From Marshes to the Continental Shelf: Results of the Western Component of the US EPA National Coastal Assessment

W. G. Nelson, H. Lee II, J. O. Lamberson, Pacific Coastal Ecology Branch, Western Ecology Division, National Health and Environmental Effects Laboratory, U.S. Environmental Protection Agency, Newport OR

Abstract—*The National Coastal Assessment of the US EPA began field work in the Western US in 1999-2000. Probabilistic sampling for biotic and abiotic condition indicators was conducted at 381 stations within estuaries and coastal embayments of Washington, Oregon and California. In 2002, intertidal and low salt marsh habitats were sampled at an additional 190 stations. As part of the intertidal effort, pilot evaluations of landscape indicators of coastal wetland condition were carried out in California. Pilot studies were also conducted in south central Alaska and in the Hawaiian Islands. In 2003, sampling for many of the same condition indicators was conducted on the continental shelf of the west coast from the Strait of Juan de Fuca to the Mexican border. By 2003, NCA-West had completed the field work for assessing the condition of soft sediment, estuarine habitats including low salt marsh, intertidal flats, and subtidal bottom, as well as continental shelf habitats down to a depth of 120 m, for the entire west coast. During summer 2004, NCA-West re-sampled estuarine systems of WA, OR, CA, AK, HI and conducted pilot sampling in the territory of Guam. NCA-West data will ultimately provide area estimates of western coastal, soft-sediment benthic habitat (exclusive of beaches) with degraded benthic conditions due to the impacts of sediment contaminants and other stressors. Results from the 1999-2000 survey for condition indicators indicate that only a small percentage of area of Western estuaries has levels of sediment contamination of either metals or organic compounds potentially toxic to benthic organisms. Water quality indicators for Western estuaries were generally good, although PO4 was high at many sites, perhaps due to natural factors. Nonindigenous species may be a more spatially widespread form of disturbance to benthic infaunal communities than sediment chemical contaminants, although the ecological consequences of these invasions are not yet known.*

Introduction

The U.S. Environmental Protection Agency, through the Environmental Monitoring and Assessment Program (EMAP), initiated in 1999 a six-year research effort as part of the National Coastal Assessment (NCA) to develop monitoring protocols for the coastal resources of the western United States. The goal of the NCA is to create an integrated, comprehensive monitoring program among the coastal states to assess ecological condition of estuaries and near-coastal waters.

The specific objectives of the NCA-West program are: to assess the condition of estuarine resources based on a range of indicators of environmental quality using an integrated survey design; to establish a baseline for evaluating how the conditions of the estuarine resources of the Western states change with time; to develop and validate improved methods for use in future coastal monitoring and assessment efforts in the Western states; and to transfer the technical approaches and methods for designing, conducting and analyzing data from probability based environmental assessments to states and tribal environmental organizations.

NCA-West involves the cooperation of numerous organizations. The project is principally funded by the U.S. Environmental Protection Agency, Office of Research and Development. The following organizations provided a wide range of field sampling, analytical and interpretive support in their respective states through individual cooperative agreements with EPA: Washington Department of Ecology, Oregon Department of Environmental Quality, Southern California Water Resources Research

Project (SCCWRP). The Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration provided field support and analysis of fish pathologies through an interagency cooperative agreement with EPA. Moss Landing Marine Laboratories provided the field crews for collection of samples in California under contract to SCCWRP. The U.S. Geological Survey, Columbia Environmental Research Center, through the Biomonitoring Environmental Status and Trends (BEST) Program, provided analyses for exposure of fish to planar halogenated hydrocarbons. Through their Marine Ecotoxicology Research Station, BEST also provided results from two sea urchin bioassays on sediment porewater toxicity.

NCA-West has focused on different coastal resource components each year. The first phase involved a two-year (1999-2000) comprehensive assessment of soft sediment habitats of all estuaries of Washington, Oregon, and California (Nelson and others 2004). In 2001, NCA-West conducted field work only in Oregon estuaries, while the NOAA Status and Trends Program conducted additional sampling in San Francisco Bay. While not formally a part of the original NCA-West assessment design, the NOAA 2001 data will also be incorporated into the NCA-West assessment database.

In 2002, NCA-West conducted a pilot assessment of condition of intertidal estuarine wetlands of Washington, Oregon, and California which included specialized study efforts focused on development of marsh condition indicators for San Francisco Bay and Southern California. Pilot assessments of estuarine and coastal indicators were also successfully conducted in south central Alaska and the state of Hawaii with the collaboration of the Alaska Dept. of Environmental Conservation, the Cook Inlet Regional Citizens Action Committee, the University of Alaska, and the University of Hawaii.

In 2003, NCA-West moved to an assessment of the condition of soft sediment habitat on the continental shelf of Washington, Oregon, and California between a depth of 30 and 120 m. In addition to the group of state partners from Washington, Oregon, California, and Alaska, the shelf assessment efforts included cooperation with NOAA National Marine Sanctuary (NMS) programs for sampling within the Olympic, Cordell Banks, Gulf of Farallones, Monterey Bay, and Channel Islands NMS.

During the summer of 2004, NCA-West re-sampled the estuarine and near-coastal systems of WA, OR, CA, AK, HI and conducted pilot sampling in the territory of Guam. Additional participants in the sampling program for 2004 include the Hawaii Department of Health and the Guam Environmental Protection Agency.

NCA-West 1999-2000 Estuarine Assessment Sample Design

NCA utilizes a probability based sampling design to develop estimates of status and trends of condition of environmental resources. To demonstrate the general design approach, the sampling design for the 1999-2000 study will be described in some detail. The sampling frame for the NCA-West was developed from USGS 1:100,000-scale digital line graphs and stored as a GIS data layer in the ARC/INFO program. A series of programs and scripts (Bourgeois and others 1998) was written to create a random sampling generator (RSG) that runs in ArcView. Site selection consisted of using the RSG to first overlay a user-defined sampling grid of hexagons over the spatial resource which consisted of all estuaries of the west coast. The area of the hexagons was controlled by adjusting the distance to hexagon centers, and by defining how many sample stations were to be generated for each sampling region. After the sampling grid was overlaid on the estuarine resource, the program randomly selected hexagons and randomly located a sampling point within the hexagon. Only one sampling site was selected from any hexagon selected. The program determined whether a sampling point fell in water or on land, and sites that fell on land were not included. The RSG was run iteratively until a hexagon size was determined which generated the desired number of sampling sites within the resource (Bourgeois and others 1998).

Specific details of the 1999-2000 West Coast sampling design are provided in Nelson and others (2004). In brief, the sampling effort in 1999 consisted of 210 sample stations located within the smaller estuarine systems of Washington, Oregon, and California, while 171 locations in Puget Sound, San Francisco Bay and the main channel of the Columbia River up to Bonneville Dam were sampled in 2000 (fig. 1). In 1999, 50 stations were sampled within each state. There were also two regionally focused sampling efforts of 30 stations each for Tillamook Bay, Oregon and for a group of small, northern California estuaries. Approximately equal numbers of stations within the 150 stations of the basic sample effort were partitioned among estuaries of <5, 5-25 and >25 km^2 to ensure some level of sampling across the entire range of estuarine sizes.

The 2000 sampling designs for Puget Sound and San Francisco Bay were produced to allow collaboration with surveys being conducted by the NOAA National Status and Trends Program. For Puget Sound, the NCA-West sample grid was extended to include

Figure 1. Location of NCA-West survey sites in 1999 -2000.

Table 1. Core environmental indicators for the NCA-West assessment of estuarine and near-coastal condition.

Habitat Indicators
Salinity
Water depth
pH
Water temperature
Total suspended solids
Chlorophyll *a* concentration
Nutrient concentrations (nitrate, nitrite, ammonia, & phosphate)
Secchi depth
Percent silt-clay of sediments
Percent Total Organic Carbon (TOC) in sediments
Benthic Condition Indicators
Infaunal species composition
Infaunal abundance
Infaunal species richness and diversity
Demersal fish species composition
Demersal fish abundance
Demersal fish species richness and diversity
Percent Light Transmission
External pathological anomalies in fish
Nonindigenous species
Exposure Indicators
Dissolved oxygen concentration
Sediment contaminants Metals, PAHs, PCBs, Pesticides, Hydrocarbons (AK only)
Fish tissue contaminants
Sediment toxicity (Ampelisca abdita, Eohaustorius estuarius, Hyallela azteca acute toxicity tests)

Canadian waters at the north end of Puget Sound, and then was overlaid on the existing probability based, randomized NOAA monitoring sites. If a NOAA site fell within a grid cell, the site was designated as the NCA-West sampling point. If not, a random site was selected based on the NCA-West protocols. There were 41 stations selected based on the NOAA sampling stations, in addition to 30 new EMAP stations, of which 10 were associated with the San Juan Islands. Similarly, in San Francisco Bay, NOAA Status and Trends used a probability based design to characterize condition of the sub-estuaries within San Francisco Bay. To insure complete coverage of the bay for the NCA-West study, the NOAA design was augmented with a sampling design which generated 31 sites in the open bay and 19 sites in smaller surrounding systems.

The 2000 sampling design for the Columbia River partitioned the main channel up to Bonneville Dam into 20 stations within the lower, saline portion and 30 stations within the upper, freshwater portion. Side channels of the Columbia River were sampled in 1999 as part of the small system survey. No alternate sites were selected as part of the 1999-2000 sampling design, and thus any sites which could not be sampled were not replaced.

NCA-West Assessment Indicators

The environmental condition indicators used in this study (table 1) included measures of: 1) general habitat condition (depth, salinity, temperature, pH, total suspended solids, sediment characteristics); 2) water quality indicators (chlorophyll a, nutrients); 3) pollutant exposure indicators (dissolved oxygen concentration, sediment contaminants, fish tissue contaminants, sediment toxicity); and 4) benthic condition indicators (diversity and abundance of benthic infaunal and demersal species, fish pathological anomalies).

2002 NCA-West Intertidal Wetlands Sampling Design

Because the principal focus of the 1999-2000 NCA-West estuarine assessment was on subtidal soft sediment habitat, the 2002 assessment was directed towards intertidal wetlands (habitat between mean lower low water and mean high water) to develop a more complete picture of estuarine condition. Thirty sites were randomly

Table 2. List of environmental condition indicators for the 2002 NCA-West intertidal wetlands assessment study.

Tidal water temperature, depth, salinity	Infaunal abundance
Sediment pore water salinity	Infaunal species richness and diversity
Sediment bulk density	Emergent macrophyte species richness
Sediment percent organic carbon	Emergent macrophyte species diversity
Sediment grain size	Emergent macrophyte species maximum stem or shoot length
Sediment inorganic contaminants	Percent of macrophyte species as nonindigenous species
Sediment percent phosphorus	Submerged aquatic vegetation or macroalgal percent cover
Infaunal species composition	Submerged aquatic vegetation maximum shoot length

Table 3. List of environmental condition indicators for the 2002 intertidal wetlands intensification studies in San Francisco Bay and Southern California.

Plant community composition and percent cover for drainage system	Habitat connectivity of tidal marsh patches
Wrack line trash composition for drainage system	Percent attenuation of spring tide range
Threatened/endangered species for habitat patch	Intertidal channel density for habitat patch
Nonindigenous species plants for habitat patch	Total acreage for habitat patch
Management objectives for habitat patch	Total perimeter for habitat patch
Number of recreational facilities and annual visitors for habitat patch	Shoreline development index for habitat patch
Presence of man made water control structures and levees	Shape index for habitat patch
Total annual POTW, industrial and power plant discharge to wetland watershed	Adjacent land cover for habitat patch
Human population density for watershed	Size class distribution for all habitat patches
Human population age structure for watershed	

allocated along the California coastline, and 30 sites were randomly allocated within each of the two intensification regions. All indicators in table 2 were measured at the 90 sites, allowing for a statewide assessment of intertidal wetland condition as well as independent assessments of Southern California (Point Conception to the Mexican border) and San Francisco Bay. The list of condition indicators was modified to reflect the intertidal habitat focus (table 2) and included a variety of plant community indicators.

The intensification studies in southern California and the San Francisco Bay area provided the opportunity to examine additional indicators (table 3). The use of additional indicators allows NCA to broaden its focus beyond an emphasis on sediment contamination to include issues specific to the intertidal wetland habitats, such as habitat fragmentation, threatened and endangered native species, the spread of nonindigenous species, modification of tidal flushing, and the impacts of land use alteration on wetlands.

In the intensification areas, a double randomization design based on the sample frame was employed. Thirty systems were randomly sampled from the list of all wetland systems within a region, with a random sampling point then chosen from the intertidal area of each of the 30 wetland units selected. The advantage of this approach is that it allows condition estimates based on percentage of systems, while at the same time also allowing for the areal extent estimates of condition that have been the basis for all other NCA-West activities.

2002 NCA-West Surveys in Alaska and Hawaii

A survey of the ecological condition of Alaska's near-coastal resources in the south-central region of the state (Alaskan Province) was completed in 2002. The south-central region of the state was selected for the first Alaskan survey because of the importance of the major estuarine resources in the region (Prince William Sound and Cook Inlet) to the local and state economy, as well as to aquatic living resources. The survey design included 50 core sites and 25 alternate sites, of which 55 stations were successfully sampled. The indicators collected during the survey are the same as those collected by the western states in 1999-2000, with the additional inclusion of analysis of petroleum hydrocarbons in sediments.

2003 NCA-West Continental Shelf Assessment Survey

NCA-West conducted a probability based assessment of condition of soft sediment benthic resources of the continental shelf of the west coast in summer of 2003. NOAA was a major partner in the study effort, contributing ship time on the R.V. McArthur II to the assessment effort. Fifty stations per state were sampled in the depth range between 30 and 120 m for the majority of the indicators listed in table 1, although sediment toxicity test and fish community indicators were omitted for a combination of cost and logistical issues. In order to allow development of an assessment of condition in the west coast NMS, 30 stations were selected within the Olympic NMS, and 30 stations were randomly selected within the Cordell Banks, Gulf of Farallones, Monterey Bay, and Channel Islands National Marine Sanctuaries. The remaining 90 stations were distributed in the area on the shelf of Washington, Oregon, and California north of Pt. Conception that was not included in a NMS. The shelf region between Pt. Conception and the Mexican border was sampled for most of the same condition indicators used by NCA-West during summer 2003 as part of the Bight '03 study by a consortium of agencies led by SCCWRP. The Bight '03 data will be integrated with the NCA-West data to provide the overall assessment of condition of the continental shelf of the West Coast.

2004 NCA-West Surveys

During 2004, NCA-West conducted a reassessment of estuarine resource condition in Washington, Oregon and California, using essentially the same sample frame that was used for the 1999-2000 sample effort. One change was the restriction of the sampling the Columbia River to the marine portions of the river system. Alaska conducted a second assessment in southeastern Alaska, a different biogeographic region of the state. Hawaii conducted its second state wide assessment of condition, but revised the sample frame to include not only estuaries and restricted coastal bays, but all state marine waters within the 60 foot depth contour. The territory of Guam conducted its first probability based assessment of marine waters, also using the 60 foot depth contour as the basis for the sample frame.

Selected 1999-2000 Assessment Results

The control corrected mean survivorship of the amphipods in toxicity tests of sediments collected (fig. 2) ranged from 0 percent to 109.9 percent, across the 306 stations that were included in the analysis. Approximately 17 percent of the area of West Coast estuaries had survivorship < 80 percent, indicating sediments that were toxic to amphipods due to some factor.

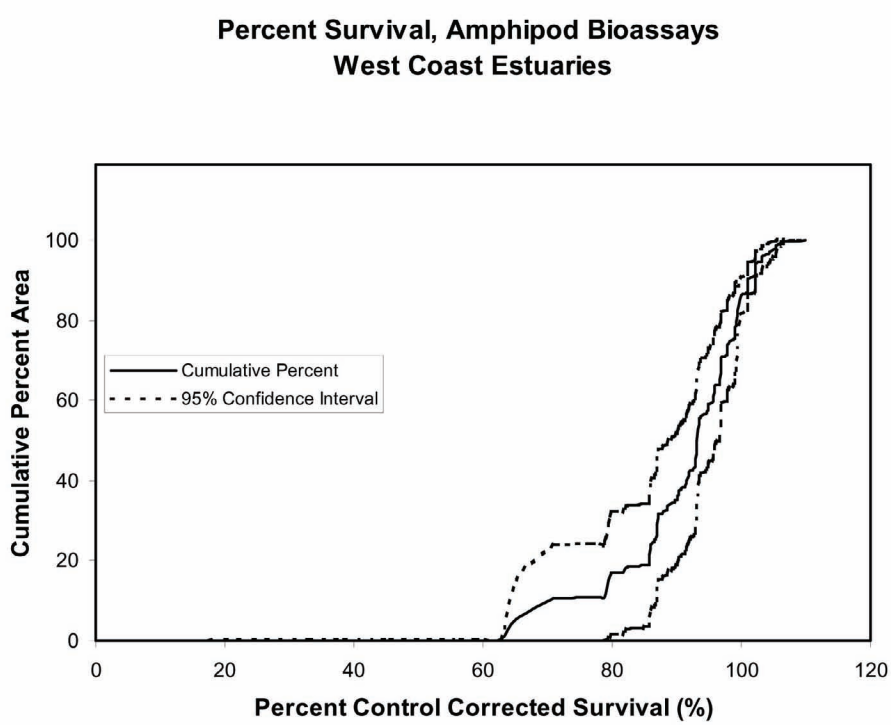

Figure 2. Percent area (and 95 percent C.I.) of West Coast estuaries vs. percent control corrected survivorship of the amphipod crustaceans (*Ampelisca abdita, Hyalella azteca* in the freshwater Columbia River).

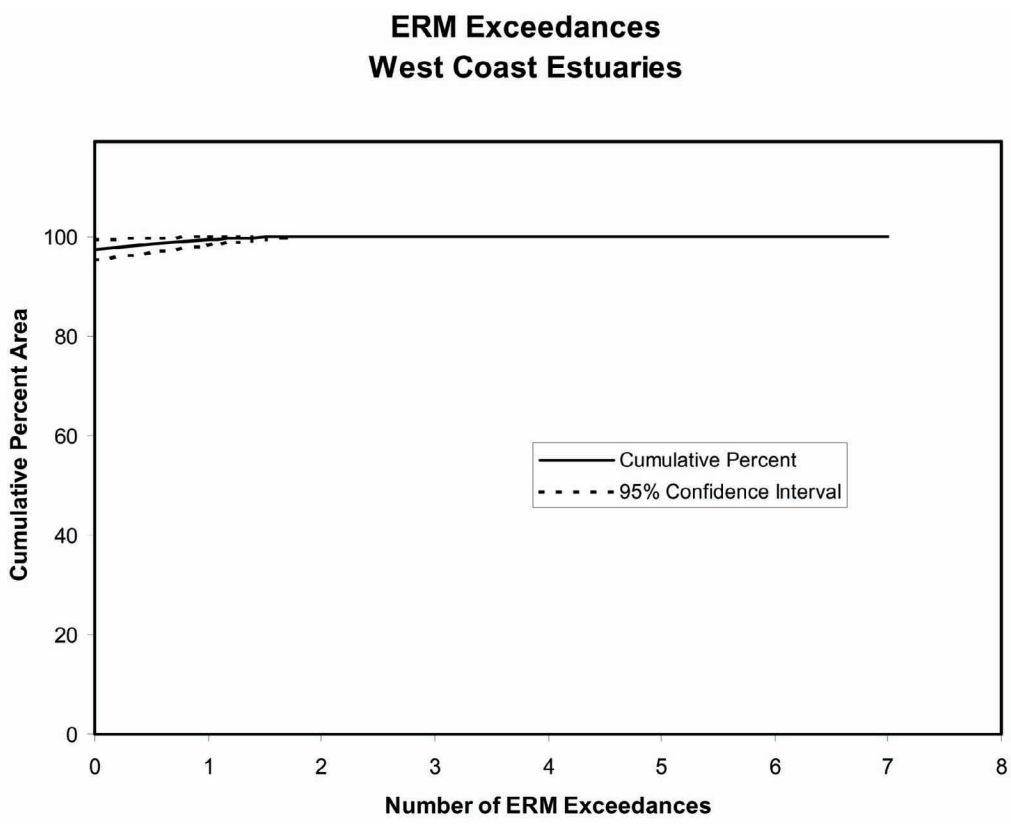

Figure 3. Percent area (and 95 percent C.I.) of West Coast estuaries vs. exceedances of the ERM concentrations for sediment contaminants.

Excluding nickel which has a low reliability for West Coast conditions, sediment concentrations exceeded their respective Effects Range Median (ERM) values at 24 stations, representing 3percent of the estuarine area (fig. 3). Twenty of these sites were in California, four in Washington, and none in Oregon. In California, all of the concentrations that exceeded the ERMs north of San Luis Obispo Bay were due to chromium, mercury, or copper. In Southern California, the exceedances were due to DDT, with the exception of the Los Angeles Harbor, which had high concentrations of several metals and PAHs. In Washington, three of the sediment concentrations that exceeded the ERMs occurred in harbors and bays within the Puget Sound system; one was in the Columbia River. All of these exceedances were due to either PAHs or PCBs.

Of the 18 stations with poor amphipod survivorship, there were five stations, all in California, which also had exceedances of at least one ERM. Therefore factors besides sediment toxicity may be responsible for the low survivorship observed at the remaining 13 sites.

The benthic infaunal community data from 2000 for the large estuaries are not yet finalized. However, the 1999 data indicate that the soft-bottom benthos in the smaller West Coast estuaries are diverse, with a total of 852 non-colonial taxa and an average of 22.3 taxa per grab (N=187). The two most abundant species were the native amphipods *Americorophium spinicorne* and *A. salmonis*, which reached densities as great as 397,000 m^2 in Northern California river mouth estuaries. Overall, nonindigenous species were moderately abundant, constituting almost 13 percent of both the native abundance and the native species (53 nonindigenous compared to 421 native species). The remaining taxa were either cryptogenic (104 species) or indeterminate (274 taxa), where cryptogenic species are species of uncertain origin (Carlton, 1996) and indeterminate taxa are those not identified to a sufficiently low level to classify as native or nonindigenous (Lee and others 2003). A more telling indicator of the extent of invasion in these small West Coast estuaries is that 124 of the 187 grabs (66 percent) contained at least one nonindigenous species, representing 74.5 percent of the area of the small estuaries (fig. 4).

Summary

NCA-West has primarily utilized indicators of biotic condition, physical and chemical characteristics, and exposure to pollutants, but is evolving to include indicators of landscape condition and hydrology. At the conclusion of the program in 2005, NCA-West will provide an integrated assessment of coastal condition of the west coast states in soft sediment habitat from the intertidal low marsh to 120 m depth. In addition, NCA-West has

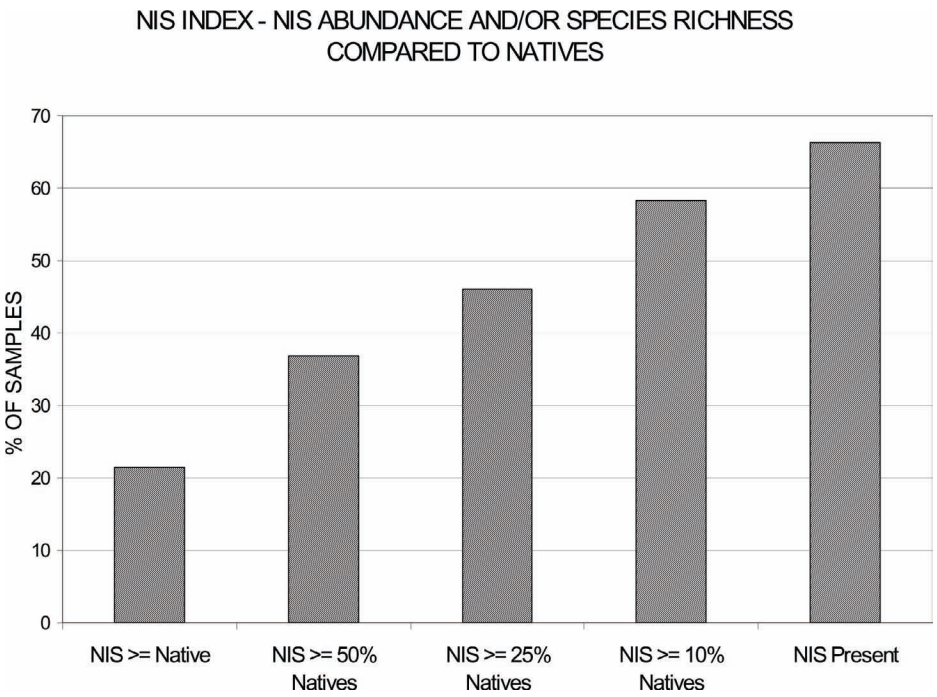

Figure 4. Percentage of benthic infaunal samples (N=187) with either abundance or species richness of nonindigenous (NIS) species that exceed various levels relative to native species abundance or species richness. The percentage of samples with NIS present is also shown.

developed methods for sampling the highly varied coral, coral rubble and soft sediment habitats of the tropical Pacific islands. In Alaska, NCA-West has assessed two of five biogeographic provinces, but still faces major challenges in completing a complete assessment in a state with more shoreline than that of the other 49 states combined.

Analysis of results from the 1999-2000 assessment effort shows an elevated mortality in amphipod sediment toxicity tests at 18 stations representing 17 percent of estuarine area. Two thirds of these sites with sediment toxicity had no measured chemical contaminants at concentrations above the ERM. In contrast, data from 1999 showed that nonindigenous species were present at a majority of sites and comprised 13 percent compared to the native abundance. The results of the NCA-West assessment suggest that at least within western small estuaries, nonindigenous species may be a far more widespread form of disturbance to benthic communities than sediment chemical contaminants.

References

Bourgeois, P.E., V.J. Sclafani, J.K. Summers, S. C. Robb, and B.A.Vairin. 1998. Think before you sample. *GEOWorld*. Vol. 11: No 12.

Carlton, J. T. 1996. Biological invasions and cryptogenic species. *Ecology* 77:1653-1654.

Lee II, H., Thompson, B. and Lowe, S. 2003. Estuarine and scalar patterns of invasion in the soft-bottom benthic communities of the San Francisco Estuary. *Biological Invasions* 5:85-102.

Nelson, W. G., Lee II, H., Lamberson, J. O., Engle, V., Harwell, L., Smith, L. M. 2004. Condition of Estuaries of Western United States for 1999: A Statistical Summary. Office of Research and Development, National Health and Environmental Effects Research Laboratory, Report in Review.