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Invasive Marine Organisms

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Introduction

by Scott Redman, Puget Sound Water Quality Action Team

Responding to the threats posed by invasive marine organisms is a priority issue for the Puget Sound/Georgia Basin International Task Force. In 1997, the Task Force approved a plan that identifies education, control of pathways of introduction, response planning, monitoring and research actions to minimize threats posed by non-native marine organisms. Copies of this plan are available from the Puget Sound Water Quality Action Team. Submit your request to blester@psat.wa.gov or call 1-800-54SOUND (in Washington) or 360-407-7300.

The 1998 Washington State Legislature passed a bill (Washington State Laws of 1998, Chapter 153) directing the Washington State Department of Fish and Wildlife to create a task force to develop recommendations about how to respond to the threats from two specific potential invaders: the European green crab (*Carcinus maenus*) and the zebra mussel (*Dreissena polymorpha*). This task force has begun meeting and will develop its recommendations by December 1998.

In June 1998, the state of Washington developed an "Aquatic Nuisance Species Management Plan", which builds upon the Puget Sound/Georgia Basin implementation plan and incorporates the legislative directives of the 1998 state law. Copies of this plan are available from Scott Smith (smithsss@dfw.wa.gov, 360-902-2724), Aquatic Nuisance Species Coordinator, Washington State Department of Fish and Wildlife.

Recent efforts of many agencies, organizations and individuals to control *Spartina* (cordgrass) in Washington's coastal estuaries and in Puget Sound have informed the initiatives to minimize threats from invasive species. Our experience with *Spartina* management taught us that control and eradication efforts are costly and won't succeed overnight. Successful responses to threats of exotic species will entail "up front" work to pre-empt invasions or to plan appropriate responses.

In this issue of Puget Sound Notes, we present information on Asian copepods (*Pseudodiaptomus spp.*) invading Pacific Northwest estuaries, the status of *Spartina* control activities in Puget Sound, and the threats to Puget Sound from a potential invasion by Chinese mitten crab (*Eriocheir sinensis*). These articles provide only a small glimpse at the information available on the threats of invading organisms and the activities planned to address these invaders. Two specific items that we hope to present in upcoming issues of this newsletter include: (1) the results of the September 1998 Puget Sound Expedition, a survey of organisms around Puget Sound docks and floats, and (2) a summary of European green crab (*Carcinus maenus*) monitoring efforts as this invader appears to move up the coast toward Puget Sound.

Asian Copepods in Pacific Northwest Estuaries

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The Threat of Copepod Invasions

Devastation caused by exotic species that invade terrestrial and freshwater ecosystems has been extensive (U. S. Congress, Office of Technology Assessment 1993). Effects of marine and estuarine invasions, while less studied, can be similarly profound (Carlton and Geller 1993, Hedgepeth 1993). Ships move millions of cubic meters of water between coastal environments around the world, transporting entire faunal assemblages (Carlton 1985, 1987, Carlton and Geller 1993, Ruiz et al. 1997). Establishment of species from these assemblages in their new environments usually results in changes in native assemblages. The catastrophic displacement of preexisting assemblages in San Francisco Bay by the Asian clam *Potamocorbula amurensis* (Carlton et al. 1990, Nichols et al. 1990) and in the Great Lakes by the zebra mussel *Dreissena* spp. (Roberts 1990, Ludyanskiy et al. 1993, Nalepa and Schloesser 1993) are only two dramatic examples of the impact of ballast water introductions.

Puget Sound and other Pacific Northwest estuaries and coastal bays may be especially susceptible to invasion by estuarine zooplankton—water column dwelling larvae of larger animals and adults of smaller animals. Among the reasons for this susceptibility are that our estuaries are geologically young and therefore have low plankton species diversity, are often sites for ballast dumping, and are increasingly disturbed by human activity. In fact, the rate of estuarine exotic species introductions appears to be accelerating in estuaries such as San Francisco and Willapa bays (Cohen and Carlton 1998, J. Cordell personal observations). The most likely avenue for ballast water introduc-

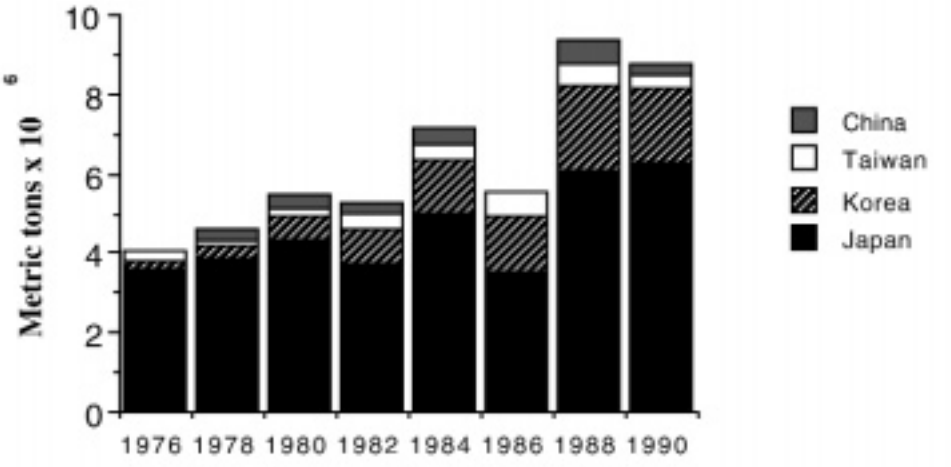

Fig. 1. Net tonnage of ballasted ships entering the Columbia River from Asian ports, 1976-1990. Data from Reports of Arrival Logs, U.S. Customs, Portland, Oregon (from Cordell at al. 1992)

tions in Pacific Northwest estuaries is via ballasted ships arriving from Asia. With increased demand in Asia for Northwest wood products (primarily raw logs and wood chips), Northwest ports have seen an increasing proportion of ships without cargo (i.e. fully ballasted) in recent years (see Fig. 1 for an example of increase in Asian ballast water entry into the Columbia River). Another source of introductions is from intracoastal transport of ballast water from heavily invaded ports (such as San Francisco) to other West Coast ports. Some of the most abundant of the planktonic animals transported in ballast are copepods.

Copepods are small crustaceans that are ubiquitous in marine, estuarine, and freshwater habitats—they occur from the deepest ocean trenches to temporary pools and are abundant in bottom sediments, on aquatic plants, and in the water column. Because of their abundance and availability, they form a fundamental link in aquatic food chains by providing forage for a variety of other invertebrates and small fish. For example, copepods are a major food resource for many species of commercially important fishes that spend their early life in Puget Sound and other estuaries, such as salmon, herring, smelts, striped bass, and many species of flatfish.

Unfortunately, recent findings elsewhere suggest that ecological effects of planktonic invaders can be quite severe. Although examples of devastating invasions by marine planktonic organisms are relatively rare (but see Zaitsev 1992 on the profound effects of an invasive marine ctenophore), three exotic freshwater planktonic cladocerans are known to have invaded North American lakes (Lehman 1987, Lieder 1991, Havel and Hebert 1993, Gould et al. 1995, Havel et al. 1995). At least one, the ballast-introduced spined cladoceran *Bythotrephes cederstroemi*, appears to have caused major perturbations in native plankton communities (Lehman 1988, 1991, Lehman and Caceres 1993, Branstrator 1995). To summarize, the invasion of *Bythotrephes* seems to have caused a reduction in the abundance of a native predatory cladoceran (*Leptodora kindtii*) and a reduction in the abundance and diversity of the offshore *Daphnia* assemblage. Alterations in the vertical distribution of *Daphnia* also accompanied the invasion of *Bythotrephes*. Interestingly, these marked changes in the zooplankton assemblage did not appear to significantly affect algal biomass. *Bythotrephes* also appears to have changed predator-prey interactions in invaded lakes because of fish avoidance of the cladoceran (Barnhisel and Kerfoot 1994, Barnhisel and Harvey 1995).

A striking example of an invasion of an estuary by ballast-introduced planktonic copepods is that of the introduced Asian copepods *Pseudodiaptomus marinus, P. forbesi, Limnoithona sinensis, L. tetraspina, Sinocalanus doerii, Acartiella sinensis,* and *Tortanus dextrilobatus* in the Sacramento-San Joaquin estuary (Orsi et al. 1983, Ferrari and Orsi 1984, 1995, Fleminger and Kramer 1988, Orsi and Walter 1991, Obrebski et al. 1992, Orsi 1995, 1998). Recently two of these species (*P. forbesi* and *S. doerii*) were implicated as possible causes of recruitment failure in striped bass (*Morone saxatilis*) due to reduced feeding efficiency of first-feeding larvae on introduced copepods compared to native, displaced copepods (*Eurytemora affinis* and *Cyclops* sp.) that have historically been important as larval prey (Meng and Orsi 1991). In particular, these authors found behavioral differences (i.e., swimming and escape responses) between introduced and native copepods that accounted for the reduced feeding efficiency of larval striped bass. In addition, recent data on feeding of the endangered delta smelt in the Sacramento-San Joaquin estuary has suggested that, while *P. forbesi* is a dominant prey item for these fish, it may be suboptimal in relation to the native copepod *Eurytemora affinis* (Lott 1998, Nobriga 1998). The establishment of exotic copepods in the Sacramento-San Joaquin estuary has been accompanied by a decline and shift in seasonality in the previously dominant *E. affinis*. Kimmerer (1991) found that in laboratory experiments the introduced Asian clam *Potamocorbula* fed on *Eurytemora* but not *Pseudodiaptomus* species, and Kimmerer et al. (1994) argued that the decline in *Eurytemora* was due to this differential predation. However, the decline may have also been partly due to direct competition with *P. forbesi*.: Orsi (1995) noted that *Eurytemora* continues to be seasonally present in winter and spring when *P. forbesi* is scarce, both within and upstream of *Potamocorbula's* range. Interestingly, *P. forbesi* itself may be declining due to predation by yet another recently introduced calanoid copepod, *Tortanus dextrilobatus* (Orsi 1995).

P.inopinus Photo by Jeff Cordell

Non-native Copepods in Pacific Northwest Estuaries

In 1990, we found that the Columbia River estuary had been invaded by *Pseudodiaptomus inopinus*, probably via introduction by ballast water dumping (Cordell et al. 1992). Subsequent biological surveys of Oregon, Washington, and British Columbia in 1991-2 and 1996 revealed that *P. inopinus* has persisted in and invaded many other estuaries between southern Washington and southern Oregon (Cordell and Morrison 1996; Figure 2). *P. forbesi* has also been found in Washington's coastal estuaries and, during the summer of 1998, several examples of *P. marinus* were noted in epibenthic samples from Elliott Bay (Seattle) in Puget Sound (J. Cordell, unpublished data). This is the first observation of this genus in Puget Sound.

When *P. inopinus* occurs in Pacific Northwest estuaries, it is abundant and usually numerically dominates the zooplankton (Cordell and Morrison 1996, J. Cordell, unpublished data). Currently, the extent and rate of its spread and its ecological effects on these estuaries are largely unknown. Little is known of the biology and ecology of this species in its natural habitats, except that in Northeast Asia it appears to be geographically widespread, occurs in a number of freshwater and estuarine habitats, and is most abundant in autumn (Mashiko 1951, Shen and Song 1979, Oka et al. 1991). Even less is known about *P. inopinus* in its invaded habitats. In surveys to date, this species has only been found to have invaded coastal estuaries in Washington and Oregon (Cordell and Morrison 1996, J. Cordell unpublished data; Figure 1). Unexpectedly, it has not yet arrived in British Columbia or Puget Sound estuaries, despite intensive international shipping in such ports as Vancouver, Everett, Seattle, and Tacoma. Preliminary data indicate that only coastal estuaries in the Pacific Northwest with relatively high temperatures and those with low elevation gradients and long salinity transition zones are susceptible to invasion by *P. inopinus* (Cordell and Morrison 1996). Invasions occur in river estuaries both with and without international shipping, and in large and small estuaries.

Whether *P. inopinus* has affected fish and plankton assemblages of Pacific Northwest estuaries is unclear; there is little recent data on the feeding of native fish and invertebrate species in estuaries that have been invaded by *P. inopinus*. However, the little data that do exist on the ecology and feeding habits of juvenile salmon in tidal fresh- and brackish waters of Pacific Northwest estuaries indicate that these regions are important. Juvenile salmon residence and use of these areas appears to be greater than once thought, and zooplankton species are often prominent in their diets (Craddock et al. 1976, Tschaplinski 1987, Simenstad et al. 1992, 1993). For example, zooplankton (mainly the cladocerans *Daphnia* spp. and the calanoid copepod *Eurytemora affinis)* were prominent in the diet of spring outmigrating juvenile chum salmon from the Duwamish River in 1996 (Cordell et al. 1997). Other invertebrates such as the estuarine mysid shrimp *Neomysis mercedis* also occur prominently in juvenile salmon diets (Simenstad et al. 1992, 1993) and may be affected by introduced zooplankton because the shrimp feed on copepods (Simenstad and Cordell 1985).

Investigation of the effects of *P. inopinus* on Pacific Northwest estuarine food webs and commercially important finfish such as salmonids will be a major focus of new research on this species that began in July 1998 in the Chehalis River estuary. In this study, we will sample zooplankton twice per month. Potential predators of *P. inopinus*, including fishes, mysids, and sand shrimp will also be collected bi-monthly. Invertebrate predators will be collected from the plankton net samples (e.g., the mysid *Neomysis mercedis*) and by benthic sled samplers (e.g.,

Figure 2. River estuaries sampled for introduced copepods in 1991-2 and 1996. Filled circles indicate presence, open circles absence of established *Pseudodiaptomus inopinus* populations.

Cordell and Morrison 1996, J. Cordell unpublished data

the sand shrimp *Crangon franciscorum*). Juvenile fishes will be collected mainly with beach seines. Subsequent laboratory analysis of potential predators will include identification of copepods in predator stomachs. In an effort to further evaluate the potential importance of *P. inopinus* in the trophic structure and function of estuarine food webs, we will also experimentally determine the degree to which *P. inopinus* is preferred (positively or negatively) by potential predators. We expect to use native copepods as alternative prey. Results of these experiments will complement the field studies of diets, and the combined data set will allow us to determine the degree to which *P. inopinus* will be an appropriate prey item for fish and invertebrates should it continue to spread and increase in abundance in Pacific Northwest estuaries.

ACKNOWLEDGMENTS

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1997-1998 *Spartina* Monitoring and Control in Puget Sound

by Wendy Sue Bishop, Washington Department of Agriculture

Spartina

The goal of the *Spartina* program is eradication of this invasive and extraordinarily persistent plant from Washington state. In the near term, a major objective is preventing seed production from existing infestations, as seed can spread the infestation to new areas at an exponential rate. Another objective is to contain the spread of existing infestations, a particularly important step in dealing with weeds with a high rate of vegetative growth (spread). It may take several years of control - the average is three years - with a variety of treatment methods (such as mowing the plants down to the mud, herbicide applications, and hand pulling) before an infestation of *Spartina* is eradicated. After eradication is achieved, the area must be monitored and any new seedlings removed to assure no re-establishment occurs.

Table 1. 1997 Treatment Efforts by County

County	Estimate of Actual Area of *Spartina* Treated in 1997 (acres)
Clallam	0.50 *
Grays Harbor	0.60
Island	253.50
Jefferson	3.50 *
King	0.25 *
Kitsap	1.00
Pacific	741.30
San Juan	0.06 *
Skagit	91.20 *
Snohomish	89.00
TOTAL	1,181

* = All Known *Spartina* Infestations Treated

A new strategy for containment and eventual eradication of the state's *Spartina* infestation was inaugurated by the Washington State Department of Agriculture (WSDA) in the 1997 season. The "fireline" strategy drew lines across maps of Northern Puget Sound and Willapa Bay, targeting the *Spartina* populations outside these lines for concerted treatment and, wherever possible, one-season eradication. Firelines will be moved inward in succeeding years as the overall infestation is geographically reduced. Adherence to the principles of integrated pest management and the fireline approach will allow participating agencies to build on efforts made in successive control seasons and to make the most effective use of resources.

As was done in 1996, WSDA provided funds to Snohomish, Skagit and Island counties, so that the county noxious weed boards could conduct meaningful control programs in 1997 and 1998. These three counties contain the majority of *Spartina* in the northern part of the state. In 1997 and 1998, these funds allowed the counties to hire control crews and/or a contractor to treat identified "priority areas" located outside the 1997 firelines.

Control and monitoring activities in five other infested counties (San Juan, Jefferson, Clallam, Kitsap and King) were undertaken by WSDA staff in cooperation with Adopt-A-Beach volunteers, landowners, tribal members, and staff from other state agencies. Because three counties (Clallam, Jefferson and Kitsap) did not have active county noxious weed boards at that time and were outside the firelines, control of all known infestations in those counties was a particular priority for and specific responsibility of WSDA.

WSDA and Washington State Department of Natural Resources (WDNR), in conjunction with the State Parks and Recreation Commission and the Washington State Department of Fish and Wildlife (WDFW), have obtained special, additional funding for *Spartina* control efforts. Under a specific, one-time agreement, WSDA and WDFW were awarded $450,000 from the Coastal Protection Fund for a two-season control and eradication effort in Northern Puget Sound, and WSDA was awarded $64,000 for a two season effort in Southern Puget Sound.

Statewide Control Efforts Summary

It is estimated that a total of 18,374 acres of intertidal land in Washington suffer some level of *Spartina* infestation. This total acreage is equivalent to approximately 6,807 acres of solid *Spartina*. During the 1997 control season, combined efforts of all participants resulted in the treatment of 4,970 acres (the equivalent of 1,181 acres of solid infestation) by mowing, herbicide application, hand pulling, or a combination of these methods. Table 1 shows how this effort was distributed among the infested counties.

Actions in Northern Puget Sound: Skagit, Island, and Snohomish Counties

In keeping with the fireline strategy and focus on eradication (where possible) and control in priority areas, *Spartina* control efforts in Northern Puget Sound were concentrated on keeping the infestation in Padilla Bay from spreading further north into Samish Bay and from moving further south to Kitsap County. These efforts appear to have been successful.

In fulfillment of its contract with WSDA for the 1997 season, Island County eradicated the northernmost outlier clones of its infestation and treated all Whidbey Island infestations. All infestations in Skagit County were treated, which fulfilled 1997 goals in its contract with WSDA. In Snohomish County, earlier infestations at the south end of the county had been eradicated with no known returning *Spartina*. In the 1997 season, a county crew continued to concentrate its efforts on the southern edge of the remaining infestation. Snohomish County did not entirely meet its *Spartina* management goals, due to unanticipated problems with property ownership and the distance between treatment sites.

WSDA feels the 1997 season was highly successful in this three county region. The agencies involved devoted notable effort to controlling a significant amount of *Spartina* and also operated with focused coordination and cooperation. Overall, the four most successful components of the 1997 program in Northern Puget Sound were (1) the introduction of the fireline approach, (2) prioritizing control activities through WSDA contracts with the counties, (3) large scale coordination, and (4) availability of multiple crews for combined efforts on large infestations.

For 1998, the firelines were moved inward from their original positions and control is underway in all counties in the Northern Puget Sound region.

Actions in Other Puget Sound Areas

Other Puget Sound counties involved in the *Spartina* program include King, Kitsap, Clallam, Jefferson, and San Juan County. Control efforts in the Southern Puget Sound region (the first four counties listed above) are focused on keeping the Southern Puget Sound infestation from spreading south of Kitsap County. San Juan County has been the location of a few *Spartina* control activities in 1997 and 1998.

WSDA has hired crews to control and, where possible, eradicate the known outlier infestations in the Southern Puget Sound counties. During the 1997 season, the crew treated 11 infested sites three times. Of those sites, populations of *Spartina* on six sites were eradicated, and five required treatment again in 1998.

In King County, areas from which *Spartina* was believed to be eradicated in 1996 were monitored in 1997 to make sure they had not experienced regrowth and that new seedlings had not established.

In San Juan County re-treatment was necessary at the sole previously known infestation. A second infestation was discovered and treated in 1997. Both populations were also treated in the 1998 control season. A survey of San Juan County is planned for the fall of 1998.

WSDA worked with Adopt-A-Beach, the Environmental Protection Agency, and private citizens to survey and control infestations in counties without active noxious weed control boards. Surveys conducted by these organizations in Jefferson County resulted in identifying an infestation not previously documented. This new infestation was eradicated in 1997. A substantial amount of Southern Puget Sound, the Straits of Juan de Fuca and the Olympic Peninsula has been surveyed by WSDA staff, Adopt-A-Beach and Washington Water Trails. A few inaccessible islands had yet to be surveyed by the end of 1997. These islands are targeted for survey in 1998.

Chinese Mitten Crab A Threat to Washington State Waters?

by Robyn Draheim, Graduate Student, School of Marine Affairs, University of Washington

Chinese mitten crabs (*Eriocheir sinenis*) – also known as hairy-fisted or woolly-handed crabs – are one of a number of invasive species threatening Washington's environment and economy. Is Puget Sound their next stop? Quite possibly, yes.

Not truly a freshwater species, Chinese mitten crabs reproduce in estuaries but rear in freshwater for two to three years before they return to brackish water to mate and die. Each summer, adult mitten crabs release vast quantities of larvae into estuarine waters. Estuarine water containing mitten crab larvae can be carried to distant locations (e.g., as ballast in ships).

Potential Threats From Chinese Mitten Crabs

The potential impact of Chinese mitten crabs invading the U.S. was clearly recognized in 1989 when the U.S. Fish and Wildlife Service listed Chinese mitten crabs as an injurious species, making their importation, capture and possession a serious crime. Based on the mitten crab impacts in their native and newly established ranges, the undesirable effects of a mitten crab population in Puget Sound might include:

- damage to river banks and levees by the crab's burrows;
- disturbance to human activities and structures as large numbers migrate over and around dams, through city streets, and into intake pipes by the thousands;
- damage to fishing nets and catch when crabs are present as by-catch in sufficient numbers; and
- disturbance to existing communities and populations of estuarine and freshwater organisms through competition and predation.

Invading mitten crabs might also pose a threat to human health. In Asia, the mitten crab is an intermediate host for the Oriental lung fluke, a parasite that can be contracted through the consumption of raw or undercooked crab meat. Human infestation by this fluke can cause sometimes-fatal tuberculosis-like symptoms. Because mitten crabs are considered a delicacy, there is concern that the invading crabs might become a source of infection.

Chinese Mitten Crab Invasions

Chinese mitten crabs have a history of invasion. In 1912 German fishermen found them upon pulling up their flounder nets. In 1992 shrimpers in San Francisco Bay were catching them in their trawls. And in 1997 a sturgeon fisherman landed a specimen at the mouth of the Columbia River.

Mitten crabs may have entered San Francisco Bay in the ballast water of vessels coming from Asia. With mitten crabs now established in three centers of global shipping (China, Europe and San Francisco), there seems to be a clear risk for ballast water discharges to introduce a viable population of this organism to Puget Sound.

Another possible source of the San Francisco Bay invasion is the intentional, though illegal, introduction by persons wishing to establish a harvestable population of this organism. There is an established demand and potential (black) market for mitten crabs. Shipments of live mitten crabs have been confiscated at airports in Los Angeles, San Francisco and Seattle.

Additional information

Additional information on invasive marine organisms that threaten Puget Sound or other coastal areas is available on the Internet. Web sites that may be of interest include:

- Washington's Aquatic Nuisance Species Response
  www.wa.gov/wdfw/fish/nuisance/ans1.htm

- The September 1998 Puget Sound Expedition
  http://weber.u.washington.edu/~cemills/psx.html

- Nonindigenous Aquatic Species Information from USGS' Biological Resources Division
  http://nas.nfrcg.gov/nas.htm

- Mitten Crab Invasion in California
  www2.delta.dfg.ca.gov/mittencrab/index.html

- Varnish Clam in Washington and British Columbia
  http://weber.u.washington.edu/~cemills/Nuttallia.html

- Green Crab on the West Coast of North America
  http://www.pac.dfompo.gc.ca/ops/fm/crab/GREENCR.HTML
  http://www.tidepool.org/derek/greencrab.html

Mark Sytsma has set up an e-mail listserver to facilitate discussion of invasion, impacts, and management of aquatic nonindigenous species in the Pacific Northwest. To subscribe, please send following e-mail message to:

listserv@freya.cc.pdx.edu:

subscribe PNW_ANS-L

The list is unmoderated for subscribers. If you subscribe, you may post messages to the list at will. Please be polite and respectful.

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This newsletter is intended to inform the interested public about events that affect Puget Sound, to disseminate information about the Puget Sound Estuary Program, and to encourage public participation in the government policy-making process. Publication of this newsletter has been funded wholly or in part by the U.S. EPA under cooperative agreement CE-990622-02 to the Puget Sound Water Quality Action Team. It is distributed free of charge as a public service. Address corrections or mailing list additions should be mailed to: ***Puget Sound Notes***, Puget Sound Water Quality Action Team, P.O. Box 40900, Olympia, WA 98504-0900.

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