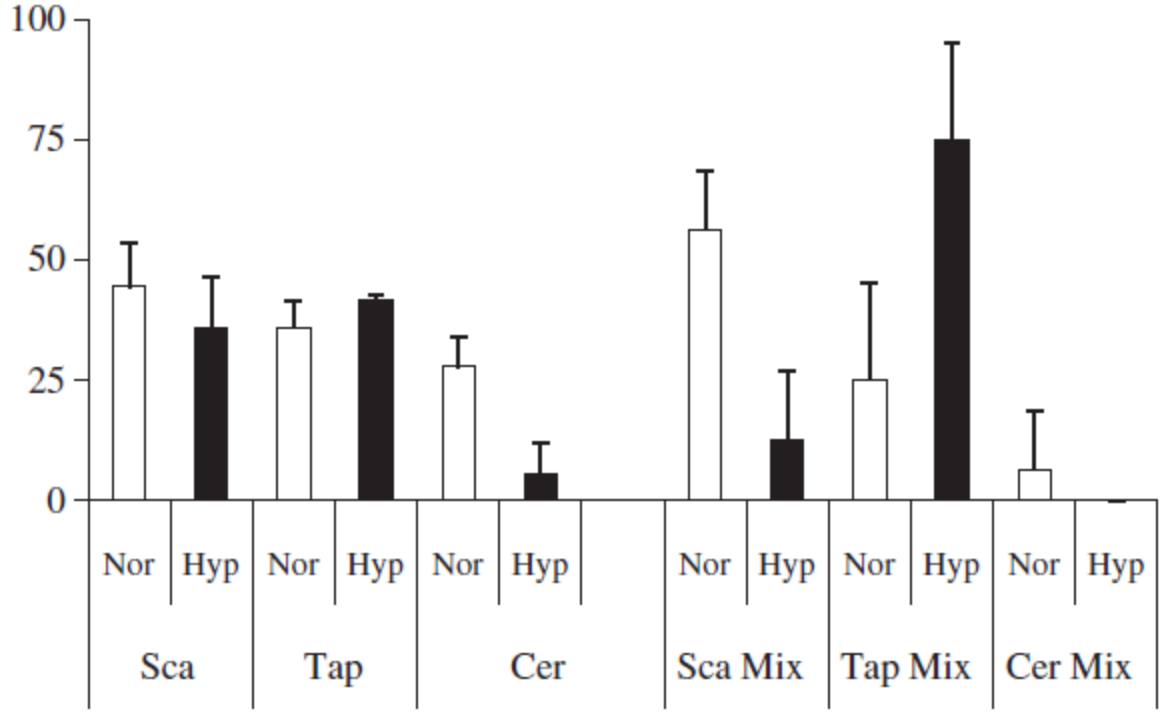


Fig. 1. Mortality of prey (*Scapharca inaequivalvis*, *Tapes philippinarum*, *Cerastoderma glaucum*) under normoxia (Nor) and after hypoxia (Hyp), when offered as single prey (Sca, Tap, Cer) in no choice experiments, and mixed (Sca Mix, Tap Mix, Cer Mix) in choice of prey experiments (bars: sd).

Booth et al. 2012 - study of taxa pre and post *Z. Japonica* removal

Table 2. Absolute Abundance ($\bar{x}$ ± S.E.) of all organisms combined or within each of 3 major taxa at the Taylor Bed before (May 19) and after (August 29) treatment of 0.1 ac plot (imaz) with a.i./ac imizamox in late May and an adjacent untreated plot fully covered with *Z. japonica* (*Z.j.*). Bolded values indicate significant differences (t-test, P=0.05).

Treatment	May 19				August 29			
	All Organisms	Polychaetes	Mollusks	Crustaceans	All Organisms	Polychaetes	Mollusks	Crustaceans
Imaz	226.0 ± 49.0	**70.6 ± 13.4 a**	2.6 ± 0.3	138.1 ± 36.6	524.1 ± 101.4	**116.2 ± 9.1 a**	**53.8 ± 2.8 b**	397.8 ± 99.4
Z.j.	321.6 ± 47.9	**122.0 ± 17.2 b**	2.8 ± 0.6	220.8 ± 37.3	732.2 ± 129.3	**296.9 ± 19.8 b**	**37.8 ± 3.1 a**	450.4 ± 130.0

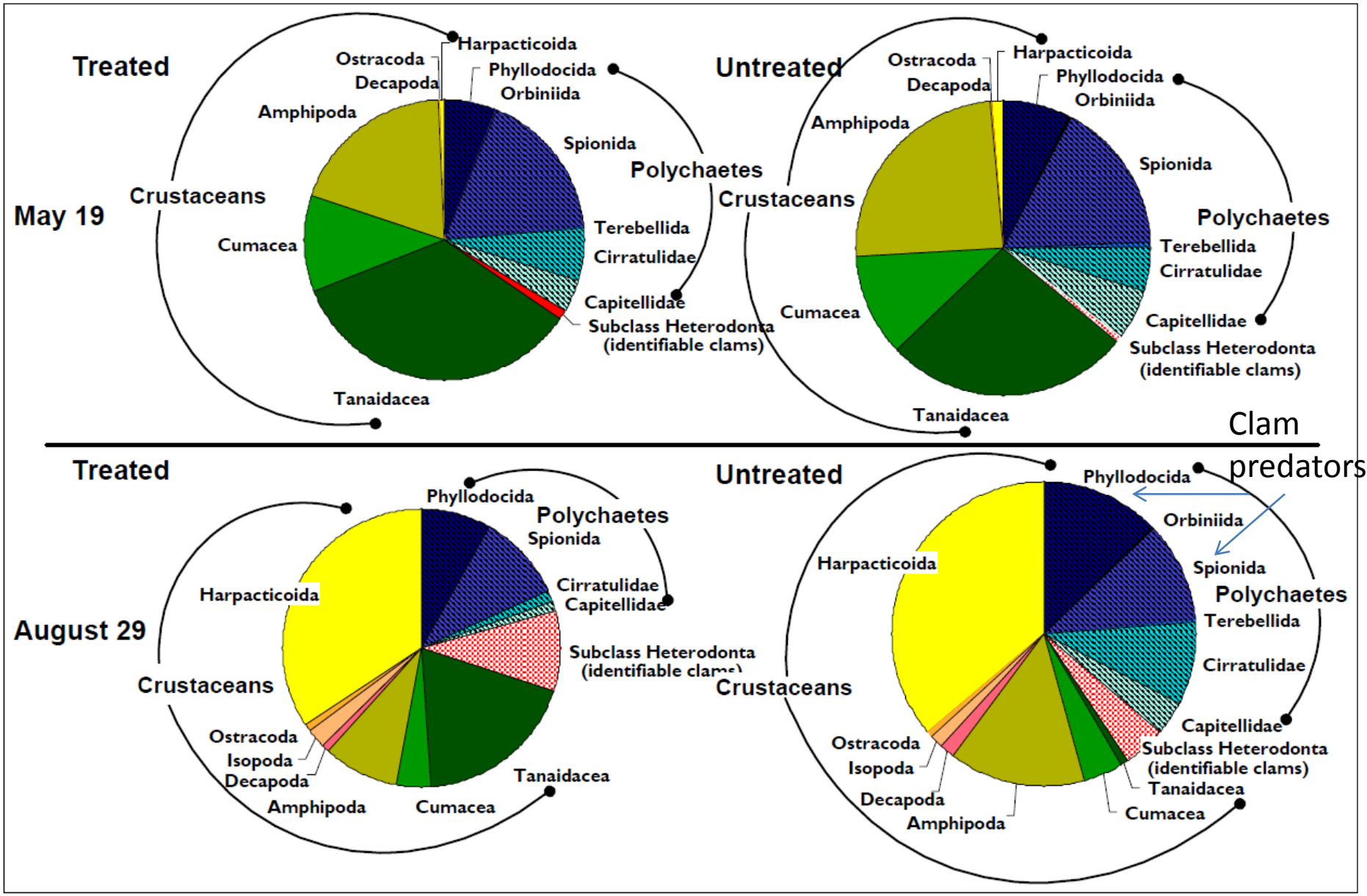


Figure 1. Proportions of 13 dominant orders and the subclass Heterodonta (identifiable clams) of benthic invertebrates a plot of dense *Z. japonica* and an adjacent similar plot treated with the herbicide Imazamox on May 27, thus barren of vegetation on August 29.

- Harmful algae bloom (HAB)

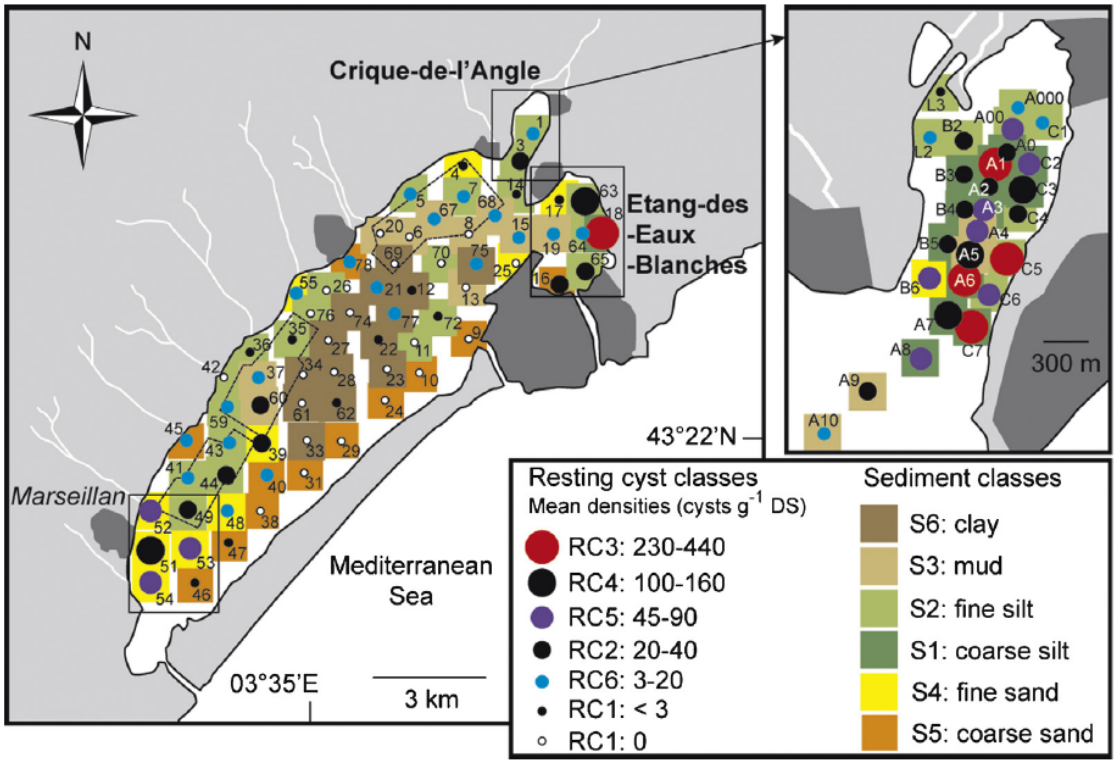


Fig. 3. Distribution maps of *Alexandrium catenella/tamarense* resting cysts in the Thau Lagoon and Crique-de-l'Angle combined with sediment characteristics (as indicated by the sediment class) across the whole lagoon (left, sampling in June 2003) and in the Crique-de-l'Angle Cove (right, sampling in March 2004). Cyst densities were expressed as cysts g^{-1} dry sediment (DS).

Genovesi et al 2013

Influences of sedimentation and hydrodynamics on the spatial distribution of *Alexandrium catenella/tamarense* resting cysts in a shellfish farming lagoon impacted by toxic blooms

Increased HAB cysts in silt

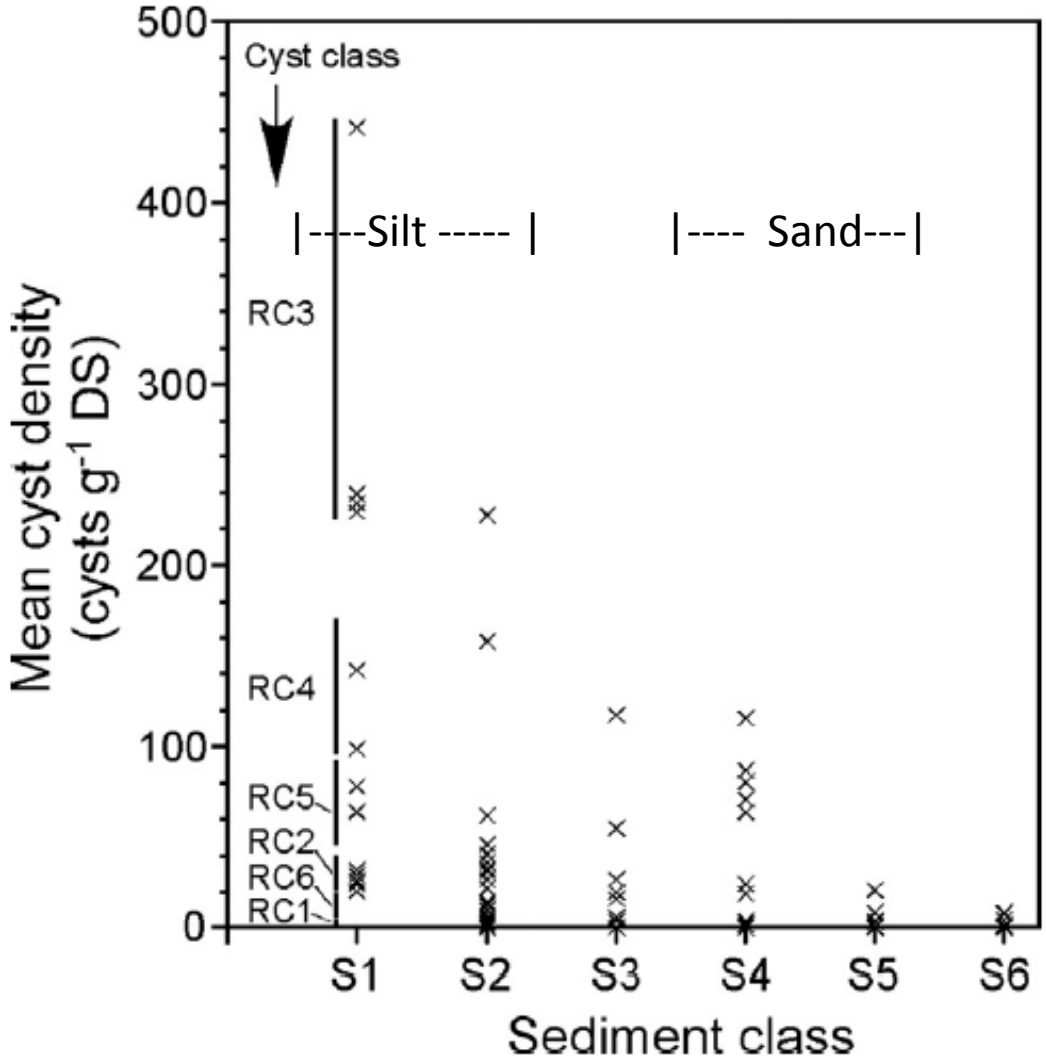
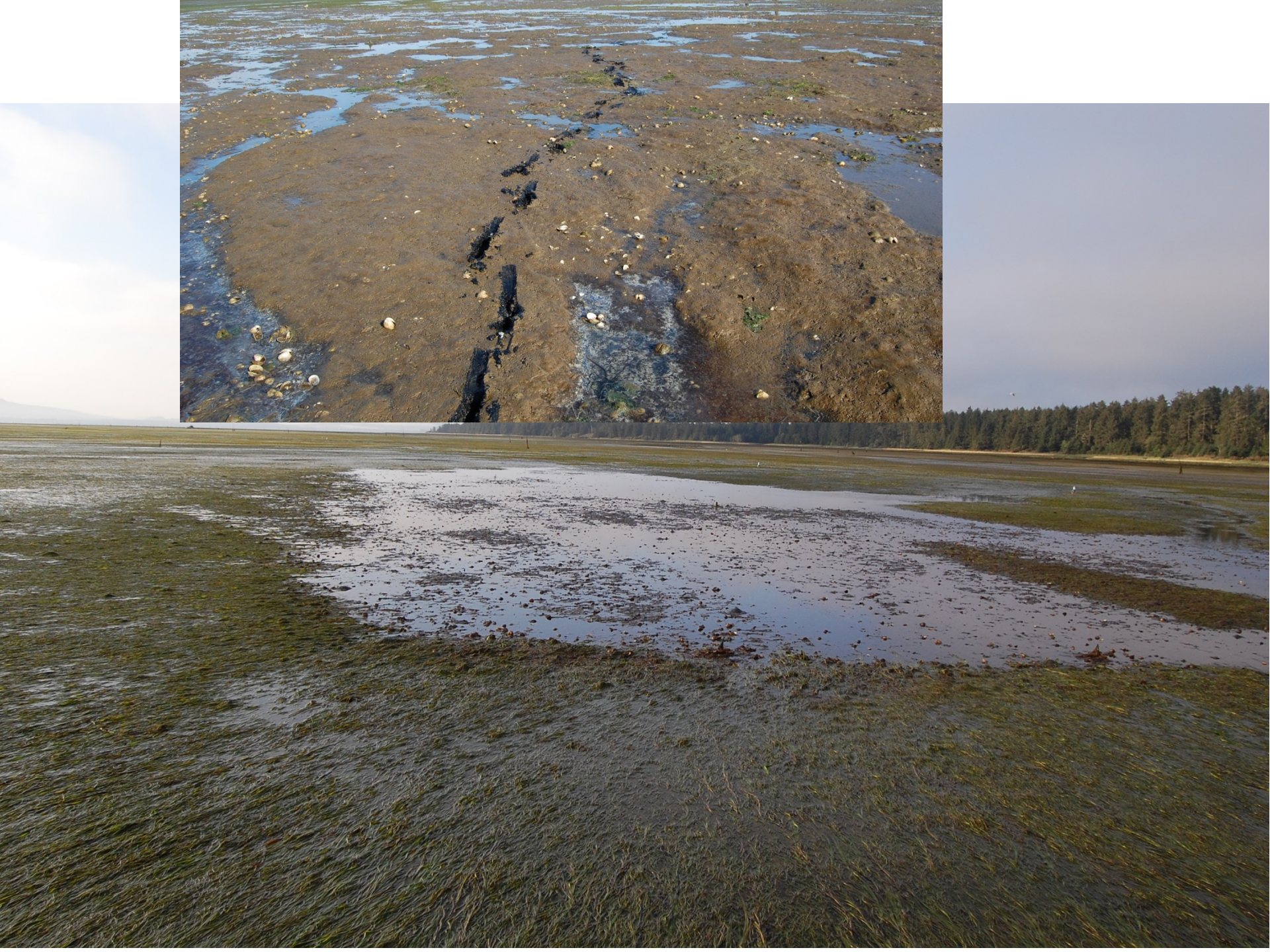


Fig. 4. Distribution of mean cyst densities within the six sediment classes as delineated by HCA in the 95 Thau Lagoon stations.

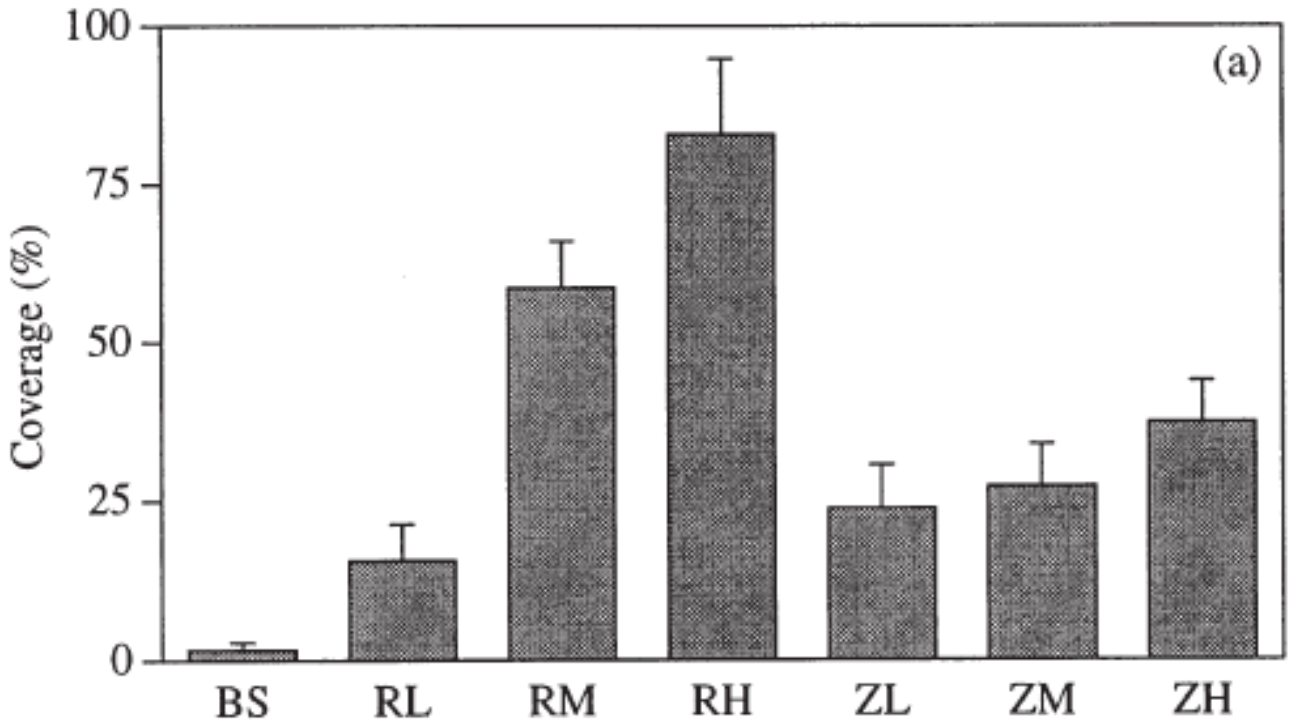
- Bio-fouling
  - No published data on *Z. japonica* effects
  - Grower anecdotal reports suggest fouling enhanced w/ *Z. japonica*.
  - Other seagrass – noted to increase bio-fouling

Increased biofouling



Bostrom & Bonsdorff, 2000

Drift
algae
% coverage



BS –
bare sand

Ruppia maritima
Low density (RL)
Medium density (RM)
High density (RH)

Z marina
Low density (ZL)
Medium density (ZM)
High density (ZH)

Summary – Diseases, parasites, predation, HAB, biofouling

- Disease – no data
- Parasites – trematodes increased on cockles with *Z. noltii*, no data for *Z. japonica*.
- Predation – no direct data on *Z. japonica* effect, but
  - There is a decoupling of recruit populations with juvenile populations
  - Z. japonica enhances overall infauna and megafauna population, including several potential predators
- HAB – no data, but *Z japonica* improves conditions for cysts.
- Biofouling – no data

- Harvesting - grower reports
  - Increased cost to harvest and clean
  - Increased crop losses during harvest due to not being able to recover all the crop
  - Mechanical harvest – not viable in thick *Z. japonica*

Projected net income ($) of Manila clam harvests at Willapa Bay, WA sites with and without Japanese eelgrass*

Treatment	Oysterville -1	Oysterville. -2	Leadbetter Point	Stackpole	South Nahcotta	Mean All Sites
No japonica	32208	9996	15751	7875	11207	15408
Z. Japonica	14766	5770	9419	5092	3479	7705
Difference	17443	4225	6331	2784	7728	7702

***assumes: (a) $2.35/lb. wholesale; (b) $0.65/lb. digging cost, $0.65/lb.to produce, clean, package, and market product; (c) an extra $0.05/lb. cleaning cost for Z. japonica-infested sites; and (d) 5 percent crop loss for Z. japonica sites due to clams left unharvested, or damaged.**

Patten et al 2012.

Summary – harvesting

- Thick *Z. japonica* increases harvest costs & harvest losses of Manila clams (anecdotal)
- Crop losses of $2.7 to $17.4K/ac/harvest cycle with *Z. japonica* infest clam beds.

Summary –

- Ample evidence that *Z. japonica* negatively affects shellfish in Willapa Bay
- Research needs
  - Studies have been limited to very small plots, but the impacts are likely to be more significant at the large scale (acres to 100's of acres)
  - Disease, health, predation, biofouling, sediment & water quality, fine sediment accretion.
  - Other shellfish (oysters)
  - Other sites (non- Willapa)

Questions