

The use of biota sampling for environmental contaminant analysis for characterization of benthic communities in the Aleutians

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Abstract

It is increasingly clear that the public, native tribes, and governmental agencies are interested in assessing the well-being of natural resources and ecosystems. This may take the form of understanding species presence, monitoring population status and trends, measuring behavior, or quantifying physiology, biological stresses, or chemical/radiological exposure through biomarkers. Often there is a separation between understanding the biological aspects of species well-being and assessing exposure to contaminants. In this paper we examine the applicability of using scuba sampling aimed primarily at specimen collection for radionuclide analysis to assess species presence/absence and to compare among sampling sites and depths. We were especially interested in whether dive transects could provide information on species presence and potential exposure to environmental contaminants. In June/July 2004 we sampled at 49 depth stations along 19 transects at Amchitka and Kiska Islands in the western Aleutian Islands in the Northern Pacific/Bering Sea region. Amchitka Island, a former World War II U.S. Navy base, was the site of three underground nuclear test shots from 1965 to 1971. Four to six transects were established at three Amchitka sites and two Kiska Sites, and 2 to 4 stations were sampled on each transect. Bottom conditions, weather and currents prevented a complete sampling of all stations. There were interspecific differences in the percent of stations where biota were found and collected, in their occurrence near the three test shots on Amchitka, and in the depth where they were found. There were no significant differences between Amchitka and Kiska Island in the percent of stations where species were found. These data suggest that information gathered incidentally to the collection of specimens for chemical/radiological analysis can prove useful for understanding the presence of benthic organisms along particular transects, at given depths, and at different geographical locations. This information also provides a baseline for the range of organisms that could be exposed to future physical or chemical/radiological stressors. The data are useful for developing future biomonitoring plans to assess biological well-being and chemical/radiological exposure only if they are published and available to the public, public policy makers, and managers. Just as it is critical to select endpoints and bioindicators that are of interest for assessing both human and ecological health, specimens should be collected using a protocol that is useful for both chemical/radiological analysis and biological information.

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1. Introduction

It is clear that the public, native tribes, regulators, resource stewards, and public policy/risk managers are interested in assessing the well-being of natural resources and ecosystems. This may take the form of understanding species presence, population status and trends, biological stresses, and chemical/radiological exposure, as well as ecosystem processes and bioindicators. There are many studies that examine the fate and effects of chemical/radiological contaminants in ecosystems, as well as probabilistic approaches to concentrations in biota (Higley et al., 2003). There are a number of studies that systematically examine or summarize pollution in high latitude environments (AMAP, 2002), including the Bering Sea Ecosystem (NRC, 1996; Brodeur et al., 2002; Baskaran et al., 2003; Johnson, 2003). Often there is a separation between understanding the biological aspects of species (i.e. presence, habitat use, effects of invasive species, predators, competitors) well-being and the chemical exposure aspects of well-being. While clearly physical, biological, and contaminants stressors all impact the health and well-being of species and their ecosystems, it has been easier to assess the effects of only one or two stressors at a time. This often means that information gathered for one purpose (e.g. specimens to be used for chemical analysis) are not used for other purposes (e.g. species presence, community structure, biodiversity, or distribution), although specimen banking is a key component of many contaminants programs (Krahn et al., 1997).

In this paper we examine the applicability of using scuba sampling aimed at specimen collection for radionuclide analysis to assess species presence. We were especially interested in whether dive transects could provide information on benthic species presence and potential exposure to environmental contaminants, as a function of geographical location and depth. Such information is key to providing baseline information for particular ecosystems, and for designing any biomonitoring program for the future. This study is part of a larger project to examine the levels of radionuclides in biota at Amchitka Island, where the U. S. detonated three underground nuclear tests (1965–1971), and at Kiska Island, which served as our reference site (Powers et al., 2005, 2006; Burger et al., 2006). While it is not always feasible to locate organisms, such as highly mobile species (e.g. Vetter et al., 1996; Ylitalo et al., 2001), benthic organisms, especially sedentary ones, lend themselves to specific habitat studies. We recommend that information

gathered incidental to collecting specimens for analysis, can be used for other purposes, as long as the original objectives are clearly enunciated and understood.

2. Study site

We conducted our studies at three locations adjacent to the test shots at Amchitka Island, and on two sides of Kiska Island. Both islands in the Western Aleutians are part of the Bering Sea/North Pacific marine ecosystem, which is rich biologically, and contains a high biodiversity of organisms (Merritt and Fuller, 1977; NRC, 1996). The benthic organisms in this region exhibit a range of lifestyles: sessile (e.g. kelp, barnacles), largely sedentary or low mobility (e.g. sea urchins), local movements (e.g. some fish), or are highly mobile (e.g. birds, some marine mammals, some large fish). There is considerable stakeholder interest and concern about the resources in this region, including the Native interests represented by the Aleutian/Pribilof Island Association(A/PIA), the U.S. Fish and Wildlife Service (USFWS), the State of Alaska, and several other health and environment groups (CRESP, 2002; Burger et al., 2005).

Amchitka Island is part of the Department of Energy's "Complex" of contaminated sites (Crowley and Ahearne, 2002). These sites range in size from a few acres to over a thousand square miles, have different degrees of contamination, and are in different stages of remediation. Amchitka Island is designated part of the Alaskan Maritime National Wildlife Refuge, administered by the U.S. Fish and Wildlife Service. Both islands are bordered on the south by the North Pacific and on the north by the Bering Sea (Fig. 1). The marine biological resources in the region are of high value in cultural, commercial, and ecological terms (Merritt and Fuller, 1977; NRC, 1996). The benthic resources are also potentially important to the subsistence lifestyle of the Aleut/Pribilof Islanders and to commercial fisheries of the region (Patrick, 2002).

In the 1960s Amchitka Island was chosen by the Atomic Energy Commission (a predecessor of the DOE) for nuclear tests. *Cannikin* (1971), the last and largest shot (ca. 5 Mt), had an elevator shaft that was over 1800 m below the surface, and the blast and resulting chimney collapse formed a new lake (Cannikin Lake) on the island surface. The three Amchitka test shots accounted for about 16% of the total energy released from the US underground testing program (Robbins et al., 1991; Norris and Arkin, 1998; DOE, 2000), and *Cannikin* was the largest U.S. underground blast.

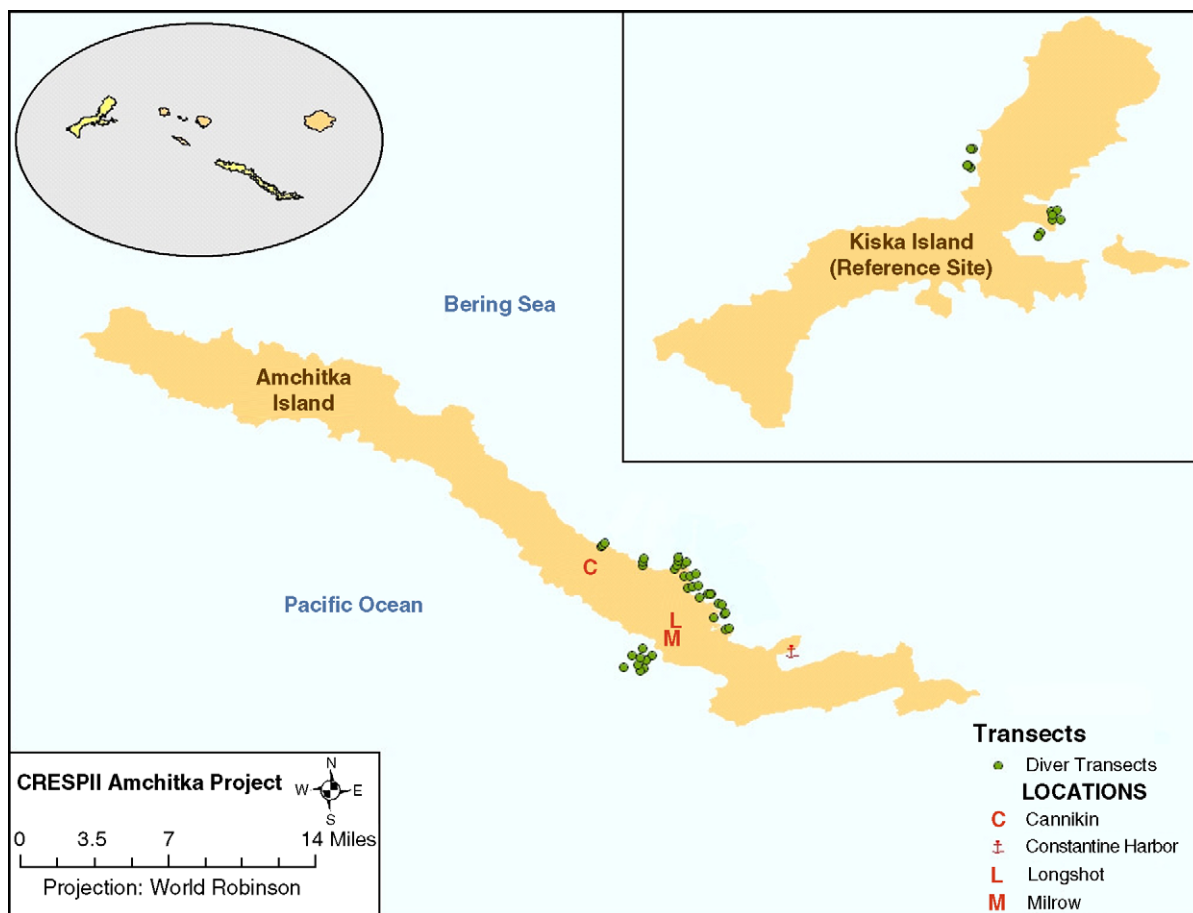


Fig. 1. Maps showing the transects for dive collections at Amchitka Island and Kiska Island in the Aleutian Chain.

Although there was some release of radiation to the surface, the leaks were not considered to pose serious health risks at the time (Seymour and Nelson, 1977; Faller and Farmer, 1998). No technology exists to remediate the test cavities or to inactivate or entrap radiation, nor are there plans to disrupt the shot cavities for remediation purposes. However, since Amchitka Island is in one of the most volcanically and seismically active regions of the world (Jacob, 1984; Page et al., 1991), stakeholders are concerned that earthquakes or other processes could open subterranean pathways and accelerate the movement of radiation into the sea and marine food webs. Thus, there is interest not only in ascertaining the levels of radionuclides in marine biota, but in assessing particular organisms as potential bioindicators of exposure. Dasher et al. (2002) recently examined possible seepage of anthropogenic radionuclides from the nuclear test sites to the surface environment. A DOE groundwater model (DOE, 2002) predicted that

breakthrough of radionuclides to the sea might occur between 10 and 1000 years after the tests.

Kiska Island contains many of the same terrestrial and benthic environments. It did not experience any underground nuclear test shots. The marine benthic resources around Kiska Island have not been described extensively.

3. Methods

Our overall approach was to collect organisms that had been collected previously at Amchitka and in the Aleutians, to collect subsistence foods of the Aleuts and those caught for commercial fisheries, and to provide information needed for developing a long-term biomonitoring/stewardship plan (Jewett, 2002; CRESPII, 2003; Burger et al., 2005). The species we collected and recorded were those that were of interest to a wide range of stakeholders, including regulators, wildlife managers, Aleut subsistence hunters/fishers, and the

Table 1
List of marine species collected at Amchitka and Kiska

Common Name	Scientific Name
Alaria type	mainly <i>Alaria fistulosa</i>
Laminaria type	mainly <i>Laminaria saccharina</i>
Sponge	Geodiidae
Blue Mussel	<i>Mytilus trossulus</i>
Horse Mussel	<i>Modiolus modiolus</i>
Rock Jingle	<i>Pododesmus macrochisma</i>
Gumboot Chiton	<i>Cryptochiton stelleri</i>
Oregon Triton	<i>Fusitriton oregonensis</i>
Giant Octopus	<i>Enteroctopus dofleini</i>
Green Sea Urchin	<i>Strongylocentrotus polyacanthus</i>
Rock Greenling	<i>Hexagrammos lagocephalus</i>
Red Irish Lord	<i>Hemilepidotus hemilepidotus</i>
Yellow Irish Lord	<i>Hemilepidotus jordani</i>
Black Rockfish	<i>Sebastes melanops</i>

general public (Burger et al., in press). We then used these collections to determine presence/absence by location (3 Amchitka and 2 Kiska sites) and depth.

Diving and collections were made from 29 June through 19 July 2004 from the F/V *Ocean Explorer*, a 55 m long trawler, which was dedicated to this work. The sampling areas selected were those that were adjacent to the three test sites (CRESP, 2003); a series of parallel transects was established, which were then used to collect physical oceanography data along the Bering Seashore off *Cannikin* and *Long Shot*. We chose to use a systematic sampling regime rather than a random sampling pattern because we wanted to standardize the depths and to ensure coverage of the marine environment around the test shots, and at Kiska. Further, the remoteness of the study sites, the use of a 55 m long ship, the difficulties of diving in the rough Aleutian seas, and the potential health and safety issues made it necessary to optimize our diving operations and movements around the islands.

The transects were close to the 1965 *Long Shot* test (Square Bay), close to the 1969 *Milrow* test (Makarius Bay), and close to the 1971 *Cannikin* test (adjacent to Cannikin Lake). At Kiska our sites were on the west coast and on the East Coast off Kiska Harbor (Fig. 1). The *Cannikin* and *Long Shot* bathymetry transects were then extended shore-ward until they reached the intertidal. At Makarius Bay and the Kiska sites, we established perpendicular transects from the shoreline, since no oceanographic data were obtained. Using a GPS Mapping Program (BlueChart nautical chart program) we located points on each transect corresponding to 5, 9, 18, and 27 m depths. From BlueChart we loaded the GPS coordinates into portable units (Garmin GPSmap 60SC). Diving operations were con-

ducted 2–3 times a day, weather and safety permitting. Diving transects and stations are shown in Fig. 1. Due to weather, surge and current considerations, and the desire to adhere to no-decompression diving, we could not collect at all dive stations (Jewett et al., 2006). Only two 27 m stations were sampled.

Diving operations were conducted by two dive teams, each consisting of two divers and a tender operating from inflatable skiffs. Dive teams worked on adjacent stations for safety and to allow communication. Once the skiff arrived at a GPS-station location, depth was confirmed using depth sounders (Speedtech Instruments Model SM-5). Detailed dive and health and safety plans were implemented, by the on-board divemaster and a physician (Gochfeld et al., in press).

While our initial collecting protocol was developed before the expedition, we amended it to reflect species presence after initial dives at Adak Island (not part of the data presented herein) and at Amchitka. Species collected (with scientific names) are listed in Table 1. During each dive, the divers descended to the anchor, and sampled within a 60 m radius of the anchor. Depending upon depth, dive time varied from 20 to 60 min. Each diver had a mesh bag for storing specimens, and a dive knife and/or spear for collecting organisms. The decision rule for collecting was to obtain

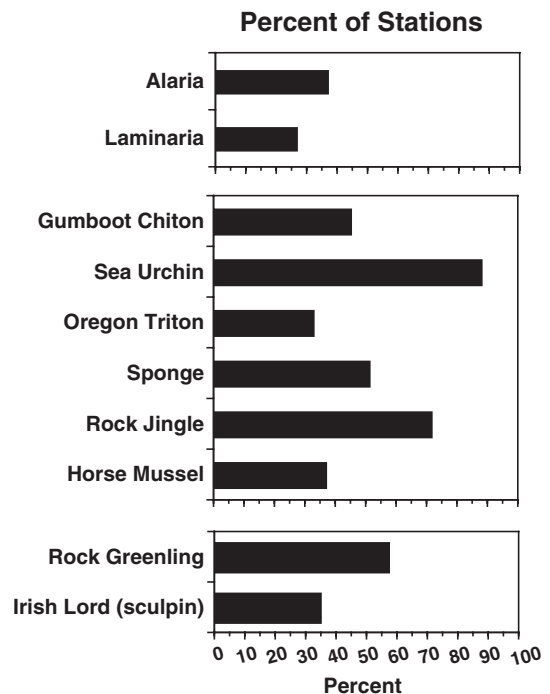


Fig. 2. Percent of benthic stations where organisms were found and collected in the Aleutians in summer 2004.

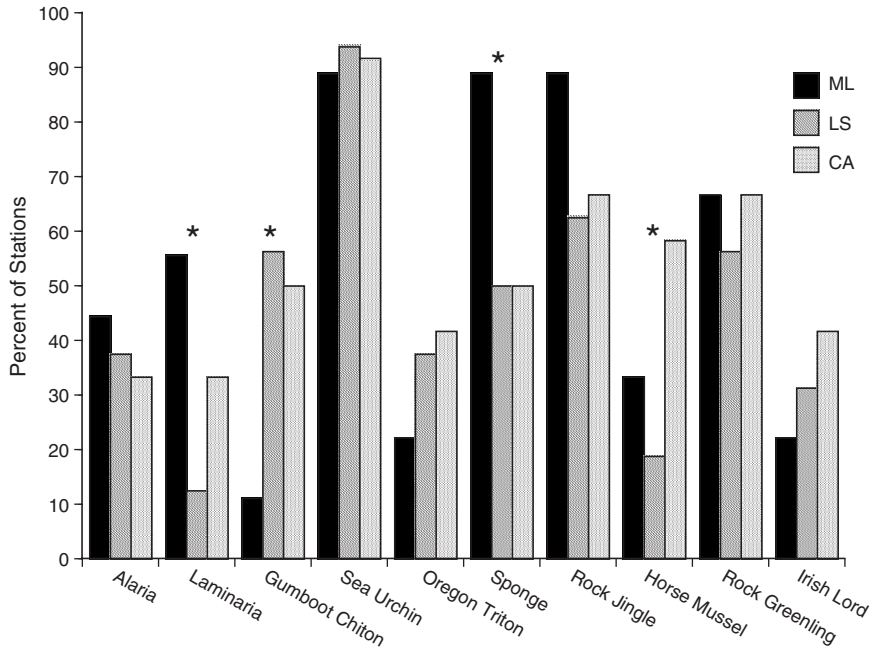


Fig. 3. Occurrence of organisms near the test shots around Amchitka Island. Given are percent of benthic stations where organisms were found and collected. *=significant differences at $P < 0.10$. ML=Milrow, LS=Long Shot, CA=Cannikin.

a diversity of organisms at each dive station. For each of the species listed in Table 1, divers were instructed to bring back a sufficient quantity for analysis, if the species was present at the station. Where size was an issue (i.e.

excessively long kelp fronds), divers had a protocol for which segment to bag. Samples were collected at 49 stations along 19 transects, with 136 person-dives, and a total bottom time of 93 h.

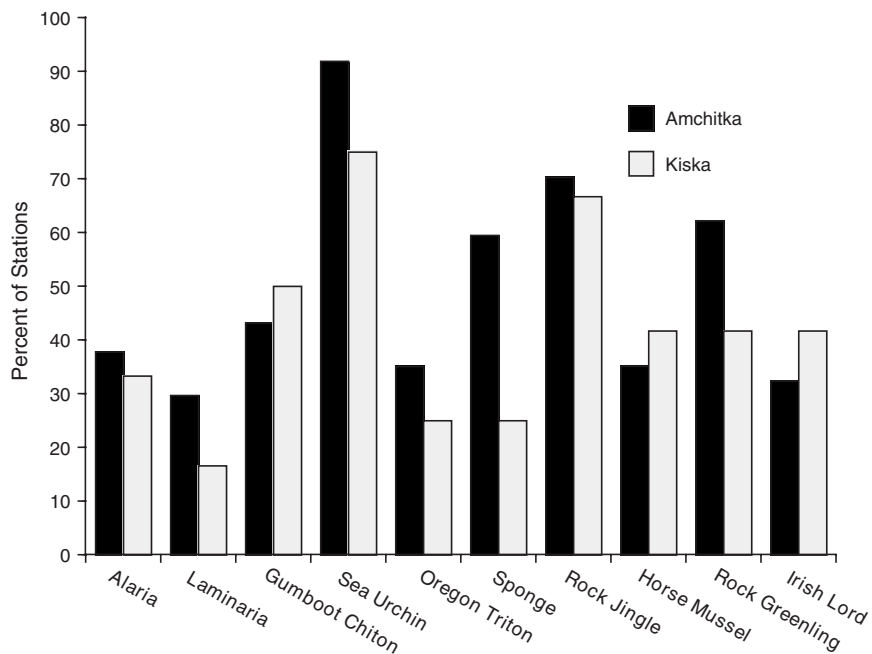


Fig. 4. Comparison of occurrence of organisms at Amchitka and Kiska Islands. There were no significant differences.

Species presence/absence was compared using the Kruskal–Wallis one-way non-parametric analysis of variance (generating a χ^2 statistic) or with 2×2 contingency table.

4. Results

Overall, there was variation in the percent of stations where organisms were found and collected: sea urchins and rock jingles were found in more stations overall than the other species (Fig. 2). Rock greenling were collected at over half of the stations, and probably could have

been collected in more if sufficient time were available (they had to be speared and were thus more difficult to catch). Blue mussels were relatively rare, and were mainly found in harbors on docks (not included in these data), while horse mussels were more common.

There were significant differences in the organisms found adjacent to the different test shots on Amchitka (Fig. 3). The greatest differences were for *Laminaria*, horse mussel, rock jingle, gumboot chiton, and sponges. In general, organisms were more diverse and numerous near *Milrow* (Pacific Ocean), and less common at *Long Shot* (Bering Sea). However, each of these organisms

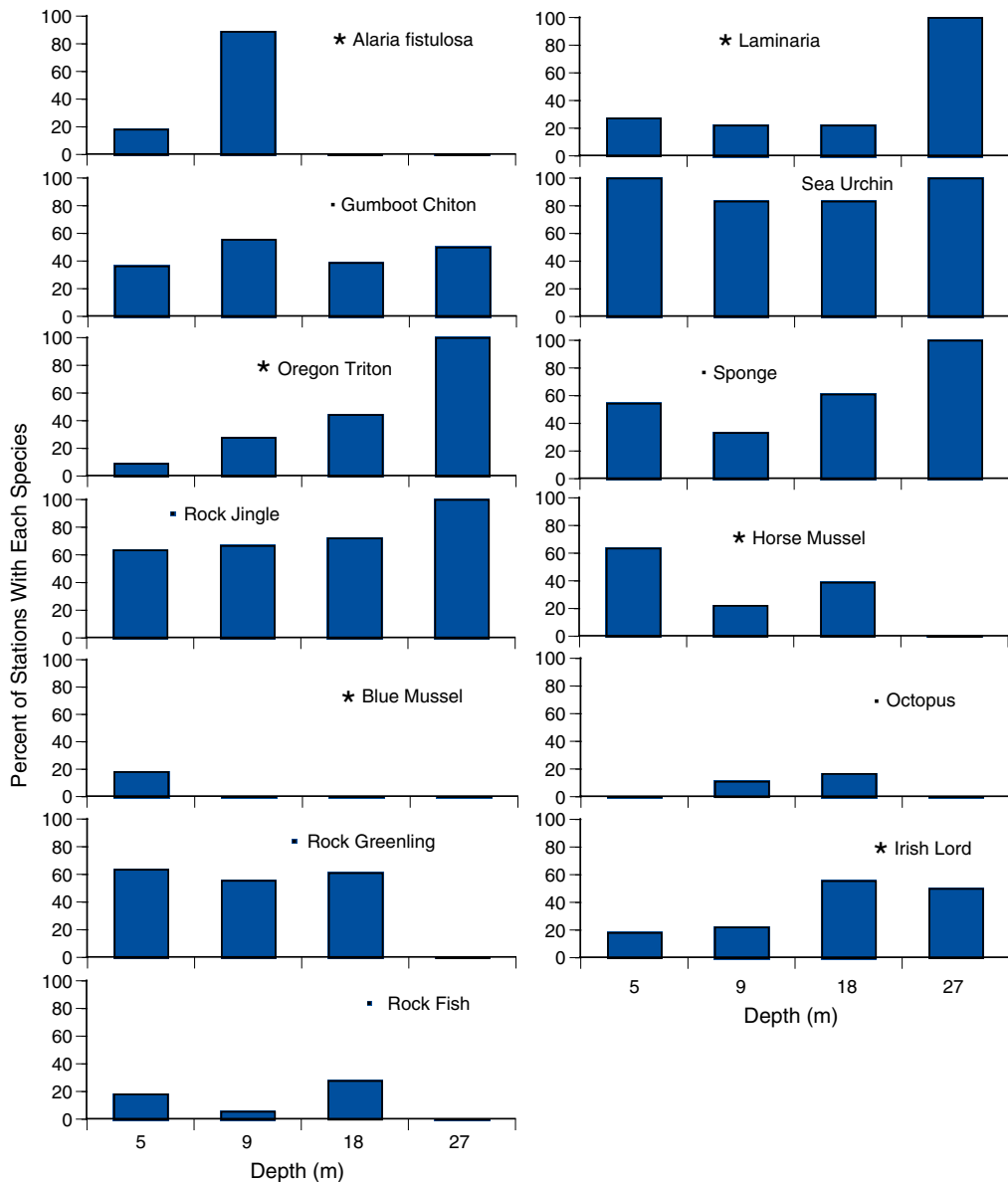


Fig. 5. Location of organisms by depth for species collected at Amchitka and Kiska Islands. *=significant difference at $P < 0.10$.

occurred at some stations on both coasts, and can be collected from the marine environment adjacent to each test shot in future biomonitoring plans.

There were no significant differences (χ^2 tests) in the occurrence of organisms in our benthic transects at Amchitka compared to Kiska Island (Fig. 4). The greatest differences were in sponges and rock greenling, perhaps due to a greater proportion of sandy substrate at stations on the east side of Kiska.

As expected, there were differences in the depths different organisms were found and collected (Fig. 5). Some species became increasingly common with increasing depth (sponges, jingles, Oregon triton), others were more common near shore (mussels), and others were fairly evenly distributed (sea urchins). Observations at 27 m indicate that some of these organisms were continuously distributed to depths greater than 27 m.

5. Discussion

5.1. Sampling strategy at Amchitka

The collection approach taken in this study differed from many studies where samples are either taken opportunistically or in very few specific places. In many studies, specimens are collected from a given spot (e.g. at the end of a pier, intertidal, in a bay), without regard for a systematic sampling regime that could be repeated (Fialkowski and Newman, 1998). Even when specific transects were conducted (e.g. Zauke et al., 1999), specific data on those transects, or the presence of species along those transects, are not given.

In this study, several series of parallel transects were established, and sampling stations were designated at particular depths with GPS points obtained from a computerized bathymetry chart. This assured that different benthic habitats were systematically sampled in the area close to each test shot, and at the reference site. In the case of Amchitka Island, such a sampling scheme was essential because it is not known where seepage from the test shot cavities might occur, now or at some future point. Thus, it was essential to have systematic coverage in three dimensional-space to assess whether seepage had occurred, to serve as a basis for future biomonitoring to detect seeps or seepage in shore, and to establish species presence or absence (CRESP, 2003).

Examining the spatial distribution, both horizontally and at different depths, is extremely important for Amchitka because it demonstrates the extent of the benthic ecosystems with organisms that could be exposed if there were seepage of radionuclides into

the sea. The DOE and its contractors have developed groundwater models (DOE, 2002) in which they have assumed that any seepage from the underground nuclear test shots would not pose a risk to the marine environment because such seepage would occur where there were no biologic receptors and would entail dilution without buildup in the food chain. The results from this study clearly indicate that there are some organisms at most stations, and that some of these are sedentary species. The importance of examining the spatial distribution thus also lies in being able to clearly demonstrate the geographical range of potential exposure from physical or chemical/radiological events.

Finally, the method described in this paper, examining species presence as a function of occurrence at stations used for collecting organisms for radiological analysis, has the advantage of being a rapid assessment method. Establishing plots and counting (and measuring) all the organisms within those plots is far more time-consuming (e.g. Palmisano and Estes, 1977), and is unlikely to be accomplished while doing routine specimen collection for biomonitoring.

5.2. Temporal differences in Amchitka benthic fauna

Following the nuclear test shots from 1965–1971, there were extensive studies of the marine algae (Lebednik and Palmisano, 1977), fish communities (Simenstad et al., 1977), marine intertidal invertebrates (O'Clair, 1977), and various marine mammals (Abegglen, 1977; Morrison et al., 1977; Estes, 1977), but scant data on the benthic communities except as they relate to sea otters (*Enhydra lutris*, Palmisano and Estes, 1977). Palmisano and Estes (1977) noted that barnacles, mussels, limpets, and sea urchins were inconspicuous in the intertidal zone, which we noted as well. They attributed this poor development to the reduced wave shock, rather than the presence of kelp beds, competition for space, predation, or lack of food. We found that blue mussels were most common on docks and rocks in the harbors, where they were quite dense. At Kiska, mussels also covered many of the rocks along the edge of Little Kiska Island. Palmisano and Estes (1977) transported mussels from Puget Sound as part of their experiments, and we can only wonder whether their transplantation has resulted in the increase in mussels in the Aleutian Islands. Restructuring of subtidal community may have occurred as a result of the decline in the sea otter populations. The population was high at the time of the test shots (Estes, 1977), but began declining in the early 1990s, possible due to predation from Orca whales (*Orcinus orca*, Estes et al., 1998). Sea otters around Amchitka were marked reduced from 1991 to 2004, and sightings were rare in 2004.

5.3. Maximizing biological information from specimen collection

When scientists collect specimens for contaminant analysis, the specimens are usually prepared and frozen, and little thought is given to their use as an indicator of ecosystem well-being. Yet information on the prevalence and distribution of organisms can be used to compare the biological communities from different locations, as well as occurrence at different depths. Both are essential for the development of biomonitoring plans for assessing both physical and chemical/radionuclide exposure. While it is obviously preferable to design a rigorous sampling plan for assessing presence and abundance of organisms in different transects, at different depths, it is not always efficacious in terms of time and money when specimens need to be collected for chemical or radiological analysis. Further, there are few studies that compare different types of sampling regimes in sublittoral and benthic habitats, although Somerfield and Clarke (1997) demonstrated a smooth shift in community structure when using different sampling regimes.

Nonetheless, we suggest that the establishment of sampling stations along transects, and the collecting of organisms at these sampling sites, can provide information that is useful in and of itself, including assessment of presence/absence, and presence of subsistence foods (Rothschild and Duffy, 2002; Patrick, 2002). The sample scheme we developed featured not only locational coverage, but depth information, a key feature of many biological studies of benthic communities (Morrison, 1988). Many types of information that usually are the main focus of biological studies can be gathered by a systematic specimen collection scheme. For example, the role of grazers on kelp (see Dean et al., 1989) can be partly examined by comparing the overlap of these species.

The present study showed that there were interspecific differences in the percent of benthic stations where biota were found and collected, in their occurrence near the three test shots on Amchitka, and in the depth where they were found. There were no significant differences between Amchitka and Kiska Island in the percent of stations where species were found. These data suggest that information gathered incidentally to the collection of specimens for chemical/radiological analysis can prove useful for understanding the presence of benthic organisms along particular transects, at given depths, and at different geographical locations. Such information is rarely tabulated, and almost never published, resulting in the loss of valuable information that can be useful both in designing future biodiversity studies, and future

studies for contaminants or other stressors (such as incidences of disease, condition, weight or size). This biological information is useful for developing future biomonitoring plans to assess health, well-being, and chemical/radiological exposure only if they are published and available to the public, public policy makers, and managers. We suggest that researchers designing collecting schemes for chemical/radiological analysis should take the time before collection to assure that biological information can be gathered incidentally to the specimens, without additional time and cost.

5.4. Policy and management suggestions

Understanding contaminant fate and effects is a large part of environmental monitoring and assessment, and an endpoint in itself, particularly for human and ecological risk assessment. However, we are suggesting that with small changes in the design of sampling programs, and in information recorded while sampling, important additional data on occurrence and range of species can be gathered that will be invaluable both to understand these systems and to develop chemical/radiological biomonitoring plans in the future. To some extent, this may involve a shift in the thinking of managers, public policy makers, and funding agencies to encourage and enable researchers to build into their specimen collecting schemes the collection of biodiversity information. Just as quality assurance/quality control (QA/QC) measures are now an integral part of all chemical/radiological studies, obtaining sufficient biodiversity information (at least at the level of presence/absence) could be encouraged, and in some cases, required. That is, many federal funding agencies require formalized QA/QC protocols as part of grant/contract proposals. Similar requirements for a formalized, standardized sampling regime (rather than haphazard sampling at specific sites) could be implemented with stipulations that such information should be published. Such information could easily be presented in tabular form in journal articles.

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References

- Abegglen CE. Sea mammals: resources and population. In: Merritt ML, Fuller RG, editors. The environment of Amchitka Island, Alaska. Washington, D.C.: Technical Information Center, Energy and Research Development Administration; 1977. p. 493–510. Report NVO-79.
- Arctic Monitoring and Assessment Programme. Arctic pollution. <http://www.amp.no/homepage.htm> (accessed December 2002).
- Baskaran M, Hong GH, Dayton S, Bodkin JL, Kelley JJ. Temporal variations of natural and anthropogenic radionuclides in sea otter skull tissue in the North Pacific Ocean. *J Environ Radioact* 2003;64:1–18.
- Brodeur RD, Wilson MT, Ciannelli L, Doyle M, Napp JM. Interannual and regional variability in distribution and ecology of juvenile pollock and their prey in frontal structures of the Bering Sea. *Deep-Sea Res* 2002;49:6051–67.
- Burger J, Gochfeld M, Kosson D, Powers CW, Friedlander B, Eichelberger JE, et al. Science, policy, and stakeholders: developing a consensus science plan for Amchitka Island, Aleutians, Alaska. *Environ Manage* 2005;35:557–68.
- Burger J, Gochfeld M, Kosson DS, Powers CW. Biomonitoring for ecosystem and human health protection at Amchitka Island. Consortium for risk evaluation with stakeholder participation, Piscataway, New Jersey; 2006.
- Burger J, Gochfeld M, Jewett SC. Selecting species for marine assessment of radionuclides around Amchitka: planning for diverse goals and interests. *Environ Monit Assess* in press.
- Consortium for Risk Evaluation with Stakeholder Participation (CRESP). Proceedings of the Amchitka long-term stewardship workshop. Fairbanks, Alaska: CRESP/University of Alaska; 2002. held 12–14 February 2002.
- Consortium for Risk Evaluation with Stakeholder Participation (CRESP). Amchitka independent assessment science plan. Piscataway, NJ: CRESP; 2003. <http://www.cresp.org>.
- Crowley KD, Ahearn JF. Managing the environmental legacy of U.S. nuclear-weapons production. *Am Sci* 2002;90:514–23.
- Dasher D, Hanson W, Read S, Faller S, Farmer D, Efurud W, Kelley J, Patrick R. An assessment of the reported leakage of anthropogenic radionuclides from the underground nuclear test sites at Amchitka Island, Alaska, USA to the surface environment. *2002;60:165–187*.
- Dean TA, Thies K, Logos SL. Survival of juvenile giant kelp: the effects of demographic factors, competitors, and grazers. *Ecol* 1989;70:483–95.
- Department of Energy (DOE). United States nuclear tests July 1945 through September 1992. Las Vegas, Nevada: Nevada Operations Office; 2000. DOE/NV-209.
- Department of Energy (DOE). Modeling groundwater flow and transport of radionuclides at Amchitka Island's underground nuclear tests: Milrow, Long Shot, and Cannikan. Las Vegas, Nevada: Nevada Operations Office; 2002. DOE/NV-11508-51.
- Estes JA. Population estimates and feeding behavior of sea otters. In: Merritt ML, Fuller RG, editors. The environment of Amchitka Island, Alaska. Washington D.C.: Technical Information Center, Energy and Research Development Administration; 1977. p. 511–26. Report NVO-79.
- Estes JA, Tinker MT, Williams TM, Doak DF. Killer whale predation on sea otters linking oceanic and nearshore ecosystems. *Science* 1998;282:473–6.
- Faller SH, Farmer DE. Long-term hydrological monitoring program: Amchitka, Alaska. Washington, D.C.: U.S. Environmental Protection Agency; 1998. EPA-402-R-98-002.
- Fialkowski W, Newman WA. A pilot study of heavy metal accumulations in a barnacle from the Salton Sea, Southern California. *Mar Pollut Bull* 1998;36:138–43.
- Gochfeld M, Volz D, Burger J, Jewett SC, Powers CW, Friedlander B. Developing a health and safety plan for hazardous fieldwork in remote areas. *J Occup Environ Hygiene* in press.
- Higley KA, Domotor SL, Antonio EJ. A probabilistic approach to obtaining limiting estimates of radionuclide concentration in biota. *J Environ Radioact* 2003;66:75–87.
- Jacob K. Estimates of long-term probabilities for future great earthquakes in the Aleutians. *Geophys Res Lett* 1984;11:295–8.
- Jewett SC. Radionuclide contamination in nearshore habitats around Amchitka Island, Alaska. Proceedings of the Amchitka long-term stewardship workshop. Fairbanks, AL: CRESP, Univ of Alaska; 2002.
- Jewett SC, Hoberg M, Chenelot H, Harper S, Burger J, Gochfeld M. Scuba techniques used in risk assessment of possible nuclear leakage around Amchitka Island Alaska. In: Godfrey J, Shumway S, editors. Diving for Science: American Academy of Underwater Science 24th Annual Symposium. U. Conn. Sea Grant, STSG-06-03; 2006. p. 143–56.
- Johnson T. The Bering Sea and Aleutian Islands. Alaska Sea Grant College Program. Fairbanks: Univ of AL; 2003.
- Krahn MM, Becker PR, Tilbury KL, Stein JE. Organochlorine contaminants in blubber of four seal species: integrating biomonitoring and specimen banking. *Chemosphere* 1997;34:2109–21.
- Lebednik PA, Palmisano JF. Ecology of marine algae. The environment of Amchitka Island, Alaska. Washington D.C.: U.S.

- Technical Information Center, Energy Research and Development Administration; 1977. p. 353–94. Report NVO-79.
- Merritt ML, Fuller RG, editors. The environment of Amchitka Island, Alaska, U.S. Washington D.C.: Technical Information Center, Energy Research and Development Administration; 1977. Report NVO-79.
- Morrison D. Comparing fish and urchin grazing in shallow and deeper coral reef algal communities. *Ecol* 1988;69:1367–82.
- Morrison PR, Rosenmann M, Estes JA. Sea otter metabolism and heat economy. In: Merritt ML, Fuller RG, editors. The environment of Amchitka Island, Alaska. Washington D.C.: Technical Information Center, Energy and Research Development Administration; 1977. p. 569–78. Report NVO-79.
- National Research Council (NRC). The Bering Sea ecosystem. Washington, DC: National Academy Press; 1996.
- Norris RS, Arkin WM. NRDC nuclear notebook known nuclear tests worldwide, 1945–98. *Bull At Sci* 1998;56(6):65–7.
- O'Clair CE. Marine invertebrates in rocky intertidal communities. In: Merritt ML, Fuller RG, editors. The environment of Amchitka Island, Alaska. Washington D.C.: Technical Information Center, Energy and Research Development Administration; 1977. p. 395–450. Report NVO-79.
- Page RA, Biswas NN, Lahr JC, Pulpan H. Seismicity of continental Alaska. In: Slemmons DB, Engldahl ER, Zoback MD, Blackwell DD, editors. Neotectonics of North America. Boulder, Colorado: Geological Society of America; 1991. p. 47–68.
- Palmisano JF, Estes JA. Ecological interactions involving sea otter. In: Merritt ML, Fuller RG, editors. The Environment of Amchitka Island, Alaska. Washington D.C.: Technical Information Center, Energy and Research Development Administration; 1977. p. 527–68. Report NVO-79.
- Patrick R. How local Alaska native communities view the Amchitka issue. Proceedings of the Amchitka long-term stewardship workshop. Fairbanks, AL: CRESPI, Univ of Alaska; 2002.
- Powers CW, Burger J, Kosson D, Gochfeld M, Barnes D, editors. Amchitka independent science assessment: biological and geophysical aspects of potential radionuclide exposure in the Amchitka marine environment. Piscataway, New Jersey: Consortium for Risk Evaluation with Stakeholder Participation, (http://www.instrm.org/Amchitka/Final_Report/index_FinalReport.htm).
- Powers CW, Burger J, Kosson D, Gochfeld M. Selection radiologic data for bioindicator selection. Piscataway, New Jersey: Consortium for Risk Evaluation with Stakeholder Participation, (http://www.cresp.org/Amchitka/FINAL_AmchitkaAddendum_1_24_06.pdf).
- Robbins A, Makhijani A, Yih K. Radioactive heaven and earth — the health and environmental effects of nuclear weapon testing in, on and above the earth. New York, New York: Apex Press; 1991.
- Rothschild RFN, Duffy LK. Preliminary study on total mercury in the common prepared subsistence foods of a rural Alaskan village. *Al Med* 2002;4:89–102.
- Seymour AH, Nelson VA. Radionuclides in air, water, and biota. In: Merritt ML, Fuller RG, editors. The Environment of Amchitka Island, Alaska. Washington, D.C.: Technical Information Center, Energy Research and Development Administration; 1977. p. 579–613. Report TID-26712.
- Simenstad CA, Isakson JS, Nakatani RE. Marine fish communities. In: Merritt ML, Fuller RG, editors. The environment of Amchitka Island, Alaska. Washington, D.C.: Technical Information Center, Energy Research and Development Administration; 1977. p. 451–92. Report TID-26712.
- Somerfield PJ, Clarke KR. A comparison of some methods commonly used for the collection of sublittoral sediments and their associated fauna. *Mar Environ Res* 1997;43:145–56.
- Vetter W, Luckas B, Heidemann G, Skirmisson K. Organochlorine residues in marine mammals from the northern hemisphere — a consideration of the composition of organochlorine residues in the blubber of marine mammals. *Sci Total Environ* 1996;186:29–39.
- Ylitalo GM, Matkin CO, Buzitis J, Krahn MM, Jones LL, Rowles T, et al. Influence of life-history parameters on organochlorine concentrations in free-ranging killer whales (*Orcinus orca*) from Prince William Sound, AK. *Sci Total Environ* 2001;281:183–203.
- Zauke GP, Savinov VM, Ritterhoff J, Savinova T. Heavy metals in fish from the Barents Sea. *Sci Total Environ* 1999;227:161–73 [summer 1994].