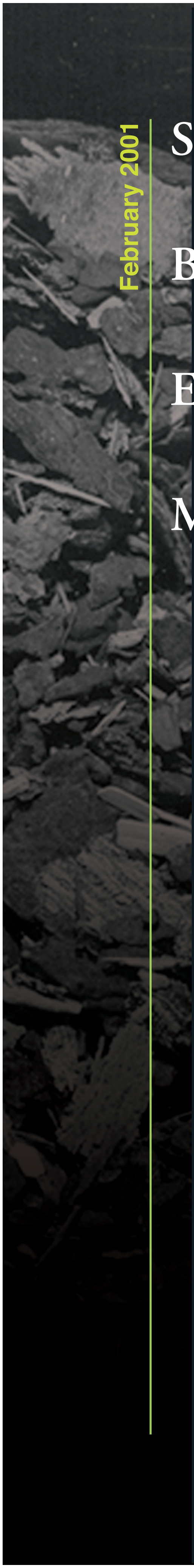


February 2001

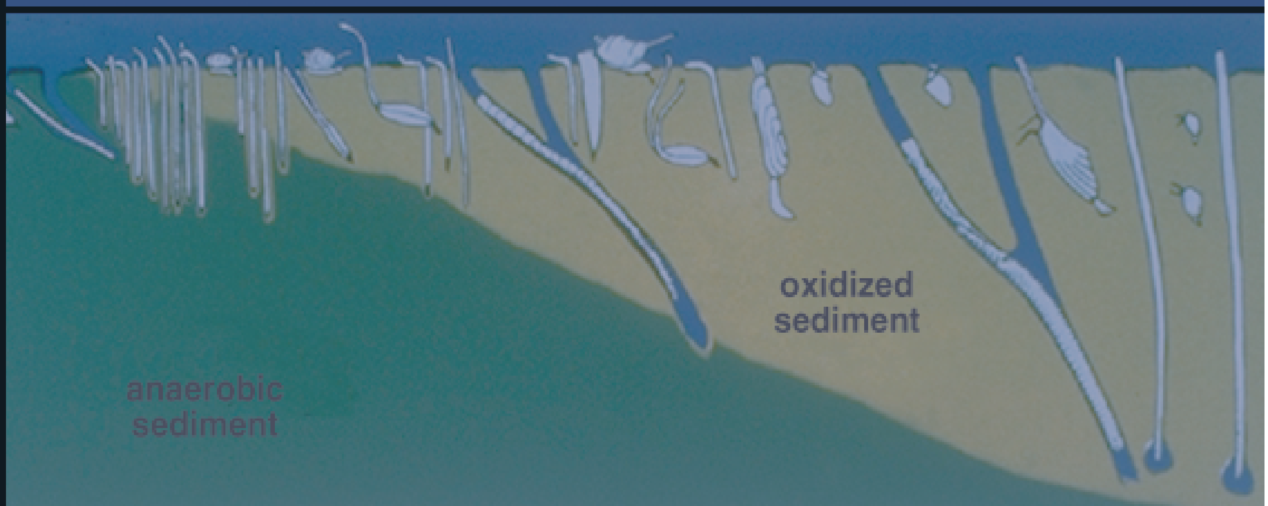
Silver Bay Baseline Environmental Monitoring

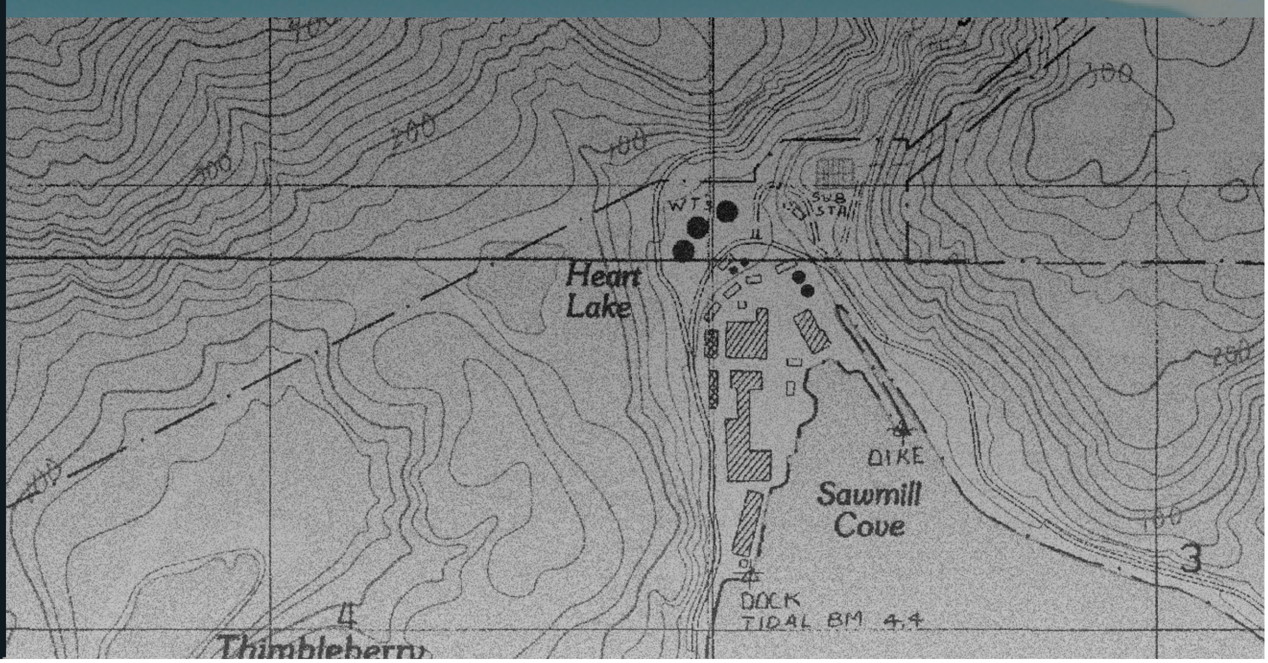
Prepared by

EVS environment consultants

Prepared for

City and Borough of Sitka, Alaska





Silver Bay Baseline Environmental Monitoring
Sitka, Alaska

FINAL REPORT:
BASELINE CHARACTERIZATION

Prepared for

City and Borough of Sitka
Department of Public Works
416 Galena Drive
Sitka, AK 99835

Prepared by

EVS Environment Consultants, Inc.
200 West Mercer Street, Suite 403
Seattle, WA 98119

EVS Project No.

2-1015-01

FEBRUARY 2001

The Ballad of Sawmill Cove

by Joe Germano

Come and listen for a moment, friends, take heed of what I say
About what we found in samples that we took in Silver Bay,
Well, Alaska Pulp shut down the mill way back in '93
And the tests were done to see if there was some toxicity.
Instead of mud, the bottom of the Cove was logs and pulp
And the costs of all the RI sampling made some people gulp
So they drew a line where wood was found and called it AOC
And then analyzed for metals, PAH and PCBs.

Well the RI did in fact conclude there were no COC's
So the Record of Decision said: "Natural Recovery"
Even though there were alternatives with engineering force
The solution was to just let mother nature run her course.
But some monitoring was needed to insure that this took place
Or else the City and ADEC would have egg on their face.
So in summer of 2000 all the baseline tasks were done
To see if a wasteland did exist or recovery had begun.

Well with video and bottom grabs and profile camera too
The whole AOC in Sawmill Cove was sampled through and through.
And when areas that fish and shrimp used were put on the map
It would reassure them they were right when they said not to cap.
The profile camera and the grabs did show for all to see
Most of the site's recolonized with Stages 1 through 3.
And it's really not surprising that things happened as they should
After all, this isn't hazardous waste, it's just a pile of wood.

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LIST OF ACRONYMS

AOC	area of concern
AVS	acid volatile sulfide
BOD	biochemical oxygen demand
CBS	City and Borough of Sitka
COD	chemical oxygen demand
DEC	Alaska Department of Environmental Conservation
DGPS	digital global positioning system
EVS	EVS Environment Consultants
NED	U.S. Army Corps of Engineers, New England Division
OSI	organism-sediment index
OU	Bay Operable Unit
RAO	remedial action objective
RI	remedial investigation
ROD	Record of Decision
RPD	redox potential discontinuity
SOD	sediment oxygen demand
SOP	standard operating procedure
SPI	sediment profile imaging
TOC	total organic carbon

1.0 INTRODUCTION

This report presents the results of the baseline monitoring program in Sawmill Cove, Alaska, conducted by EVS Environment Consultants (EVS) as part of the remedial action objective (RAO) from the closure of the Alaska Pulp Corporation's mill. The purpose of this initial monitoring program was to document initial conditions of the benthic community in the area of concern (AOC) within the cove. The rest of this introduction presents the site background, the objectives of the monitoring program, an overview of the approach, and the modifications to the baseline monitoring plan that were recommended to the City and Borough of Sitka (CBS) and the Alaska Department of Environmental Conservation (DEC). Section 2 of this report contains results from the first phase of the baseline monitoring, and Section 3 contains results from the final phase of monitoring. A synthesis and evaluation of results from both monitoring surveys are discussed in Section 4, and conclusions and recommendations are presented in Section 5. Literature citations and data appendices are included at the end of the report.

1.1 SITE BACKGROUND

Sawmill Cove is located near the mouth of Silver Bay in southeast Alaska. The cove was the receiving point for effluent and storm water discharges from the Alaska Pulp Mill, which produced pulp at the site from 1959 to 1993. Operations at the mill resulted in the accumulation of wood solids on the seafloor adjacent to the site.

A remedial investigation and ecological risk assessment of the Bay Operable Unit (OU), encompassing Sawmill Cove, were conducted during 1996 and 1997. The results of these studies were used to delineate an AOC in Sawmill Cove (Figure 1-1). The RAO for the AOC in Sawmill Cove, as defined in the Record of Decision (ROD), is to reduce to an acceptable level ecologically significant adverse effects to populations of bottom-dwelling life from hazardous substances, including wood waste degradation chemicals (DEC 1999). The acceptable level is defined as an observable succession of benthic species that will result in balanced, stable communities as assessed by measures of abundance and diversity at various locations over time. DEC determined that the RAO would best be obtained by natural recovery with long-term monitoring. The ultimate goal is to have 75 percent of the AOC in an equilibrium community by the year 2040. The ecological recovery management milestones are presented in Table 1-1 (DEC 1999).

Table 1-1. AOC recovery milestones

Milestone	Area	Time (years)	Successional Status
1	>75 % coverage of the AOC	5–10	Decomposers and primary producers
2	>75 % coverage of the AOC	10–20	Primary consumers and detritivores
3	>75 % coverage of the AOC	20–40	Secondary consumers
4	>75 % coverage of the AOC	> 40	Climax (equilibrium) community

1.2 MONITORING OBJECTIVES

The Silver Bay Monitoring Program was designed to measure the degree of natural recovery toward the natural resource management milestones outlined in the ROD. The objectives of the monitoring program outlined in the original work plan (Foster Wheeler 1999) are as follows:

- To compare benthic community abundance and diversity over time to document progress towards natural recovery
- To map natural recovery in the AOC based on changes in benthic community structure over time
- To avoid unnecessary sampling by identifying recovered areas as soon as possible
- To correlate benthic community structure with sediment chemistry parameters to explain spatial or numeric trends in benthic community parameters that deviate from the benthic succession model and the milestones established for recovery

1.3 OVERVIEW OF BASELINE MONITORING APPROACH

The intent of the Silver Bay Monitoring Program is to measure progress towards the monitoring objectives using sediment profile imaging (SPI), epifaunal video surveys, benthic community analyses, and sediment chemical analyses. The work plan for the monitoring program was prepared by Foster Wheeler (1999). According to this monitoring plan, the baseline tasks would consist of the following:

- Performing an initial review and assessment of the original remedial investigation (RI) data to determine whether the outlined baseline sampling design should be executed as initially designed

- Conducting Tier 1 sampling using SPI technology and epifaunal video surveys; data would be used to select station locations for Tier 2 sampling

- Conducting Tier 2 sampling for benthic community analysis and associated sediment chemistry

- Evaluating data and characterizing the AOC

The monitoring program recommended that sampling of areas within the AOC be stratified based on types of benthic communities and the anticipated speed of recovery. This approach would allow for the potential reduction of sampling effort in future years by eliminating areas that had been designated as recovered within various strata, thereby allowing efforts to be focused on those remaining areas that are still in the process of recovering.

1.4 REMEDIAL INVESTIGATION REVIEW AND WORK PLAN MODIFICATIONS

Soon after contract award, EVS scientists reviewed the available historical data from the Bay Operable Unit RI to determine whether the results supported the sampling design originally proposed for the baseline monitoring. The review also afforded the opportunity to recommend improvements to increase the efficiency and effectiveness of the original sampling design. Results of the RI review and recommended modifications are described in detail in several EVS memoranda (EVS 2000a,b,c; Appendix A). DEC's approved modifications were issued on June 28, 2000 (DEC 2000; Appendix A).

1.4.1 Stratum Definition

Seven preliminary strata were identified in the monitoring plan based on water depth and depth of wood waste (Foster Wheeler 1998). After a review of literature, EVS recommended that data from the SPI and towed video collected during the Tier 1 sampling be used to provide better stratum definitions. Sediment sampling stations could then be based on observed gradients in physical sedimentary conditions or in biological communities (EVS 2000a). This modification was incorporated into the baseline monitoring program (DEC 2000).

1.4.2 Benthic Community Analysis

The monitoring plan proposed the identification of benthic samples to a species level. However, numerous publications have documented that this level of analysis was not necessary to provide sufficient information to meet program objectives (Chessman 1995; Ellis 1985; Ferraro and Cole 1990, 1992, 1995; Kingston and Riddle 1989; Marchant et al. 1995; Olsgard et al. 1997; Warwick 1988a,b, 1993). Instead, it was determined that benthic samples would be identified to family level. Similarly, it was concluded that calculation of diversity and evenness indices, proposed as part of the benthic community analysis, would not provide meaningful information about benthic community recovery (EVS 2000c; DEC 2000). These calculations were not included in the analysis of the baseline monitoring data.

1.4.3 Control Station Sampling

The monitoring plan recommended the sampling of one control area with five random points within Sawmill Cove. Assuming the purpose of the control area was to document natural environmental variability outside the AOC, EVS determined that one control with five samples would not be adequate to encompass the spatial and temporal heterogeneity both inside and outside the AOC (EVS 2000c). Investigations carried out during the RI also concluded that there were no valid control stations within Silver Bay (Foster Wheeler 1998). Documentation of recovery within the AOC and progress toward the RAO could still be fulfilled without information from a control area (EVS 2000c). It was agreed that control sampling would not be conducted during the baseline or subsequent monitoring efforts (DEC 2000).

1.4.4 Chemical Parameters

The monitoring plan proposed sediment collection for chemical analysis within each of the seven strata, in addition to a control area. Within each stratum or control area, five samples would be collected and combined to make a total of eight composite samples submitted for laboratory analyses. Chemical analyses were to include biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia, and acid volatile sulfide (AVS). In addition, sufficient sediments from each composite sample were to be archived for analysis of 4-methylphenol.

EVS concluded that data from composite samples would be difficult to interpret because the results could not be directly related to benthic community data collected at any of the individual locations. In addition, the physical mixing of the sediment to make the composite samples would result in substantial loss of the relatively volatile compounds, AVS and ammonia (EVS 2000b). Therefore, it was determined that eight discrete samples would be collected instead of the eight composite samples (DEC 2000). The sample locations were determined based on results from Tier 1 sampling, as described in Section 2.4.1, Stratum Definition.

Additional modifications to sampling for chemical parameters included 1) analysis of total sulfides rather than AVS, because it would provide a more comprehensive measure of all forms of sulfide present in the sediment, and 2) elimination of sample archival for potential 4-methylphenol analysis. Our recommendation was that 4-methylphenol was not really a potential chemical of concern, because organic-carbon normalized concentrations were well below the organic-carbon normalized Apparent Effects Threshold concentrations (EVS 2000b; DEC 2000).

2.0
TIER 1 SURVEY

The Tier 1 survey consisted of visual observations of the epifauna from a towed video survey and the physical and biological gradients in the benthic habitat from both the towed video and SPI surveys. The objectives for this tier of sampling were to characterize the benthic habitat and to determine the final delineation of strata for the selection of benthic grab stations for Tier 2 sampling. The Tier 1 survey design was based on a 200-ft-interval survey grid, with SPI images collected at each intersection and towed video images at eleven line transects along the north/south component (Figure 2-1). The following sections present results for the video and SPI surveys and describe how these results were used to design the sampling scheme for Tier 2.

2.1 TOWED VIDEO SURVEY

2.1.1 Video Methods

The underwater video survey was conducted between April 18 and 20, 2000, aboard the M/V *Raven's Fire*, a 60-ft charter vessel. A detailed description of the video survey methods is presented in Appendix B; a summary of the methods is provided here, and the cruise report from the sampling event is included in Appendix C.

Eleven line transects spaced 200 ft apart through the AOC were defined for the video survey. Wind and current conditions coupled with the area's complex topography made it difficult to follow the defined straight-line transects, and most of the tracks meandered back and forth over the intended straight survey lines. The actual video track lines are shown in Figure 2-2. Some transects were extended beyond the southern and eastern edges of the AOC as part of additional work EVS performed for DEC to help refine state-defined Impaired Water Body boundaries in Silver Bay (EVS 2000d).

Towed video surveying was conducted according to the general methods presented in the monitoring plan (Foster Wheeler 1998). Navigation for this field effort was provided by Blue Water Engineering using a Trimble Ag132 Differential Global Positioning System (DGPS) receiver. The real-time differential corrections were obtained from the United States Coast Guard public DGPS network using the NAD 83 datum. The DGPS data were recorded with a laptop computer running Coastal Oceanographics Hypack software, version 8.9. Video images were obtained using an underwater color camera mounted towards the seafloor on a heavy towfish. Two lasers mounted 10 cm apart were attached to the camera to provide a reference scale for sizing objects, and an underwater light provided illumination. Date, time, latitude, longitude, and transect identification numbers were stored directly onto the image while videotaping. A real-time mapping system was also utilized, providing a continuously updated preliminary map of seafloor attributes as sampling proceeded.

To process the data after videotaping, a spreadsheet of all time and position records was created, with one record for each second. Investigators entered a specific code for each record where a particular attribute of interest was noted. Patches of the sulfur-reducing colonial bacteria *Beggiatoa* were classified on a qualitative density scale of 1 to 3, ranging from isolated patches or subtle appearance to domination of the bottom surface and illumination of the video screen. Wood debris was recorded as one of four categories: logs, “possible” logs, wood, and “possible” wood. Anemones, fish, shrimp, and crabs were recorded as either present or absent. Nudibranchs were observed but were difficult to see and therefore not classified or recorded on data sheets.

The original monitoring plan proposed a method of data analysis to determine the percentage of seafloor covered by *Beggiatoa* using a modification of Carleton and Done (1995); this is a random point sampling method for estimating benthic coverage on coral reefs. This method did not prove useful for this survey because it was originally developed for organisms with patchy distributions, whereas the *Beggiatoa* colonies at this site formed extensive, continuous mats. When *Beggiatoa* was visible, it was visible throughout the entire field of view. Selecting a random point within each randomly selected frame along a transect and noting whether the point touched *Beggiatoa*, according to the Carleton and Done methodology, would not have been meaningful.

The line-transect method (Norris et al. 1997) would have been applicable for determining percentage coverage of *Beggiatoa* if the actual transects had been straight. This method relies on the underlying theory that the percentage of a random straight line through a study area with the attribute of interest is an unbiased estimate of the percentage of the entire study area that has that attribute. However, if a transect meanders more in regions where the attribute is present than in regions where the attribute is absent (or vice versa), the estimate of the percentage present will be positively or negatively biased. In aquatic applications, some meandering is unavoidable; however, the transects in this study meandered beyond acceptable bounds and invalidated the Norris et al. (1997) calculation method.

Estimates of the percentage coverage of *Beggiatoa* were made over the area that was actually surveyed. The area of observed *Beggiatoa* was calculated using the number of records with *Beggiatoa* multiplied by the average recorded view area (0.335 m^2). The area actually surveyed was calculated using the total number of acceptably visible records and the record area. For attributes other than *Beggiatoa*, the percentage of surveyed area in which presence was observed was calculated in the same way.

2.1.2 Video Results

A total of 20,616 time/position records were examined during the video analysis, of which 15,933 (77 percent) were deemed to have acceptable images. The unacceptable records did not yield useful information due to excessive turbidity, debris covering the lens, the camera not yet reaching the bottom on initial deployment, the camera off-bottom during a transect, or the camera dragging in the sediment. The visibility on the tapes varied considerably from clear views to extremely turbid footage. This survey took place soon after the spring plankton bloom in Silver Bay, and the dead phytoplankton cells had settled to the bottom, producing a floccular detrital layer over a large portion of the site. This organic-rich layer of decomposing plant material was visible in the video survey either as a near-bottom nepheloid layer that obscured details on the sediment surface or as marine "snow" in the water column that obstructed the camera's view. Portions of the actual video transects that were considered acceptable are shown in Figure 2-3.

The acceptable records represent a total area of 5,338 m^2 surveyed. Table 2-1 summarizes the results for each attribute. The following sections describe the results for each of the attributes observed.

Table 2-1. Presence of wood and biological attributes observed during the towed video survey

Attribute	Total Number of Records	Total Area[a] (m2)	Percent of Total Area Surveyed
Logs/Wood			
Log	57	19.1	0.36
Small wood	11	3.7	0.07
"Possible" log	14	4.7	0.09
"Possible" small wood	8	2.7	0.05
Beggiatoa			
Low density	1,318	442	8.3
Medium density	1,259	422	7.9
High density	1,249	418	7.8
Organisms			
Anemones	642	215	4.0
Fish	1625	544	10.2
Shrimp	1575	528	9.9
Crab	68	23	0.43
Combined organisms	3,696	1,238	23.2

[a] Based on an average area per record of 0.335 m^2

Beggiatoa

Depending upon the visibility conditions, *Beggiatoa* was seen as a blinding white layer, a subtle glint underneath a layer of debris, or a gray-white patch. While the rating on a scale from 1 to 3 was a subjective determination by the investigator, it was still quite clear from the video when *Beggiatoa* mats were present. *Beggiatoa* was observed primarily in the central and northern portions of the AOC, with the highest densities along several transects in the northeastern section (Figure 2-4). *Beggiatoa* was not observed in any of the video records at the southern edge of the AOC. An estimated 24 percent of the area surveyed contained *Beggiatoa*.

Log and Wood Debris

The thick layer of organic debris over most of the bottom rendered it difficult to see wood debris smaller than large logs or pieces shorter than 2 ft. in length. Logs were noted on 63 occasions, possible logs on 15, small wood debris on 11, and possible small wood debris on eight. Logs and wood were present mostly in the northern and eastern parts of the AOC (Figure 2-5). Areas of bark or wood chips could not be observed because of the limited visibility from the dead phytoplankton which had settled on the bottom. Less than one percent of the area surveyed showed the presence of logs or large wood pieces.

Anemones

Metridium sea anemones were common wherever there was a solid surface for attachment, and occasionally other genera of anemones were seen. There were 653 records with anemones observed, most of them with many individual specimens. Many anemones seemed attached directly to the seabed; it was not possible to determine in each case whether there was a hard object underneath the layer of debris to which they were attached. The areas without *Beggiatoa* appeared to have the highest concentration of anemones, although some were located in areas of dense bacterial mats (Figure 2-6).

Fish

Fish were relatively easy to see but difficult to identify. Many snake pricklebacks (*Lumpenus sagitta*) were seen, but other species could not be positively identified. There were a total of 1,629 records with fish observed, many of which had more than one fish. Fish were observed throughout the AOC, including the areas with high density of *Beggiatoa* (Figure 2-7).

Shrimp

While shrimp were clearly visible in some places, there appeared to be shrimp in other places on the video record when the camera was further off the bottom (they showed up as white dots). Because other objects may appear as white dots, i.e., tube worms, the number of records with shrimp may have been overestimated. Shrimp were seen on 1,577 records located throughout the AOC, including areas with dense *Beggiatoa* colonies (Figure 2-8).

Crabs

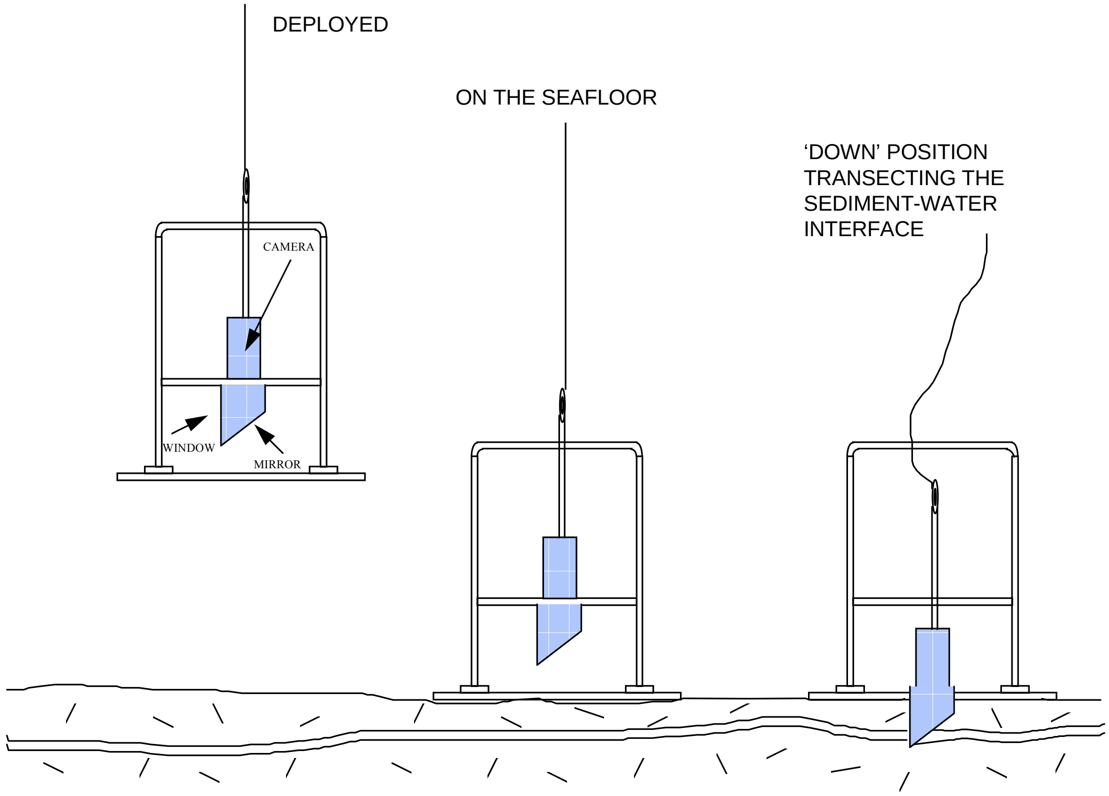
Crabs were occasionally seen but could not be identified to species. Most crabs probably were not counted because they normally hide below the sediment. There were 68 records with crab observations located throughout the AOC (Figure 2-9). The greatest concentration appeared to be in the southeastern portion of the AOC. There were a few crabs observed even in areas with dense *Beggiatoa* mats.

2.2 SPI SURVEY

2.2.1 Methods

The SPI survey was carried out on the M/V *Raven's Fire* between April 21 and 23, 2000 at the designated station locations (see Figure 2-1). Sampling station coordinates are included in Appendix D, and the cruise report from the sampling event is included in Appendix C. A Benthos Model 3731 sediment profile camera was used for this survey. The camera was deployed at a total of 97 stations. Successful images were obtained from all but 6 stations; no useful images are available from Stations 18, 23, 29, 62, 90, and 97.

SPI was developed almost two decades ago as a rapid reconnaissance tool for characterizing physical, chemical, and biological seafloor processes and has been used in numerous seafloor surveys throughout the United States, Pacific Rim, and Europe (Rhoads and Germano 1982, 1986, 1990; Revelas et al. 1987; Valente et al. 1992). The sediment profile camera works like an inverted periscope. A deep-sea 35mm camera mechanism is mounted horizontally inside a water-tight housing on top of a wedge-shaped prism. The prism has a Plexiglas® faceplate at the front with a mirror placed at a 45° angle at the back. The camera lens looks down at the mirror, which is reflecting the image from the faceplate. The prism has an internal strobe mounted inside at the back of the wedge to provide illumination for the image; this chamber is filled with distilled water, so the camera always has an optically clear path to shoot through. This wedge assembly is mounted on a moveable carriage within a stainless steel frame. The frame is lowered to the seafloor on a winch wire, and the tension on the wire keeps the prism in its "up" position. When the frame comes to rest on the seafloor, the winch wire goes slack (see illustration) and the camera prism descends into the sediment at a slow, controlled rate by the dampening action of a hydraulic piston so as not to disturb the sediment-water interface. On the way down, it trips a trigger that activates a time-delay circuit to allow the camera to penetrate the seafloor before any image is taken. The knife-sharp edge of the prism transects the sediment, and the prism penetrates the bottom. The strobe is discharged twice with each lowering to obtain two cross-sectional images of the upper



The central cradle of the camera is held in the "up" position by tension on the winch wire as it is being lowered to the seafloor (left); once the frame base hits the bottom (center), the prism is then free to penetrate the bottom (right) and take the photograph.

20 cm of the sediment column. After the two replicate images are obtained at the first location, the camera is then raised up about 2 to 3 meters off the bottom to allow the strobe to recharge. The strobe recharges within 5 seconds, and the camera is ready to be lowered again for another two images. Surveys can be accomplished rapidly by "pogo-sticking" the camera across an area of seafloor while recording positional fixes on the surface vessel. The resulting images give the viewer the same perspective as looking through the side of an aquarium half-filled with sediment.

Kodak Ektachrome® color slide film (ISO 200) was used throughout the entire survey. At the beginning of each survey day, the time on the camera's internal data logger was synchronized with the internal clock on the computerized navigation system being used to conduct the survey. Two lowerings (four images) were taken at each station; each SPI replicate is identified by the time recorded on the film and on disk along with vessel position. Even though multiple images were taken at each location, each image was assigned a unique frame number by the data logger and cross-checked with the time stamp in the navigational system's computer data file. Redundant sample logs were kept by the field crew.

Test exposures of the Kodak® Color Separation Guide (Publication No. Q-13) were fired on deck at the beginning and end of each roll of film to verify that all internal electronic systems were working to design specifications and to provide a color standard against which final film emulsion can be checked for proper color balance. Charged spare batteries were carried in the field at all times to ensure uninterrupted sample acquisition. After deployment of the camera at each station, the frame counter was also checked to ensure that the requisite number of replicates had been taken at each location. In addition, a prism penetration depth indicator on the camera frame was checked to verify that the optical prism had actually penetrated the bottom to a sufficient depth to acquire a profile image. If images were missed (frame counter indicator), additional replicates were taken.

The resulting color slides (one representative image from each station) were scanned and stored in photo-CD format by ProLab, Inc., Seattle, Washington. The slides were digitized at five levels of resolution, from 192 × 128 pixels per frame and doubling in successive intervals up to 3072 × 2048 pixels per frame. Thorough measurements of all physical parameters and some biological parameters were subsequently measured directly from the CD using a computer-image analysis system (Image Pro Plus®). The full color image analysis system can discriminate up to 16.7 million different shades of color, so subtle features can be accurately digitized and measured. Our software allows the measurement and storage of data on 21 different variables for each SPI image obtained. All data stored on disks were printed out on data sheets for editing by the principal investigator and as a hard-copy backup; a separate data sheet was generated for each SPI image. All data sheets were edited and verified by a senior-level scientist before being approved for final data synthesis and interpretation. Automatic disk storage of all parameters measured allowed data from any variables of interest to be easily compiled, sorted, displayed graphically, contoured, or compared statistically.

Specific measurement techniques for the SPI parameters measured are presented in the sections that follow.

Depositional Layer Thickness

Because of the camera's unique design, SPI has proven invaluable in detecting depositional layers ranging from 20 cm (the height of the SPI optical window) to 1 mm in thickness. During image analysis, the thickness of the newly deposited layers is determined by measuring the linear distance between the pre- and post-disposal sediment-water interface. Recently deposited material is usually evident because of its unique optical reflectance and/or color relative to the underlying material representing the pre-disposal surface. Also, in most cases, the point of contact between the two layers and a textural change in sediment composition in the new layer are clearly visible, facilitating measurement of the thickness of the newly-deposited layer.

Sediment Type Determination

The sediment grain-size major mode and range are visually estimated from the photographs by overlaying a grain-size comparator that is at the same scale. This comparator was prepared by photographing a series of Udden-Wentworth size classes (equal to or less than coarse silt up to granule and larger sizes) through the SPI camera. Seven grain-size classes are on this comparator: ≥ 4 phi, 4 to 3 phi, 3 to 2 phi, 2 to 1 phi, 1 to 0 phi, 0 to -1 phi, < -1 phi. The lower limit of optical resolution of the photographic system is about 62 microns, allowing recognition of grain sizes equal to or greater than coarse silt. The accuracy of this method has been documented by comparing our SPI estimates with grain-size statistics determined from laboratory sieve analyses.

Prism Penetration Depth

The SPI prism penetration depth is determined by measuring both the largest and smallest linear distance between the sediment-water interface and the bottom of the film frame. The SPI analysis software automatically averages these maximum and minimum values to determine the average penetration depth. All three values, maximum, minimum, and average penetration depth, are included on the data sheets. Prism penetration is potentially a noteworthy parameter; if the number of weights used in the camera is held constant throughout a survey, the camera functions as a static-load penetrometer. Comparative penetration values from sites of similar grain-size give an indication of the relative sediment water content.

Surface Boundary Roughness

Surface boundary roughness is determined by measuring the vertical distance, parallel to the film border, between the highest and lowest points of the sediment-water interface. In addition, the origin of this small-scale topographic relief is indicated when it is evident (physical or biogenic). Boundary roughness is only accurately measured when the camera is level. In sandy sediments, boundary roughness can be a measure of sand wave height. On silt-clay bottoms, boundary roughness values often reflect biogenic features such as fecal mounds or surface burrows.

Mud Clasts

When fine-grained, cohesive sediments are disturbed, either by physical bottom scour or faunal activity, e.g., decapod foraging, intact clumps of sediment are often scattered about the seafloor. These mud clasts can be seen at the sediment-water interface in SPI images. During analysis, the number of clasts is counted, the diameter of a typical clast is measured, and their oxidation state is assessed. Depending on their place of origin and the depth of disturbance of the sediment column, mud clasts can be reduced or oxidized; in SPI images, the oxidation state is apparent from their reflectance value; see section on Apparent Redox Potential Discontinuity Depth, below. Also, once at the sediment-water interface, these sediment clumps are subject to bottom-water oxygen levels and bottom currents. Based on laboratory microcosm observations of reduced sediments placed within an aerobic environment, oxidation of reduced surface layers by diffusion alone is quite rapid, occurring within 6 to 12 hours (Germano 1983). Consequently, the detection of reduced mud clasts in an obviously aerobic setting suggests a recent origin. The size and shape of mud clasts, e.g. angular versus rounded, are also considered. Mud clasts may be moved about and broken by bottom currents and/or animals (macro- or meiofauna; Germano 1983). Over time, large angular clasts become small and rounded. Overall, the abundance, distribution, oxidation state, and angularity of mud clasts are used to make inferences about the recent pattern of seafloor disturbance in an area.

Apparent Redox Potential Discontinuity Depth

Aerobic near-surface marine sediments typically have higher reflectance values relative to underlying hypoxic or anoxic sediments. Surface sands washed free of mud also have higher optical reflectance than underlying muddy sands. These differences in optical reflectance are readily apparent in SPI images; the oxidized surface sediment contains particles coated with ferric hydroxide (an olive color when associated with particles), while reduced and muddy sediments below this oxygenated layer are darker, generally grey to black. The boundary between the colored ferric hydroxide surface sediment and underlying grey to black sediment is called the apparent redox potential discontinuity (RPD).

The depth of the apparent RPD in the sediment column is an important time-integrator of dissolved oxygen conditions within sediment pore waters. In the absence of bioturbating organisms, this high reflectance layer (in muds) will typically reach a thickness of 2 mm (Rhoads 1974). This depth is related to the supply rate of molecular oxygen by diffusion into the bottom and the consumption of that oxygen by the sediment and associated microflora. In sediments that have very high sediment oxygen demand (SOD), the sediment may lack a high reflectance layer even when the overlying water column is aerobic.

In the presence of bioturbating macrofauna, the thickness of the high reflectance layer may be several centimeters. The relationship between the thickness of this high reflectance layer and the presence or absence of free molecular oxygen in the associated pore waters must be made with caution. The boundary or horizon that separates the positive Eh region of the sediment column from the underlying negative Eh region is the actual RPD. The exact location of this Eh=0 potential can only be determined accurately with microelectrodes; hence, the relationship between the change in optical reflectance, as imaged with the SPI camera, and the actual RPD can only be determined by making the appropriate *in situ* Eh measurements. For this reason, we describe the optical reflectance boundary, as imaged, as the “apparent” RPD, and it is mapped as a mean value. In general, the depth of the actual Eh=0 horizon will be either equal to or slightly shallower than the depth of the optical reflectance boundary. This is because bioturbating organisms can mix ferric hydroxide-coated particles downward into the bottom below the Eh=0 horizon. As a result, the **apparent** mean RPD depth can be used as an estimate of the depth of pore water exchange, usually through pore water irrigation (bioturbation).

The depression of the apparent RPD within the sediment is relatively slow in organic-rich muds (on the order of 200 to 300 μm per day); therefore, this parameter has a long time constant (Germano and Rhoads 1984). The rebound in the apparent RPD is also slow (Germano 1983). Measurable changes in the apparent RPD depth using the SPI optical technique can be detected over periods of one or two months. This parameter is used effectively to document changes or gradients that develop over a seasonal or yearly cycle related to water temperature effects on bioturbation rates, seasonal hypoxia, SOD, and infaunal recruitment. In sediment-profile surveys of ocean disposal sites sampled seasonally or on an annual basis throughout the New England region, SPI results have repeatedly documented a drastic reduction in apparent RPD depths at disposal sites immediately after dredged material disposal. This is followed by a progressive post-disposal apparent RPD deepening (barring further physical disturbance). Consequently, time series RPD measurements can be a critical diagnostic element in monitoring the degree of recolonization in an area by the ambient benthos.

The depth of the mean apparent RPD also can be affected by local erosion. The peaks of disposal mounds are commonly scoured by divergent flow over the mound. This can result in washing away of fines, development of shell or gravel lag deposits, and very thin apparent RPD depths. During storm periods, erosion may completely remove any evidence of the apparent RPD (Fredette et al. 1988).

Another important characteristic of the apparent RPD is the contrast in reflectance values at this boundary. This contrast is related to the interactions among the degree of organic loading, bioturbational activity in the sediment, and the levels of bottom-water dissolved oxygen in an area. High inputs of labile organic material increase sediment oxygen demand and, subsequently, sulfate reduction rates and the abundance of sulfide end-products. This results in more highly-reduced (lower-reflectance) sediments at depth and higher RPD contrasts. In a region of generally low RPD contrasts, images with high RPD contrasts indicate localized sites of relatively high past inputs of organic-rich material, e.g., organic or phytoplankton detritus, dredged material, or sewage sludge.

Sedimentary Methane

At extreme levels of organic loading, porewater sulfate is depleted and methanogenesis occurs. The process of methanogenesis is detected by the appearance of methane bubbles in the sediment column. These gas-filled voids are readily discernable in SPI images because of their irregular, generally circular aspect and glassy texture due to the reflection of the strobe off the gas. If present, the number and total area covered by all methane pockets is measured.

Infaunal Successional Stage

The mapping of successional stages is possible with SPI technology and is based on the theory that organism-sediment interactions follow a predictable sequence after a major seafloor perturbation. This theory states that primary succession results in "the predictable appearance of macrobenthic invertebrates belonging to specific functional types following a benthic disturbance. These invertebrates interact with sediment in specific ways. Because functional types are the biological units of interest..., our definition does not demand a sequential appearance of particular invertebrate species or genera" (Rhoads and Boyer 1982). This theory is formally developed in Rhoads and Germano (1982) and Rhoads and Boyer (1982), with a brief overview presented below.

After an area of bottom is disturbed, whether from natural or anthropogenic events, the first invertebrate assemblage, referred to as a Stage I assemblage, that appears within days after the disturbance are dense assemblages of tiny, tube-dwelling marine polychaetes that reach population densities of 10^4–10^6 individuals/m² (Figure 2-10). These animals feed at or near the sediment-water interface and have the effect of physically stabilizing or binding the sediment surface by the production of a mucous "glue" that they use to build their tubes. Sometimes deposited dredged material layers contain Stage I tubes still attached to mud clasts from their location of origin; these transported individuals are considered as part of the *in situ* fauna in our assignment of successional stages.

If there are no repeated disturbances to the newly-colonized area, then these initial tube-dwelling suspension or surface-deposit feeding taxa are followed by burrowing, head-down deposit-feeders that rework the sediment deeper and deeper over time and mix oxygen from the overlying water into the sediment. The animals in these later-appearing communities (Stage II or III) are larger, have lower overall population densities (10-10^2 individuals/m²) and can rework the sediments to depths of 3–20 cm or more. These animals "loosen" the sedimentary fabric, increase the sediment water content, thereby lowering the sediment shear strength, and actively recycle nutrients because of the high exchange rate with the overlying waters due to their burrowing and feeding activities.

This continuum of change in animal communities after a disturbance (primary succession) has been divided arbitrarily into three stages: Stage I is the initial community of tiny, densely-populated polychaete assemblages, Stage II is the start of the transition to head-down deposit feeders, and Stage III is the mature, equilibrium community of deep-dwelling, head-down deposit feeders.

Infaunal successional stages are recognized in SPI images by the presence of dense assemblages of near-surface polychaetes and/or the presence of subsurface feeding voids; both types of assemblages may be present in the same image.

Organism-sediment Index

The organism-sediment index (OSI) is a summary mapping statistic that is calculated on the basis of four independently measured SPI parameters: mean apparent RPD depth, presence of methane gas, low/no oxygen at the sediment-water interface, and successional status (Table 2-2). This index is a convenient way of mapping disturbance gradients in benthic habitats (Revelas et al. 1987). The highest possible OSI value is +11, which reflects a mature benthic community in relatively undisturbed conditions, generally a good yardstick for high benthic habitat quality: deeply oxidized sediment with a low inventory of anaerobic metabolites and low sediment oxygen demand, populated by a climax (Stage III) community. The lowest OSI value is -10, indicating that the sediment has a high inventory of anaerobic metabolites, has a high oxygen demand, and is azoic. In our mapping experience with this parameter over the past 15 years, we have found that OSI values of 6 or less indicate that the benthic habitat has experienced physical disturbance, eutrophication, or excessive bioavailable contamination in the recent past.

Table 2-2. Calculation of the SPI Organism-Sediment Index value

A. CHOOSE ONE VALUE:		
	Mean RPD Depth	**Index Value**
	0.00 cm	0
	> 0–0.75 cm	1
	0.76–1.50 cm	2
	1.51–2.25 cm	3
	2.26–3.00 cm	4
	3.01 –3.75 cm	5
	> 3.75 cm	6
B. CHOOSE ONE VALUE:		
	Successional Stage	**Index Value**
	Azoic	-4
	Stage I	1
	Stage I → II	2
	Stage II	3
	Stage II → III	4
	Stage III	5
	Stage I on III	5
	Stage II on III	5
C. CHOOSE ONE OR BOTH IF APPROPRIATE:		
	Chemical Parameters	**Index Value**
	Methane present	-2
	No/low dissolved oxygen[a]	-4
ORGANISM-SEDIMENT INDEX VALUE =		Total of above subset indices (A+B+C)
		RANGE: -10 to +11

[a] This is not based on a Winkler or polarigraphic electrode measurement. It is based on the imaged evidence of reduced, low reflectance (i.e., high oxygen demand) sediment at the sediment-water interface.

2.2.2 SPI Results

A complete set of all the summary data measured from each image is presented in Appendix E. Parameters such as boundary roughness and mud clast data (number, size) provide supplemental information pertaining to the physical regime and bottom sediment transport activity at a site. Mud clasts were noted at only one station in this survey because most of the sediments within the AOC are largely wood chips and fibers that do not consolidate into a cohesive clast. Therefore, mud clast data were not available for supplemental evidence of sediment transport phenomena.

Physical Parameters

The sediment grain-size major mode was fairly uniform throughout the entire site. With the exception of four stations that had large rocks and cobble on the sediment surface preventing prism penetration (Stations 2, 17, 25, and 41), the remaining stations within the AOC were all primarily fine-grained sediments ($\geq 4\ \phi$) consisting mainly of decomposing wood particles. Wood fibers and fragments of various sizes (Figure 2-11) were evident in the cross-sectional profile at most of the stations.

The size of the wood particles seen in the cross-sectional images was most likely dependent on the stage of microbial decomposition and the amount of meiofaunal activity. The wood fragments ranged in size from distinct chips/chunks 2–4 cm in diameter (Figure 2-12a) to medium fragments < 1 cm in diameter (Figure 2-12b) to fine sand- or silt-sized particles (Figure 2-12c). Evidence of wood fibers/waste was present in all but five of the stations throughout the site (Figure 2-13).

Not unexpectedly, sediment shear strength was relatively low in most areas, with the camera prism over-penetrating the bottom (Figure 2-14) at about 20 percent of the stations sampled. With this large volume of both labile and refractory organic matter at the sediment surface, the SOD is relatively high compared with other nearshore embayments.

Evidence of organic loading contributing to the high SOD is prevalent throughout the site and documented in the profile images in a number of different parameters: the absence of an apparent RPD boundary, low reflectance values of dark sediments, the presence of methane gas bubbles, and a seasonal input pulse of labile organic matter from dead phytoplankton. This organic-rich layer of decomposing plant material was visible in the video survey when accumulations were thick enough, but it was readily detectable even at relatively thin layers in the sediment profile images (Figure 2-15). The distribution of stressors contributing to organic loading is shown in Figure 2-16.

The distribution of mean apparent RPD depth is shown in Figure 2-17, with values exceeding 3 cm at only about 10 percent of the stations. The mean apparent RPD values showed a fairly consistent pattern; with the exception of Stations 4 and 5, most stations closest to the shoreline within the AOC did not have any evidence of an RPD in the sediment (Figure 2-17). In areas with extreme organic loading and high SOD, the RPD is found somewhere in the water column above the sediment-water interface. A substantial number of stations that are close to the shoreline where the apparent RPD could not be measured due to overpenetration of the camera prism most likely did not have a redox layer present in the sediment (Figure 2-18). Well-developed redox boundaries are encountered in the eastern and southern areas of the site (Figure 2-19).

Biological Parameters

Not surprisingly, the distribution of infaunal successional assemblages followed a pattern similar to that described for the mean apparent RPD (Figure 2-20). Those stations closest to the coastline showing the most severe signs of organic loading appeared virtually azoic; if any infauna were present at these locations, they would be there in extremely low densities. Successional stages could not be assigned to a total of 25 stations (27 percent) because of excessive prism penetration, while 15 stations (16 percent) had a depauperate fauna and were classified as azoic (Figure 2-21).

Recolonization and recovery has definitely started within the site at more than half the stations sampled. As one moves to the south and east within the AOC, Stage I polychaete assemblages (Figure 2-22) appear at 37 stations (ca. 41 percent of the total area sampled). Six stations (7 percent) exhibited evidence of the start of a transitional deposit-feeding community developing (Figure 2-23), and 8 stations (9 percent) primarily at the southern end of the AOC had well-developed Stage III assemblages present (Figure 2-24).

In addition to visual evidence of macrofaunal recolonization, the sediment profile images also revealed evidence of microfaunal colonization in the form of anoxic, sulfur-reducing bacteria (*Beggiatoa* or other similar species). The diagnostic white, string-like colonies of anoxic bacteria are readily visible in SPI photographs, even when they are in low densities as individual strands (Figure 2-25a) or in high densities as a “white skin” on the sediment surface (Figure 2-25b). Sulfur-reducing bacterial colonies were found at almost half (42 out of 91) of the locations sampled (Figure 2-26).

The overall pattern of habitat “stress” due primarily to excess organic loading is perhaps best revealed in the distributional map of OSI values (Figure 2-27). Stations with values less than or equal to 6 are reflecting signs of disturbance, and those with negative numbers (closest to the coastline) are experiencing the most severe stress; as with RPD values, conditions improve as one moves to the southern and eastern edge of the AOC, away from the heaviest accumulation of wood waste.

2.3 DISCUSSION

The two reconnaissance survey methods used during the Tier 1 survey operate at different scales. The towed video is good for seeing large objects on the surface of the sediment in the centimeter-to-meter size range (the average width of the video field of view was between 0.5 and 0.75 m), whereas the SPI camera can detect structures in the sediment on the millimeter-to-centimeter scale. For mapping large-scale attributes such as the presence or absence of wood waste or bacterial mats, the two technologies can be effectively combined to complement one another. The SPI camera can view wood chips to smaller wood fibers or pulp particles in the fine-sand to coarse silt-sized range, whereas the video camera can reveal the presence of larger wood pieces and logs on the sediment surface. The video survey showed the presence of wood and logs mostly in locations away from the shore, indicating that the larger wood objects have settled in the topographically low areas (the deepest water); this is consistent with the historical practices in Sawmill Cove as far as where the log rafting and main log traffic took place. The SPI survey showed the presence of wood particles throughout most of the AOC (Figure 2-13); in general, the largest wood particles observed in the profile images were from locations surveyed closer to the shoreline.

The same difference in scaling factors applied to the detection of the sulfur-reducing bacterial colonies. There were numerous locations where the SPI camera observed the presence of *Beggiatoa* that was undetected by the underwater video camera, either because of the layer of phytoplankton detritus obscuring it from view from the video camera or because the scale of the colonies was beyond the resolution of the towed video array. While the video camera underestimated the *Beggiatoa* distribution, it was useful in showing areas with either large-scale patches or continuous mats covering the bottom surface.

While the blanket of wood waste—fibers, chips, logs—that was originally delineated in the RI investigations was still readily detectable throughout most of the AOC, it was encouraging to document through both optical survey methods used during the Tier 1 sampling that ecosystem recovery had indeed started within the site. Both the SPI and video results showed that the area was being extensively utilized as habitat for both infauna and epifauna; in fact, the Tier 1 results showed that the first recovery management milestone, decomposers and primary producers present in greater than 75 percent of the AOC had already been achieved (Figure 2-28).

2.4 TIER 2 SAMPLING DESIGN

2.4.1 Stratum Definition

Strata for Tier 2 sampling were determined by conducting statistical cluster analysis with Tier 1 data on the successional stage, water depth, presence of wood and bacteria, and location of stations. Because the Tier 1 data were a combination of continuous data variables and ordinal or categorical variables, a dissimilarity metric (Kaufman and Rousseeuw 1990) that allows for different types of variables was applied. For this method, the dissimilarity value differs depending on the type of variable, but all variables are scaled to the same interval and hence have equal weight. The multidimensional distance between two points is the sum of the dissimilarity for each variable, scaled to the interval [0,1]. The clustering algorithm known as *partitioning around medoids* (Kaufman and Rousseeuw 1990) was used for the statistical analysis. Partitioning cluster methods such as this one divide the stations into a pre-specified number of groups based on minimizing the dissimilarities within each group. Initial cluster analysis did not result in spatially contiguous strata due to the extent and patchy quality of bacteria and wood in the AOC. Therefore, these two variables were removed from the cluster analysis and used qualitatively in the final definition of strata.

The statistical cluster analysis based on successional stage, water depth, and location identified three clusters with spatially contiguous stations. Attempts to add more clusters resulted in a loss of clear spatial groupings. The three identified strata had clear separation in terms of depth and successional stage, with the exception of one area in the southwest boundary area of the AOC. This area was on a very steep incline and showed elements of two strata without fitting neatly into either one. The topographic profile in this area is best visualized as a steep cliff with terrace-like formations of intermittent ledges; deep accumulations of wood waste have collected on these ledges, making whatever horizontal surface that is available one of extremely low bearing strength. Because of this, the successional stage at several of the SPI stations in this area could not be determined due to overpenetration of the camera prism in these soft sediments, and there were no video results in this area due to the rapid change in depth. For these reasons, the stations in this area were used to define a fourth stratum, so that conditions in this area could be documented separately. Figure 2-29 displays successional stage ranking values, wood presence, bacteria presence, and depth contours within the proposed stratum boundaries. Table 2-3 contains a summary of selected SPI results for each of the strata.

Table 2-3. Summary of selected SPI results by stratum

STRATUM	1	2	3	4
Number of stations	27	11	45	8
Depth range (m)	13-48	64-69	44-66	14-66
Successional stage:				
Indeterminate	12	0	2	1
Azoic	12	0	10	3
Stage I	3	0	28	4
Stage I -> II	0	0	2	0
Stage II	0	2	2	0
Stage II -> III	0	0	0	0
Stage III	0	9	1	0
Stations with wood	93% fine to coarse	55% fine to medium	100% fine to chips	75% fine to medium
Stations with bacteria	52%	0%	53%	38%
Stations with well-developed redox layer	0% (of 20)	100%	78% (of 37)	60% (of 5)
Stations with methane	15%	0%	7%	0%
Stations with apparent low dissolved oxygen	74%	0%	22%	0%

2.4.2 Benthic Community Sampling

Sample Size

The number of samples to be collected for benthic community, total organic carbon (TOC), and grain size analyses was determined by considering the methods that would be used to evaluate the data. These methods include both the Bray-Curtis similarity index for cluster analysis and data summary analyses. For cluster analysis, there is no standard statistical method for determining the appropriate number of samples, although larger sample sizes are clearly desirable. For data summaries, the number of samples will affect the precision of estimates. The actual precision could not have been estimated in advance because there was no original estimate of variance. However, to estimate any summary statistics within a stratum, three to five samples should be the minimum number of samples taken in each stratum. Therefore, to define the allocation scheme of samples among the strata, the sample size in the smallest stratum was set to three.

Sample Allocation

To allocate samples to strata in an optimal way, an estimate of variance, or at least relative variance among strata, for the variable of interest is required. The strata with the most consistent SPI results were Stratum 1 (uniformly poor conditions) and Stratum 2 (uniformly good conditions). However, there were no previous data on benthic community variables available for the study area. Therefore, the only defensible position for baseline sampling was to conduct proportional sampling in the first year. In future sampling efforts, the sample size should be determined based on the relative variances between strata and the planned statistical analyses. Although equal sample sizes are desirable in year 1 vs. other years, they are not necessary for valid analyses.

The monitoring plan (Foster Wheeler 1998) proposed a proportional sampling scheme based on the number of grid points within each of the seven proposed strata defined by water depth and wood waste thickness. The number of samples was then reduced in the largest strata to achieve a lower overall sample size. In addition, sampling was proposed at the same grid locations used for Tier 1 sampling. If there were too few grid points within a given stratum, simple random sampling was to be used.

Because the samples taken during the Tier 2 sampling would be used to draw conclusions about the entire area within stratum boundaries, EVS proposed a modified design. Strata would be sampled in proportion to their area, with a random start point and the grid size determined by the number of samples required in each stratum.

Table 2-4 displays the results of allocating benthic community samples proportional to stratum area. The total number of benthic community samples proposed for the Tier 2 survey within the AOC and approved by DEC was 37, based on the requirement of three samples in the smallest stratum, i.e., $3 \div 0.08 = 37$.

Table 2-4. Proportional sample allocation

Stratum	Approximate Area (acres)	Proportion of Total Area	Proportional Sampling
1	25	0.28	10
2	12	0.13	5
3	46	0.51	19
4	7	0.08	3

Station Selection

In order to provide adequate coverage of each stratum, systematic (grid) sampling was used with a random start point within each stratum. Systematic sampling achieved the desired results of spatial coverage and simplicity without sacrificing the statistical benefits of simple random sampling. Figure 2-30 displays a grid layout formed with random start points in each stratum that achieved the sample sizes within each stratum shown in Table 2-4.

2.4.3 Sediment Chemistry Sampling

The monitoring program originally designated eight composite sediment samples to be taken for chemical analysis, which was later modified to eight discrete samples (see Section 1.4). Based on the stratum definition results presented above, five of the eight sampling locations were chosen within Stratum 1, the area with the poorest conditions (Figure 2-30). The sampling stations chosen were those sampled during the RI that also showed the poorest conditions. The remaining three stations were chosen from Stratum 4 because of the unknown conditions in this area. These stations are co-located with the benthic community sampling locations. DEC determined that sediment chemistry sampling was unnecessary in Strata 2 and 3 because the Tier 1 results indicated either healthy or transitional benthic communities (DEC 2000).

3.0
TIER 2 STUDY

3.1 METHODS

3.1.1 Benthic Sampling and Analysis Methods

Collection of sediment samples for benthic community and chemistry analyses was conducted from August 5 to August 10, 2000, aboard the M/V *Raven's Fire*. The cruise report for this sampling event is included in Appendix C. Samples were collected using a van Veen bottom grab sampler according to Standard Operating Procedure (SOP) 6 for benthic community sampling and SOP 5 for sediment sampling presented in Appendix B of the monitoring plan (Foster Wheeler 1998).

Modifications to SOP 6 included the identification to family level rather than to the lowest taxonomic level possible. External verification and quality assurance/quality control of the data were not required because discrepancies in identification were not encountered at the family level. Although not described in SOP 6, wet-weight biomass measurements were taken for each major taxonomic group at each station. These measurements were performed by removing the organisms from their vials and blotting them on absorbent paper. After air-drying for five minutes, their weights were recorded in grams.

A total of 37 sediment grab samples were collected for benthic community analysis. At these same stations, sediment grab samples were collected for analysis of total organic carbon and grain size. Eight sediment samples were collected for analysis of total sulfides, BOD, COD, and ammonia. Five of these samples were collected from Stratum 1 at historical RI stations. The remaining three samples were collected from co-located sediment grab stations in Stratum 4. The sampling locations and station numbers are depicted on Figure 3-1, and station coordinates are included in Appendix D.

3.1.2 Statistical Methods

A cluster analysis of the benthic community data was performed to classify stations into groups. The objective of cluster analysis is to group stations such that stations within groups are similar and stations in different groups are dissimilar. Cluster analysis is an exploratory technique that requires little or no assumptions about the data to provide insight into the data structure. Once a similarity measure has been found to be appropriate for a particular data type, e.g., the Bray-Curtis similarity metric for benthic abundance data, alternative cluster results based on different clustering algorithms can be reviewed to determine which one makes the most sense. During the exploratory stage, several clustering algorithms were used, including the model-based algorithm partitioning around medoids and several hierarchical algorithms using average and compact linkage. The cluster results reported in Section 3.2 are based on the compact link method, also known as the farthest neighbor method. Compact linkage is known as an "agglomerative" method, which starts out with each station in a separate group. At each stage the two most similar clusters are combined to form one bigger cluster. For the compact linkage method, the distance between two clusters is the largest distance between a point in one cluster and a point in the other cluster.

The cluster analysis requires a measure of distance to describe the similarity between any two stations. The Bray-Curtis distance metric of the abundance data was used to describe the similarity between stations; this metric is considered to be the most robust and powerful metric for abundance data (Faith et al. 1987; Faith et al. 1991). The Bray-Curtis similarity metric cannot be used to compute similarity between two stations that have zero for all of the variables; this results in division by zero. Several stations had abundance values of zero for all of the seven numerically dominant families. Consequently, the similarity matrix for the second cluster analysis was based on the abundance values for these seven families plus a value of one.

3.2 RESULTS

3.2.1 Benthic Results

At the 37 stations, a total of 3,543 individuals were found, belonging to 62 families in 3 phyla. Of the three phyla, annelids were the most abundant group present, representing 75 percent of the total abundance and 89 percent of the total biomass. Molluscs represented 23 percent of the total abundance and only 10 percent of the total biomass. Arthropods were the smallest group, representing 2 percent of the total abundance and less than 1 percent of the total biomass. The full dataset of taxa recorded in each grab sample is presented in Appendix F and summarized in Table 3-1.

Table 3-1. Summary of taxa recorded in the 37 grab stations in Sawmill Cove

PHYLUM	TOTAL NUMBER OF FAMILIES IDENTIFIED	TOTAL NUMBER OF INDIVIDUALS RECORDED	TOTAL BIOMASS (g)
Annelida	28	2,667	50.2
Arthropoda	11	63	0.3
Mollusca	23	813	5.7
Total	62	3,543	56.2

Most animals sampled were identified to family level, with the exception of a large number of molluscs (515 individuals, or 63 percent of the total molluscs) that could not be identified to family level. The majority of these individuals, designated simply as

"Bivalvia," were either organisms that were in poor condition or juveniles, e.g., shells not yet developed; therefore, they lacked many of the required diagnostic features used to identify them to lower taxonomic levels. The numerous pieces of wood debris in the samples provided an additional surface and acted as a finer screen to retain many of these small juveniles, which otherwise would have passed through the 1-mm sieve used to process the sediment samples. It is likely that this group of 515 individuals represents a proportional distribution of the numerically dominant molluscan taxa that were identified to the family level.

The mean total abundance is very similar across strata (Table 3-2), with the highest mean abundance in Stratum 2. However, the group of unidentified bivalves noted above accounted for a large percentage of the animals counted in Stratum 2 stations and one station in Stratum 3 (Station 3-15). These animals markedly increased the total abundance with little measurable increase in the total biomass. The variability of total abundance among stations within each stratum is high, suggesting that these strata identified from the video/SPI survey in April may not coincide with homogenous benthic community types. Figure 3-2 shows stations by location with abundance categories, and Figure 3-3 shows stations by location with biomass categories. The stations that consistently had data in the highest abundance and biomass categories were Stations 1-1, 1-2, 1-5, 1-10, 2-3, 2-4, 3-2, and 4-1.

Table 3-2. Summary of benthic grab survey results by stratum

	Stratum 1 (n=10)	Stratum 2 (n=5)	Stratum 3 (n=19)	Stratum 4 (n=3)
Mean total abundance (count/m^2 ± SD)	965 ± 1094 959 ± 1084[a]	1656 ± 625 962 ± 533[a]	769 ± 664 684 ± 568[a]	987 ± 838 987 ± 838[a]
Mean total biomass (grams/m^2 ± SD)	19.5 ± 23.5	10.5 ± 5.32	12.3 ± 12.3	27.0 ± 7.95
Mean taxonomic richness (no. of families per grab ± SD)	7.9 ± 6.8	21 ± 6.6	7.4 ± 4.2	19 ± 8.5

[a] The second row of numbers for total abundance excludes counts of Bivalvia.

Stage I taxa clearly dominated the communities at most stations in Sawmill Cove; however, many species indicative of a more mature community were also present, although in very small numbers. All but six stations (Stations 1-7, 1-9, 3-1, 3-3, 3-4, 3-9) showed the presence of at least one Stage III family. Stations 1-5, 2-3, 3-12, 3-8, 3-11, 3-6, 3-18, 3-13, and 3-7 had the highest densities of Stage III taxa (≥ 200 animals/m^2), representing between 14 and 54 percent of the total abundance at these stations. Station 1-6 had much lower densities, but the Stage III taxa dominated the community; Stage III taxa contributed 57 percent of the 70 individuals/m^2 total abundance. Stations 2-2, 4-1, and 2-5 had the highest density of Stage II taxa (≥ 60 individuals/m^2), representing approximately 5 percent of the total density at each of these stations.

Community succession can also be evaluated by the distribution of abundance across the Stage I, Stage II, and Stage III taxonomic categories (Figure 2-10). As a benthic community becomes more mature, total abundance may decrease while diversity increases (Figure 3-4; Pearson and Rosenberg 1978). To investigate the taxonomic composition, a successional stage was assigned to each of the top 29 numerically dominant families shown in Table 3-3, in decreasing order of dominance. Each of these 29 families accounted for between 0.2 and 26 percent of the total abundance across all stations, and collectively they accounted for greater than 97 percent of the total abundance in all stations. Of these 29 families, 18 families were clearly associated with only one successional stage. The remaining 11 families could not be categorized into a specific successional stage on a family level. This situation occurs when the taxa within a particular family are primarily active predators, e.g., Sigalionidae, that will be present whenever their prey are present, i.e., during all stages of recolonization. Alternatively, for two of the families present (Lumbrineridae and Flabelligeridae), some species within the family are associated with Stage I communities while other species within the same family are associated with Stage III communities; while identification to species would have clarified the successional stage assignment for these two taxa (out of the 29 total dominant taxa), it would not have changed the outcome of the overall interpretation or the discrimination of community types by cluster analysis (see below). For the 18 families that can be clearly associated with either Stage I, II, or III community types, the relative distribution among these taxa is shown using pie charts (Figure 3-5). The size of the symbol at each station indicates the total abundance category for that station.

A more thorough review of the complete community composition at each station was done using cluster analysis. A cluster analysis of the Bray-Curtis metric of family abundance data was used to examine assemblage similarities among stations. Cluster analysis provides a visual summary of the results in a tree-like diagram called a dendrogram. Once distinct groups of stations have been identified using the cluster analysis, values for the distinguishing variables can be summarized to help identify what is causing the differences among, or similarities within, station groups.

The first cluster analysis was performed based on the Bray-Curtis metric of family abundance data for all 62 families. The dendrogram is shown in Figure 3-6. The analysis resulted in a grouping of seven sets of stations and four distinct stations (Stations 1-3, 1-7, 3-1, and 4-3) at a distance of 0.75. Two stations are notable for their paucity of infauna: Station 1-7 yielded two individuals, and Station 3-1 yielded one individual.

Table 3-3. Abundance, successional stage, and trophic description of the 29 numerically dominant families present at Sawmill Cove

Family	Total Count	Cumulative Percentage[a]	Successional Stage	Comment
Chaetopteridae[b]	908	25.6	I	Mucous net suspension feeders or surface deposit feeders
Capitellidae	825	48.9	I	Classic opportunists/pollution indicators; high density tubicolous worms; tolerant of low dissolved oxygen
Bivalvia	515	63.4	NA	Bivalve larvae unidentifiable to family level
Sigalionidae	224	69.8	All stages	Active predators, not tubicolous; feed on all polychaetes; will be present during all successional stages
Thyasiridae	170	74.6	III	Burrowing molluscs
Lumbrineridae	113	77.8	I or III	Errant (no tubes); either carnivores or sub-surface deposit feeders
Ampharetidae	105	80.7	I	Surface deposit feeders; can get up to densities of 5,000/m²
Nephtyidae	74	82.8	III	Errant deposit feeders
Lucinidae	54	84.3	III	Burrowing molluscs
Spionidae	53	85.8	I	Surface deposit feeders
Phyllodocidae	45	87.1	All stages	Active predators; feed on all polychaetes; will be present during all successional stages
Dorvilleidae	43	88.3	I	Free-living algae eaters
Cirratulidae	34	89.3	I	Pollution-tolerant surface deposit feeders
Goniadidae	29	90.1	II or III	Errant carnivores
Oweniidae	29	90.9	I	Suspension or surface deposit feeders
Polynoidae	26	91.6	All stages	Active, errant predators; feed on all polychaetes; will be present during all successional stages
Syllidae	26	92.4	None	Hard bottom species; feed on hydroids and bryozoans (attached to logs or large wood particles)
Nereidae	25	93.1	III	Errant omnivores
Flabelligeridae	23	93.7	I or III	Motile surface deposit feeders (Stage I genera) or commensals (Stage III genera)
Dexaminidae	19	94.3	II	Gammarid amphipods
Amphictenidae	17	94.8	III	Subsurface deposit feeders
Polyodontoidae	16	95.2	All stages	Active predators, errant scale worms; feed on all polychaetes; will be present during all successional stages
Terebellidae	14	95.6	III	Large detritus feeders; usually present in Stage III assemblages
Scaphopoda	14	96.0	III	Tooth shells; burrowers, feed on Foraminifera
Phoxocephalidae	14	96.4	II	Amphipods
Glyceridae	11	96.7	III	Large predatory carnivores; usually only in Stage III assemblages
Columbellidae	11	97.0	None	Gastropods; epifauna
Ampeliscidae	8	97.2	II	Tubicolous amphipods; suspension or surface deposit feeders
Hesionidae	7	97.4	II and III	Carnivores and interstitial detritus feeders

[a] Cumulative percentage of abundance for dominant families at all stations.
[b] The first seven numerically dominant families are shaded, indicating that the data for these families were used in analyses based on dominant families.

The second cluster analysis was performed using the Bray-Curtis similarity metric of family abundance data for only the seven numerically dominant families. The dendrogram for this analysis is shown in Figure 3-7. This analysis resulted in a grouping of six sets of stations at a distance of 0.67. A comparison between the two cluster results provides information about how well the seven dominant families distinguish the stations based on community type. Five of the original groups in the first cluster analysis are retained in the reduced cluster analysis. The remaining two original groups along with the four distinct stations are combined into one coherent group to form the sixth group in the reduced cluster analysis. These results indicate that the community types for the 28 stations in the original five groups are predominantly defined by the seven numerically dominant families. The remaining nine stations (Group 1 in Table 3-4) are relatively distinct due to small differences in one or more of the minor families.

Table 3-4. Station allocation from cluster analysis of benthic family abundances for the seven numerically dominant families

	STATION NUMBER
Group 1	1-3, 1-6, 1-7, 3-1, 3-4, 3-5, 3-9, 4-2, 4-3
Group 2	1-8, 3-2, 3-3, 3-6, 3-10, 3-11
Group 3	1-4, 1-9, 3-14, 3-16, 3-17, 3-18, 3-19
Group 4	2-1, 2-2, 2-3, 2-4, 2-5, 3-15
Group 5	1-1, 1-2, 1-5, 1-10, 4-1
Group 6	3-7, 3-8, 3-12, 3-13

The key features of the groups are as follows (Table 3-5):

- Group 1 had the lowest abundance of Stage III taxa (mean density of 24/m^2); and the lowest overall abundance (mean density of 190/m^2). Both richness and biomass levels were low.

- Groups 2 and 5 had relatively high total abundance (mean densities of 1,140/m^2 and 2,090/m^2). These stations were dominated by Stage I taxa (mean densities of 1,000/m^2 and 1,670/m^2) but did have a moderate presence of Stage III taxa (mean densities of approximately 108/m^2). The two groups are distinguished from one another by the presence of Stage II taxa at low densities in Group 5 (and totally absent in Group 2) and by the dominance of different Stage I families (Group 2 was dominated by capitellids and Group 5 was dominated by chaetopterids). Group 5 has the highest biomass of all groups, dominated by the annelid family Chaetopteridae.

- Group 3 had moderate total abundance (mean density of 490/m^2), moderate Stage III taxa (mean densities of 96/m^2), and moderate richness values.

Table 3-5. Mean values of benthic community endpoints for the cluster analysis groups shown in Table 3-4

	Abundance (counts per m²)				Taxon Richness (no. of families per station)				Biomass (grams per m²)			
	Annelids	Molluscs	Arthropods	Total Abundance	Stage I Taxa	Stage II Taxa	Stage III Taxa	Total Richness	Annelids	Molluscs	Arthropods	Total Biomass
Group 1	160	26	4	190	100	0	24	6	6.8	0.9	0.1	8
Group 2	1,070	68	2	1,140	1,000	0	108	6	9.6	1.1	0	11
Group 3	400	90	0	490	290	0	96	8	17.0	0.8	0	18
Group 4	760	907	60	1,730	330	43	117	20	9.8	2.8	0.1	13
Group 5	1,950	106	36	2,090	1,670	30	108	16	37.2	2.5	0.2	40
Group 6	430	223	10	660	180	0	253	10	4.7	2.2	0.1	7

NOTE: na - not available

- Group 4 had high total abundance (mean density of 1,730/m^2), and high richness. Both Stage I and Stage III taxa were present in moderate densities, and Stage II taxa were present at low densities.

- Group 6 had the highest abundance of Stage III taxa (mean density of 250/m^2) and moderate total abundance (mean density of 630/m^2).

Figure 3-8 shows the spatial distribution of these station groups. While at first glance these station groups may appear to be a more heterogeneous pattern than the original groupings outlined in the Tier 1 strata, a functional analysis of trophic relationships within these groups shows much more spatial coherence (see Section 4).

3.2.2 Sediment Characteristics

Sediment TOC results are listed in Table 3-6 and presented on Figure 3-9. The TOC results show that most of the sediment in the AOC is highly enriched with organic material. Over 78 percent of the samples had TOC concentrations of 15 percent or greater. While these results are not surprising given the large quantities of decomposing wood pulp and fibers present in the AOC, they do represent extreme organic enrichment. Average concentrations for marine shelf sediments are between 1.5 and 2 percent (Tyson and Pearson 1991), and any amount over 4 percent is considered enriched (Purdy 1964). Most of the stations with TOC greater than 25 percent were situated along the shore of the cove closest to former mill activities (Figure 3-9). The grain size data are listed in Table 3-6. These data show the particle size distribution of material, which in this case is composed largely of wood fibers rather than sedimentary material; the gravel- or sand-sized particles for the most part do **not** represent gravel or sand grains. The grain size distribution of the material from any particular location within Sawmill Cove is largely a function of the size of wood particles present and the state of their decay. In general, the size distribution of these organic particles was fairly broad, reflecting the wide range in wood particle size seen in the sediment profile images.

Sediment chemistry results for the eight samples analyzed for total sulfides, BOD, COD, and ammonia are shown in Table 3-7. The sample from Station SWSDD13X contained the highest concentrations of ammonia and sulfides, and the highest BOD. This same station had the highest concentration of ammonia and the highest BOD and COD during the RI (Foster Wheeler 1998). Five stations sampled in 1996 for the RI were re-sampled as part of this baseline monitoring. A comparison of the historical and current data is shown in Table 3-8.

Table 3-6. Sediment TOC and grain size results

	Grain Size			
Station ID	>2 mm (coarse)	0.063-2 mm (medium)	<0.063 mm (fine)	TOC (%)
SC1-1	28.7	42.9	28.4	15
SC1-2	21.5	48.4	30.0	28
SC1-3	24.0	64.8	11.3	21
SC1-4	29.9	47.5	22.6	26
SC1-5[a]	1.3	72.2	26.5	5.3
SC1-6	31.5	36.8	31.7	32
SC1-7	21.2	52.1	26.7	31
SC1-8	26.7	43.6	29.7	32
SC1-9	22.5	41.6	36.0	31
SC1-10	27.7	47.1	25.2	32
SC2-1	12.2	58.9	28.9	15
SC2-2	15.8	59.0	25.2	12
SC2-3	26.0	50.0	24.0	8.8
SC2-4	19.0	51.2	29.8	9.5
SC2-5	9.2	58.9	31.9	21
SC3-1	14.7	55.9	29.4	18
SC3-2	35.3	32.1	32.6	15
SC3-3	28.4	37.2	34.4	21
SC3-4	11.0	55.3	33.8	17
SC3-5	22.8	43.9	33.3	12
SC3-6	7.6	53.4	39.0	14
SC3-7	11.3	54.4	34.3	16
SC3-8	15.8	56.3	27.8	19
SC3-9	44.4	29.7	25.9	22
SC3-10	45.6	33.9	20.4	21
SC3-11	20.8	55.1	24.2	20
SC3-12	19.2	47.7	33.1	26
SC3-13	15.0	41.4	43.5	19
SC3-14	14.1	46.2	39.7	14
SC3-15	10.5	65.8	23.7	22
SC3-16	16.5	60.1	23.4	24
SC3-17	21.5	53.2	25.3	25
SC3-18	12.6	41.7	45.7	20
SC3-19	40.1	27.0	32.9	20
SC4-1[a]	21.5	57.7	20.8	16
SC4-2	36.7	22.7	40.6	22
SC4-3	25.3	44.2	30.4	27

[a] Average of three replicates.

Table 3-7. Sediment chemistry results

Station ID	NH_4 (%)	Sulfide (mg-N/kg)	COD (mg/kg)	BOD (mg/kg)
SC4-1	14	610	130,000	5,000
SC4-2	90	2,600	240,000	10,000
SC4-3	140	4,200	230,000	9,200
Historical stations				
SWSDC4X	60	3,400	200,000	12,000
SWSDD11X	150	3,500	270,000	9,500
SWSDD12X	17	3,200	230,000	9,900
SWSDD13X	210	12,000	260,000	16,000
SWSDD25CX	45	1,600	240,000	7,400

NOTE: BOD - biochemical oxygen demand
COD - chemical oxygen demand

Table 3-8. Comparison of mean values for sediment chemistry at five stations sampled in both 1996 and 2000

Parameter	1996 Value (n=5)	2000 Value (n=5)
Mean total solids (% ± SD)	15 ± 2.4	15 ± 2.0
Mean BOD (mg/kg ± SD)	7,900 ± 2,400	11,000 ± 3,300
Mean COD (mg/kg ± SD)	390,000 ± 160,000	240,000 ± 27,000
Mean N-ammonia (mg/kg ± SD)	140 ± 180	96 ± 81
Mean AVS (mg/kg ± SD)	1,000 ± 1,000	na
Mean total sulfides (mg/kg ± SD)	na	4,700 ± 4,100

NOTE: na - not analyzed
AVS - acid volatile sulfide
BOD - biochemical oxygen demand
COD - chemical oxygen demand

4.0
DATA SYNTHESIS AND EVALUATION

Several facts are apparent from this baseline survey. First, the majority of the site would still be classified as organically enriched, given the TOC concentrations found at all the stations. The widespread distribution of sulfur-reducing bacterial colonies (Figure 2-28) that thrive in low-oxygen environments is further evidence of the widespread organic enrichment. However, one of the most surprising findings from the video survey was the widespread distribution of secondary consumers in the form of epifaunal foragers (shrimp, crabs, fish) throughout the entire AOC, even in areas where high SOD and dense bacterial colonies were present. These foragers would not be present throughout the area (Figures 2-7 through 2-9) if dissolved oxygen in the water column were below a critical threshold (2-3 mg/L; Diaz and Rosenberg 1995) or if there were not sufficient prey items (benthic infauna) to attract them (confirmed by the grab sampling results; see Figure 3-5). Therefore, while SOD is inferred to be quite elevated from the evidence presented in the sediment profile images (Figure 2-16), the low oxygen concentrations most likely do not extend much beyond the sediment-water interface or benthic boundary layer. This was confirmed by actual near-bottom dissolved oxygen measurements carried out in August during the impaired waters survey done for DEC (EVS 2000e).

4.1 THE EFFECTS OF WOOD WASTE ON BENTHOS

A variety of studies have looked at the effect of bark or wood waste accumulation on benthic communities (Pearson 1972, 1975; Pease 1973; Walker 1974; Conlan 1977; Conlan and Ellis 1979; Waldichuk 1979; Kathman et al. 1984; Elliott 1986; Jackson 1986; EVS 1992; Kirkpatrick et al. 1998). Pearson (1972, 1975) was one of the first investigators to document the impacts of organic enrichment from pulp mill effluents and fiber on benthic communities. His findings that “a complete fibre blanket” can have drastic effects on population structure, sometimes resulting in the complete elimination of macrofauna, have been corroborated by other investigators (Pease 1974; Jackson 1986; Pearson and Rosenberg 1978; this investigation). Other reported effects include reduced diversity of epifauna (Conlan and Ellis 1979; Kirkpatrick et al. 1998), reduced fitness and survival of bivalves (Freese and O’Clair 1987), and reduced fecundity of Dungeness crab (O’Clair and Freese 1988). While claims have been made that impacts of bark accumulation should not be as severe in water deeper than 20 m (CH_2M Hill 1982), preliminary evidence gathered by Kirkpatrick et al. (1998) indicates that impacts on benthic community structure similar to those documented in shallow water (< 20 meters) do exist. Other investigators have documented a loss of suspension feeders and increased abundance of deposit feeders with increasing accumulations of bark deposits (Conlan 1977; Kathman et al. 1984; Jackson 1986). Some investigators have postulated that bark deposits may preclude successful settlement of viable marine larvae (McDaniel 1973; Schultz and Berg 1976) and that bark-laden deposits may persist or remain devoid of macrofauna for several decades (Pearson 1972; Conlan and Ellis 1979; Kurau 1975; Freese et al. 1988).

This study has provided valuable additional information about the response of benthic communities to disturbances from wood waste deposition that adds to the existing body of published knowledge. In contrast to some published concerns of sites of this type remaining devoid of macrofauna for several decades, the majority of the stations are showing the classic response of high densities of opportunistic Stage I polychaete assemblages (Figure 2-20 and Figure 3-5). There is no doubt that, as with any seafloor disturbance in the marine environment, the deposit did have a substantial, measurable impact on the benthic community that very much follows the predictions originally outlined by Pearson and Rosenberg (1978) in their classic paper on organic enrichment. While overall pooled results show that benthic abundance and biomass values are comparable to sites both with and without wood waste (see next section), there are stations that still show the negative effects of the wood deposit as reflected in extremely low faunal abundance and diversity; Stations 1-6, 1-7, 3-1, and 3-9 had fewer than 10 individuals in the total grab sample. The depths of the stations sampled range from 13 to almost 70 meters, supporting Kirkpatrick et al.'s (1998) observations that adverse impacts to benthic communities do occur in deeper-(> 20 meters) as well as in shallow-water environments. There does not appear to be a reduced diversity of epifauna from the video observations both outside and inside the site (if anything, just the opposite effect because of the availability of prey items within the site for epibenthic foragers).

The observed pattern of juvenile bivalves in collected samples provides some anecdotal evidence to corroborate the observations about reduced fitness of bivalves or survival of viable larvae (McDaniel 1973; Freese and O'Clair 1987). While the abundance numbers of unidentified bivalves were high enough to rank it as one of the dominant taxonomic groups, it was notable that the high densities of these organisms occurred **only** at those stations along the southern and eastern perimeter of the site (Stations 2-1 through 2-5 and 3-15). At the SPI stations in the vicinity of these locations, wood fibers were either not detected or, if wood fibers were present, the top layer of the sediment was oxidized with an apparent RPD in excess of 2 cm. Even though one could argue that these results provide good support for Freese and O'Clair's (1987) findings because bivalve larvae should be settling over the entire region sampled, these results are considered anecdotal because the sieve size used to process the benthic samples (1-mm) is not one designed to capture larvae (Reish 1959; McCall 1975; Germano 1983).

4.2 COMPARISON WITH OTHER REGIONAL BENTHIC SURVEYS

The overall mean abundance recorded from the Sawmill Cove study site is comparable to data collected from other southeast Alaskan embayments from which significant amounts of chemical contamination are absent. A benthic community survey was conducted in Ward Cove, Alaska in 1992 to assess the environmental impacts of organic enrichment of wood waste from the Ketchikan Pulp Company (EVS 1992). That survey found stations at 18-m and 37-m water depths to be organically enriched with TOC levels ranging from 14 to 37 percent. Total abundance values ranged from 510 to over 10,000 animals per m^2. At these stations, molluscs and arthropods were rare; polychaetes and nematodes were the dominant taxa. Mean richness values (identified to species) per station ranged from 2 to 13, markedly lower than the richness values (identified to family) in Sawmill Cove stations in Strata 2 and 4, which ranged from 13 to 29. Biomass values at the Ward Cove stations ranged from 0.9 to 39 grams/m^2, with a site-wide grand mean of 16 g/m^2. Sawmill Cove stations displayed similar biomass values ranging from 0.1 to 59 g/m^2, with a site-wide grand mean of 15.2 g/m^2.

A benthic survey performed in Port Valdez in 1971–1972 by Feder and Mueller (1977) provides data on community types expected for a southeast Alaskan embayment that also lacks the extensive organic enrichment that is present in both Ward Cove and Sawmill Cove. From the December 1971 survey, total abundance values ranged from 60 to 1,223 animals/m^2, and biomass values ranged from 9.3 to 59 g/m^2. Richness values (again, identified to species) ranged from 11 to 28 per station. The dominant taxa included *Nephtys, Heteromastus*, *Lumbrinereis*, and *Melinna* spp. The spatial heterogeneity of the benthic community was very high. There was insufficient information provided in this report regarding physical or chemical features at the stations; otherwise, depth and TOC levels may have helped to explain some of the observed spatial patchiness of the benthic community. Even though these abundance and richness numbers are comparable to those found in Sawmill Cove, one must proceed with caution with comparisons of this type. Aside from the three decades separating this Port Valdez study from the present investigation, the Valdez study was also carried out in a different season (December vs. August). Other benthic investigations in southeast Alaskan fjords (Winiecki and Burrel 1985) found that abundance levels decreased and richness levels increased during the winter months, indicating that seasonal variability should be taken into account when attempting comparisons of benthic surveys in southern Alaska.

4.3 INTEGRATION OF TIER 1 AND 2 SAMPLING

Combining the information from the towed video, SPI survey, and benthic grab results gives us an integrated, comprehensive picture of benthic conditions and highlights what modifications should be made to monitor recovery within the AOC during future sampling efforts. While the towed video results allowed us to get a large-scale sense of seeing "the forest from the trees", it also had some notable limitations. The limited visibility due to high suspended material concentrations in the water column—both sediment and abundant floccular phytoplankton detritus—restricted our ability to detect many of the features being measured; it also required the camera to be closer to the bottom, limiting the field of view to a width of 0.5–1 m. Because of this, the measurements of wood, epifauna, and bacterial mats were underestimates of undetermined magnitude. While the resolution of the SPI camera is on a scale of one to two orders of magnitude smaller (centimeters to millimeters) than the video (meters) and would never be able to detect motile epifauna or the presence of large logs in other than an accidental encounter, it did provide a good "ground-truth" verification for the presence or absence of bacterial mats. While the video survey detected bacterial mats in 24 percent of the area surveyed, the SPI camera detected bacterial mats in 46 percent of the area surveyed, i.e., the video camera underestimated the presence of bacteria by almost 90 percent. Because of the difference in size range of detectable wood, the comparison of video to SPI for efficacy of detecting presence/absence of wood waste is even more dramatic: the video only detected wood in 0.57 percent of the area surveyed, whereas the SPI camera found evidence of wood fibers at 91 percent of the area surveyed. There is no independent evidence for comparable comparison of motile epifauna, but chances are that the area of the AOC being utilized by epifauna is substantially greater than the 23 percent estimated from the video survey.

The widespread layer of phytoplankton detritus over the entire site has important implications for the recovery rate of the benthic community. The contribution of primary production blooms to near-bottom oxygen demand is a well-known phenomenon (Hargrave 1972; Waite et al. 1992). The surface layer of phytoplankton detritus was always associated in the sediment profile images with the presence of sulfur-reducing bacterial colonies, indicating boundary-layer dissolved oxygen levels in the "hypoxic" range between zero and 1 ml/L (Rosenberg and Diaz 1993). This clearly represents another source of disturbance in the form of organic enrichment to the benthic community within the AOC. The seasonal inputs of excess organics from the spring and fall plankton bloom, which are part of the natural seasonal ecosystem cycle, will promote and prolong the stressed conditions within the AOC. While the area is already suffering from organic enrichment, the majority of the organic carbon is most likely in a highly refractory state at those stations where the particle size is large (> 2 mm; see Table 3-6). However, at those stations where the wood waste has decomposed to more of a "powdery" state (particle size in the fine-sand to silt-clay range), the organic carbon is likely in a more labile form; communities at these locations will probably react to the stress of the seasonal organic pulses of plankton die-off and sedimentation either by retrograding to or remaining in a Stage I community (Pearson and Rosenberg 1978; Rhoads and Germano 1986; Rosenberg and Diaz 1995).

The SPI camera proved to be an effective remote sensing tool to map the overall gradients in benthic community structure. If one views the benthic community results from the grab samples as "ground-truth" confirmation of the infaunal community gradients mapped by the profile camera, the camera appeared to be a slightly more conservative yardstick of benthic community recovery, taking into account the sediment "habitat quality" (depth of RPD, presence of methane) as well as apparent infaunal successional stage. In other words, the results from the benthic grab samples on their own show a more advanced recovery status than one would infer from the SPI images on their own. For example, 17 percent of the SPI images were classified as "azoic"; however, while no grab samples were actually azoic (i.e., all had at least one animal in them), 10 percent of the grab samples (Group 1 in the cluster analysis) had between one and seven very small individuals in them—not that much different from an "azoic" classification. The stations considered "fully recovered" by the SPI analysis (OSI values greater than +6; see Figure 2-27) or successional assemblages in the Stage II to III range (see Figure 2-20) were almost identical, comprising 20 percent and 18 percent of the total number of stations surveyed. The grab results showed 33 percent of the stations to be in transition between a Stage I and Stage III community (Groups 3 and 5 in the cluster analysis) and 27 percent of the stations to be primarily a Stage III community (Groups 4 and 6 in the cluster analysis). The geographic regions of the "stressed" and "recovered" stations according to the SPI and benthic grab do coincide with one another; it is the adjustment of the outer boundaries that would be slightly different.

While the gradient mapped by the SPI results in the first tier of sampling divided the area into four strata representing various stages of recovery, the results of the benthic grab samples combined with the SPI results show that the AOC can be divided into three strata based on benthic ecosystem recovery (Figure 4-1). Stratum 1 consists of cluster Groups 1, 2, and 5, representing the area most stressed that is just starting recovery. Group 1 represents stations with the lowest faunal abundance, Group 2 represents stations primarily with a Stage I assemblage, and Group 5 has Stage I taxa dominating with some transitional deposit-feeding taxa appearing. The SPI stations in this stratum have an overall mean apparent RPD of 1.02 cm and a median OSI value of -0.5.

Stratum 2 consists of cluster Groups 3 and 6 and represents those stations where deposit-feeding infauna are present, recovery is beyond just a Stage I assemblage with some high abundances of Stage III taxa, but the overall faunal abundances are on the low side and the sediment still has high SOD. The SPI stations in this stratum have an overall mean apparent RPD of 4.89 cm but a median OSI value of 5.

Stratum 3 consists of cluster Group 4 and represents the area that is fully recovered, with the highest taxonomic richness coupled with the greatest faunal abundance. Stage II and III deposit-feeding taxa are well represented in this group. The SPI stations in this stratum have an overall mean apparent RPD of 2.99 cm and a median OSI value of 9.

5.0
CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

While the AOC is still showing impacts due to organic enrichment (the widespread occurrence of sulfur-reducing bacterial mats, high SOD, high TOC values, presence of methane at depth), there is absolutely no doubt that natural recovery is occurring (Figure 3-5). The first two RAO recovery milestones (Table 1-1) have already been achieved: 81 percent of the site is covered with decomposers (sulfur-reducing bacterial colonies, most likely *Beggiatoa* spp.) (**Milestone 1**), and primary consumers (Stage I polychaetes) were present at all but 2 grab stations and in sufficient densities at 33 (89 percent) of the grab stations sampled (**Milestone 2**). Approximately 16 percent of the AOC (Stratum 3, Figure 5-1) has fully recovered and achieved the final management milestone, and 22 percent of the AOC (Stratum 2, Figure 5-1) is in transition to the final recovery stage with notable abundances of deposit-feeding taxa. Sixty-two percent of the AOC (Stratum 1, Figure 5-1) is still considered seriously impaired in regard to benthic community status.

It is imperative that both CBS and ADEC recognize that the successional progression of soft-bottom infaunal community recovery depicted in Figure 2-10 is not a linear progression that cannot be reversed. This figure is a representation of primary succession, when an azoic substratum where there is no pre-existing community is placed in the marine environment, and no further disturbances occur (Germano 1983). Once any community gets established in an area, there are deviations from this idealized representation, and constant ecosystem recovery is a part of the natural landscape. The recovery process is always occurring because of the frequency of natural disturbances on a wide variety of spatial and temporal scales (Thistle 1981; Sousa 1984; Hall 1994), and secondary succession, or re-establishment of communities in areas where residual fauna still exist, is the rule rather than the exception (Horn 1974; McIntosh 1980). If one monitors any area of seafloor, the results will show a patchwork-quilt pattern of bottom in different stages of successional recovery. In fact, the successional patterns will most likely be on a scale smaller (tens of meters) than one might initially suspect (Rhoads and Germano 1982). As Johnson (1972) stated so aptly, most bottoms represent “relicts of former disasters.” In fact, it is quite possible that there will never be a point when monitoring coincides with the AOC having more than 75~percent of its area ***simultaneously*** covered by a Stage III infaunal assemblage (the final recovery milestone) because of localized or small scale disturbances (physical or biological) that will be constantly occurring. Therefore, what needs to be kept in mind when evaluating the progress of the AOC toward achieving the RAO management milestones is that “full recovery” in an area is really the **capacity** of a mapped region to support a Stage III assemblage; one should not assume that once a Stage III community is established, it is there for eternity. For example, it is quite likely that if the stations in Stratum 3 (Figure 5-1) were sampled next year, some of them might show a Stage I or Stage II assemblage. This does not mean that they can no longer be considered "recovered" because just asreaching the endpoint of the continuum is not an immovable constant, so a temporary retrograde does not represent a permanent condition. Once the SOD is not at a level where only hypoxic-tolerant species can survive (*sensu* Diaz and Rosenberg 1995) and the area has been documented to have had the sediment reworked to a sufficient depth by Stage III taxa at one point in time, then that area should be considered recovered, having achieved the final RAO management milestone.

5.2 RECOMMENDATIONS

As part of the adaptive management strategy agreed to by both CBS and ADEC, sampling efforts can definitely be reduced in future monitoring operations. Our recommendations are outlined in the following sections.

5.2.1 Monitoring Tools

The monitoring tools for future surveys should include a sediment grab (modified Young or van Veen grab), a sediment profile camera, and an underwater video camera. While some sort of larger-scale optical reconnaissance survey method is needed to detect conditions on the sediment surface, our recommendation would be to not use towed video based on our experience at this site. The poor visibility coupled with the number of obstructions on the bottom and steep topographic gradients closer to the shoreline preclude effective data gathering with this technology. We would recommend that a drop video camera be used at the same locations where the sediment profile camera is deployed.

We recommend that future surveys definitely include sediment profile imaging as a reconnaissance tool to map gradients in sedimentary and biological community conditions at the site. Station density should be similar to what we sampled (200-ft intervals), but we would recommend that the number of replicate images at each station be increased to three. The underestimation of stations where Stage III taxa were detected was most likely due to analyzing only one image from each station. Stage III taxa were present at much lower densities than Stage I fauna, and were detected only in profile images by the presence of subsurface feeding voids. If a feeding void is not bisected by the profile camera, then there is no definitive evidence that Stage III taxa are present. We normally recommend making at least three replicate lowerings at each station location to ensure that Stage III taxa can be detected. This would increase on-station time by only one minute and would not represent a significant increase in field costs; some increased costs in the analytical portion of the program would result, but they are minor compared to the costs of analyzing grab samples.

Given the success of SPI technology in mapping out existing gradients in benthic community structure (and if anything, painting a more conservative picture than the grab results did), CBS and ADEC should seriously consider adapting the same recolonization monitoring strategy that the U.S. Army Corps of Engineers, New England Division (NED) has done for its dredged material disposal sites. After repeatedly monitoring recolonization of dredged material disposal deposits using grab sampling and traditional benthic community analyses, NED showed through a series of investigations that the same resource management information could be gathered much more quickly and cost-effectively through use of the profile camera alone (Germano and Rhoads 1984; Germano et al. 1992). Initially, NED continued to take grab samples and just archive them in case anomalous results appeared in the SPI data; eventually they evolved to the point where grab sampling for traditional community analyses was abandoned altogether as part of routine monitoring and reserved as a contingency based on the SPI results; if anomalous recolonization patterns were detected, then grabs would be taken in the area of interest for complete analysis of benthic community structure and sediment chemistry. We would urge CBS and ADEC to seriously consider adapting this same strategy for future monitoring periods, relying primarily on SPI technology to assess benthic community gradients. Not only did the grab results from this baseline survey confirm the gradients detected by the SPI camera as has been shown before in other monitoring programs (Germano et al. 1992; Grizzle and Penniman 1991), it also demonstrated that, if anything, the SPI camera gave a more conservative assessment of the recovery stage than was detected by the grabs. Because of the cost effectiveness of the profile camera compared to the collection and processing costs of grab samples, future monitoring efforts could rely primarily on SPI to assess the status of recolonization and determine if RAO milestones have been reached. If grab sampling is still required by CBS and ADEC, it could be used only on a limited basis to confirm the presence and abundance of Stage III taxa in those areas determined by SPI technology to be fully recovered. Once an area has been determined to have an established Stage III community either by the camera results alone, or by the combined camera and grab results, then that particular sub-area of the AOC would not require sampling during future monitoring efforts.

5.2.2 Sampling Strategy

Any one of three following approaches could be used for the next round of monitoring scheduled to take place in 10 years:

A. Continue the present tiered monitoring design of an initial optical survey (video and SPI) with confirmatory grab sampling for benthic community analysis.

B. Monitor the site with optical methods and take grabs in each stratum; archive grab samples for later benthic community analysis if anomalous or unexpected recolonization patterns emerge from the sediment profile image analysis.

C. Monitor the site with optical methods alone (video and SPI) and assess benthic community recovery through sediment profile image analysis.

If CBS and ADEC select the first option above, we have designed a tiered monitoring approach that will cost-effectively combine the SPI and grab sampling requirements. During the next monitoring phase, we recommend conducting simultaneous benthic, SPI and video surveys to avoid the costs incurred from two mobilizations. The SPI and video surveys can be conducted first and the information reviewed on site. If these real-time surveys indicate that the habitat within an area has reached full recovery and is represented by four or more adjacent benthic stations, then the number of benthic community sampling stations in that recovery area can be reduced. The rationale for this is that a uniformly healthy area indicated by the SPI results will need only a limited number of benthic community results to confirm recovery. If these real-time surveys indicate that the habitat has substantially degraded from that observed during the 2000 survey, then the number of benthic community sampling stations can be similarly reduced. In this case, however, it would be desirable to also collect sediment samples for chemical analysis (total sulfides, ammonia, BOD, and COD in addition to TOC) at all of the proposed stations. Additional information regarding the most likely chemical stressors in the sediments will be more useful than just the enumeration of a depauperate benthic community. This adaptive sampling structure is illustrated in the flow chart in Figure 5-2.

Prior to the 2000 Tier 2 sampling, we developed sampling strata based on physical characteristics (i.e., location and depth) and the Tier 1 results: apparent progress of the biological community (i.e., SPI successional stage and mean apparent RPD depth). The strata boundaries were drawn based on habitat and baseline biological information, with the expectation that stations within each stratum would develop similar communities over time. The enumeration of the benthic communities at stations within these strata were evaluated after the Tier 2 sampling. The combined results indicated that the five stations in the original “Stratum 2” plus Station 3-15 all have achieved the final milestone of benthic community recovery. Consequently, during the next monitoring round, this particular area would not require any sampling.

The grab sampling locations proposed for the revised strata are shown in Figure 5-3. The proposed Stratum 1 has stations that showed during this past year’s sampling efforts either very depauperate assemblages or communities with high densities of opportunistic Stage I taxa. This area is expected to take the longest to recover. Consequently, the sampling density in this area during the next monitoring phase for benthic community and TOC analysis can be fairly limited. As stated previously, we would emphasize that the sampling density for SPI stations be the same as for this baseline sampling effort (200-ft intervals) in both Stratum 1 and Stratum 2.

The proposed Stratum 2 has community types that appear to be in transition between Stage II and Stage III communities and are expected to be at or near recovery during the next monitoring phase. At that time, ADEC will need to be confident that this area can be considered recovered, so sampling in this area for benthic community and TOC analysis should be at the greatest intensity.

The number of benthic samples to be collected in each location was determined subjectively. There are no statistical decision criteria being computed that we could use to calculate what a “statistically sufficient sample size” would be. The primary sampling to characterize this area will be done by the sediment profile camera, using it as a remote-sensing tool to map the distribution of benthic communities on the AOC seafloor. The grab samples would represent “ground-truth” verification of the benthic community gradients mapped by SPI technology. The sample allocation was simply weighted in favor of a greater density in the transitional Stratum 2, because of the expectation that this area will be next to recover and will subsequently be removed from any future benthic community sampling. We subjectively chose a sample size of 10 in each of the two proposed strata, for a total sample size of 20 for benthic community sampling. Using systematic sampling with a random start, we placed 10 samples in Stratum 2; a separate systematic sample with a random start and a larger grid size was used to placed 10 samples in Stratum 1 (Figure 5-3). Latitude and longitude in decimal degrees for these new locations are provided in Table 5-1.

If ADEC and CBS choose the first option listed above, we would envision that in each future monitoring phase, the data from the benthic community analyses and the SPI results will be evaluated using cluster analysis. This exploratory tool will help identify groups of similar and contiguous stations that can be identified as a recovered, mature assemblage; a transitional, deposit-feeding assemblage; or a pioneering, opportunistic assemblage. We recommend that once an area has been shown to be recovered sufficiently to support a Stage III community, the requirement for future monitoring should be eliminated. Over time, the area that will require benthic community sampling will diminish. At some point in the future there will be too few data points for the cluster analysis on the benthic community data to provide sufficient information as a rule of thumb, it is desirable to have at least twice the number of observations as the number of variables. At that time, the data interpretation step may not include a cluster analysis or may be limited to a cluster analysis of the SPI variables alone. At that time, the determination of complete recovery will be based on SPI results.

Table 5-1. Proposed grab sampling stations

STATION ID	LONGITUDE	LATITUDE	STRATUM
1-1	-135.23047	57.04475	1
1-2	-135.22808	57.04475	1
1-3	-135.23046	57.04345	1
1-4	-135.22807	57.04345	1
1-5	-135.22568	57.04346	1
1-6	-135.23045	57.04215	1
1-7	-135.22806	57.04215	1
1-8	-135.23283	57.04084	1
1-9	-135.23521	57.03953	1
1-10	-135.23520	57.03835	1
2-1	-135.22634	57.04187	2
2-2	-135.22490	57.04187	2
2-3	-135.22778	57.04108	2
2-4	-135.22634	57.04108	2
2-5	-135.22489	57.04108	2
2-6	-135.23211	57.04028	2
2-7	-135.23067	57.04029	2
2-8	-135.22922	57.04029	2
2-9	-135.22778	57.04029	2
2-10	-135.23239	57.03949	2

If CBS and ADEC opt for the second approach listed (grabs taken but archived), then we would recommend following the same strategy outlined above for both the number and location of SPI, video, and grab sampling stations. The costs for sediment chemistry would still be incurred, because these samples would need to be analyzed instead of being archived (BOD and COD samples should be analyzed immediately, and freezing is not recommended for grain size samples). The grab samples would be sieved and preserved, and the samples would be sorted for taxonomic identification only if there were equivocal results from the determination of infaunal successional stage from the SPI analysis, e.g., camera prism over-penetration at the majority of stations in any region preventing accurate assessment of successional stage. If successional stage or recovery status is apparent from the sediment profile images, then there would be no need to incur the expense of sorting and identifying the benthic samples.

A decision on CBS' and ADEC's part to use the last approach and eliminate the grab sampling as part of the program would not change the suggested number or location of SPI stations. It would just require that the SPI/video survey be performed at a time of year when there is the maximum likelihood of successful image acquisition (e.g., July/August time frame when there is no plankton bloom to obscure the video survey and water temperatures would be approaching their maximum for measuring the benthic community when invertebrate metabolic rates are at their highest). Care should be taken to insure the sampling platform has a winch with sufficient control to minimize the occurrence of camera prism overpenetration so that an adequate image is obtained at each sampling location to insure a thorough assessment of the strata being sampled. This can occur if sufficient time is allowed for the field sampling, with investigators examining the images from each day's efforts before starting the next day's sampling to see which sampling locations would require changes in the camera configuration (adjustment of ring stop collars, or addition of doors to the base frame to increase the bearing surface). If proper profile images (no under- or over-penetration) are obtained from each station, infaunal successional stage can be assessed for each location.

On a final note, our prediction would be that the areas closest to the shoreline within the AOC, where the reservoir of organic material is the greatest, will most likely take the longest time to recover. These shallower areas will be more subject to other forms of natural physical disturbance such as wind, waves, and storm energy, promoting out-gassing of any methane build-up in the sediments and keeping the benthic community in an early stage of recovery for a longer period of time. There is no doubt that natural recovery will take place within the AOC; the unknown variable is the time that this will take. The site will have achieved the final RAO milestone when more than 75% of the area has demonstrated the capacity to support (i.e., documented the occurrence in that location at least once) a mature, equilibrium benthic community. The original estimate of 40 years to achieve this goal that was put forth in the RI was based on professional judgment and not on any long-term monitoring data from similar sites. Without any active resource management activities to promote aeration of the bottom sediments, it is possible that recovery in certain areas of the AOC may take longer than 40 years; however, the area over which a longer time frame is necessary for recovery may still be less than 25% of the overall area of the AOC. Similarly, the next monitoring event may provide encouraging results that would indicate recovery could occur much quicker than originally anticipated. Because the exact time frame for recovery was unknown, both CBS and ADEC have wisely structured the long-term monitoring program for the AOC in an adaptive management framework to achieve the best cost/benefit ratio. Once areas within the AOC have achieved the final RAO milestone, they can be eliminated from future monitoring efforts. While the recovery to date is quite encouraging and better than originally anticipated, making a long-term prediction about how soon the AOC will achieve its final RAO milestone will be much easier after the next sampling period when CBS and ADEC have two data points instead of just the one from this baseline survey.

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FIGURES

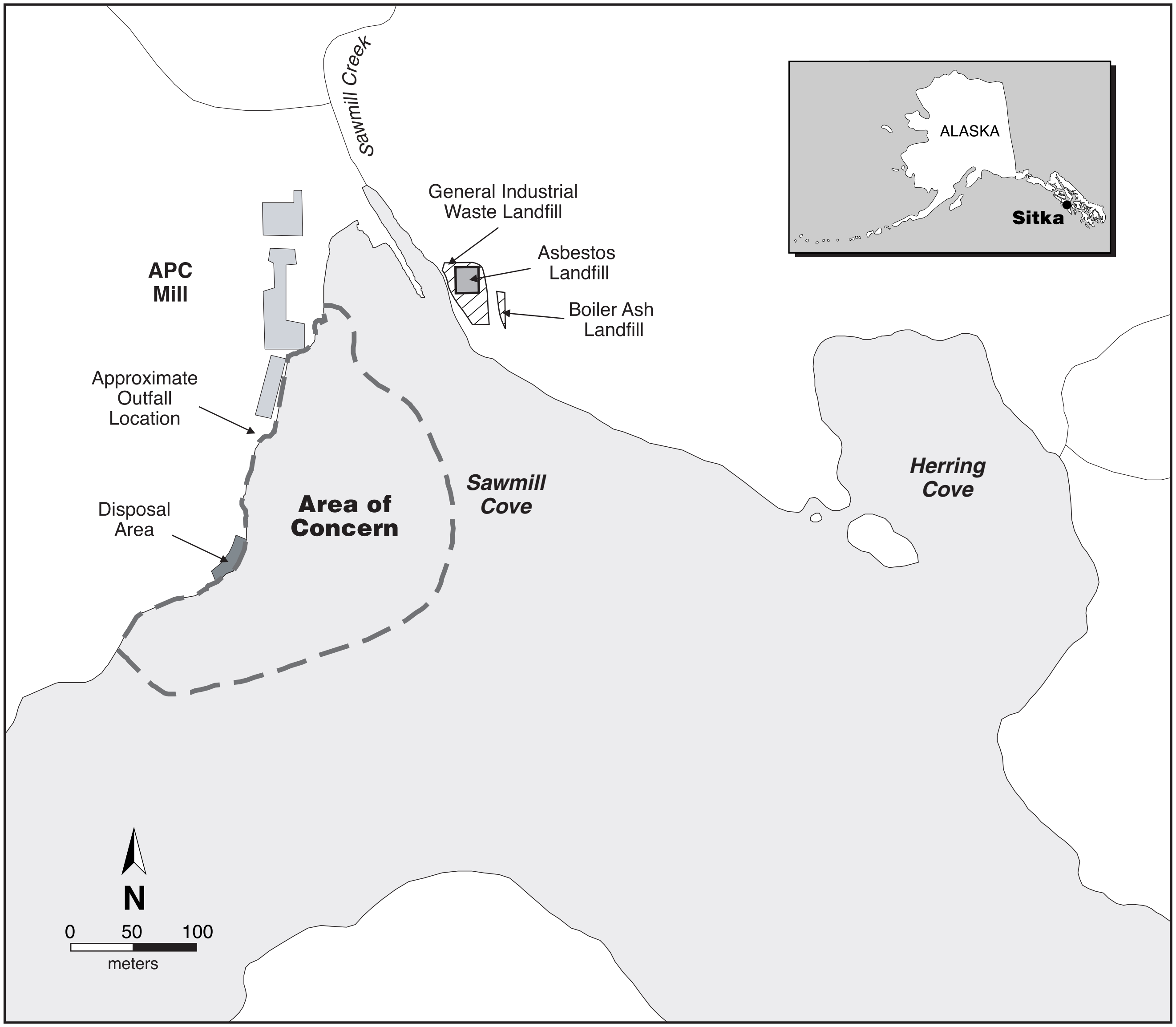

Figure 1-1. Area of Concern (AOC) adjacent to the APC site.

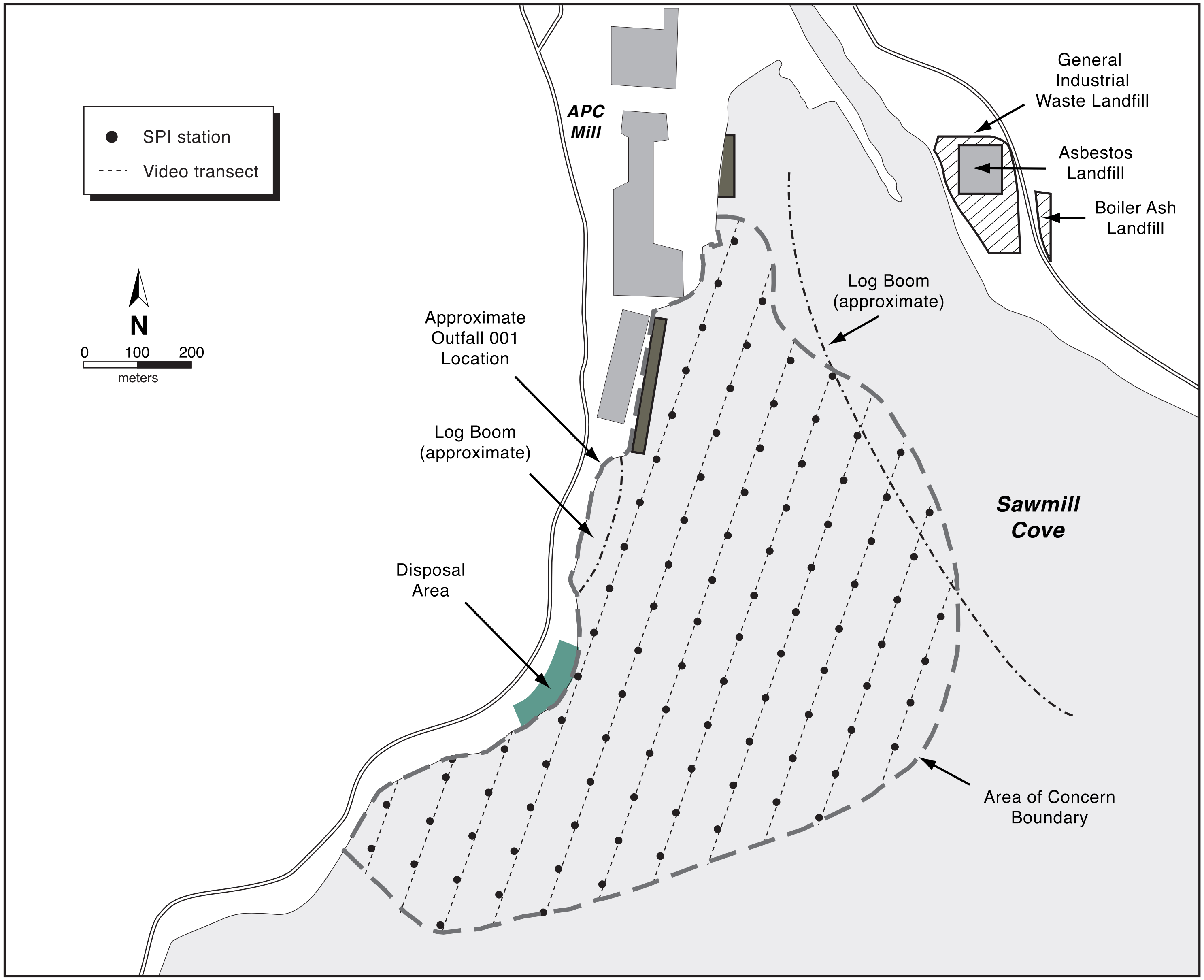

Figure 2-1. Transects and SPI stations specified in the monitoring program (Foster Wheeler 1999).

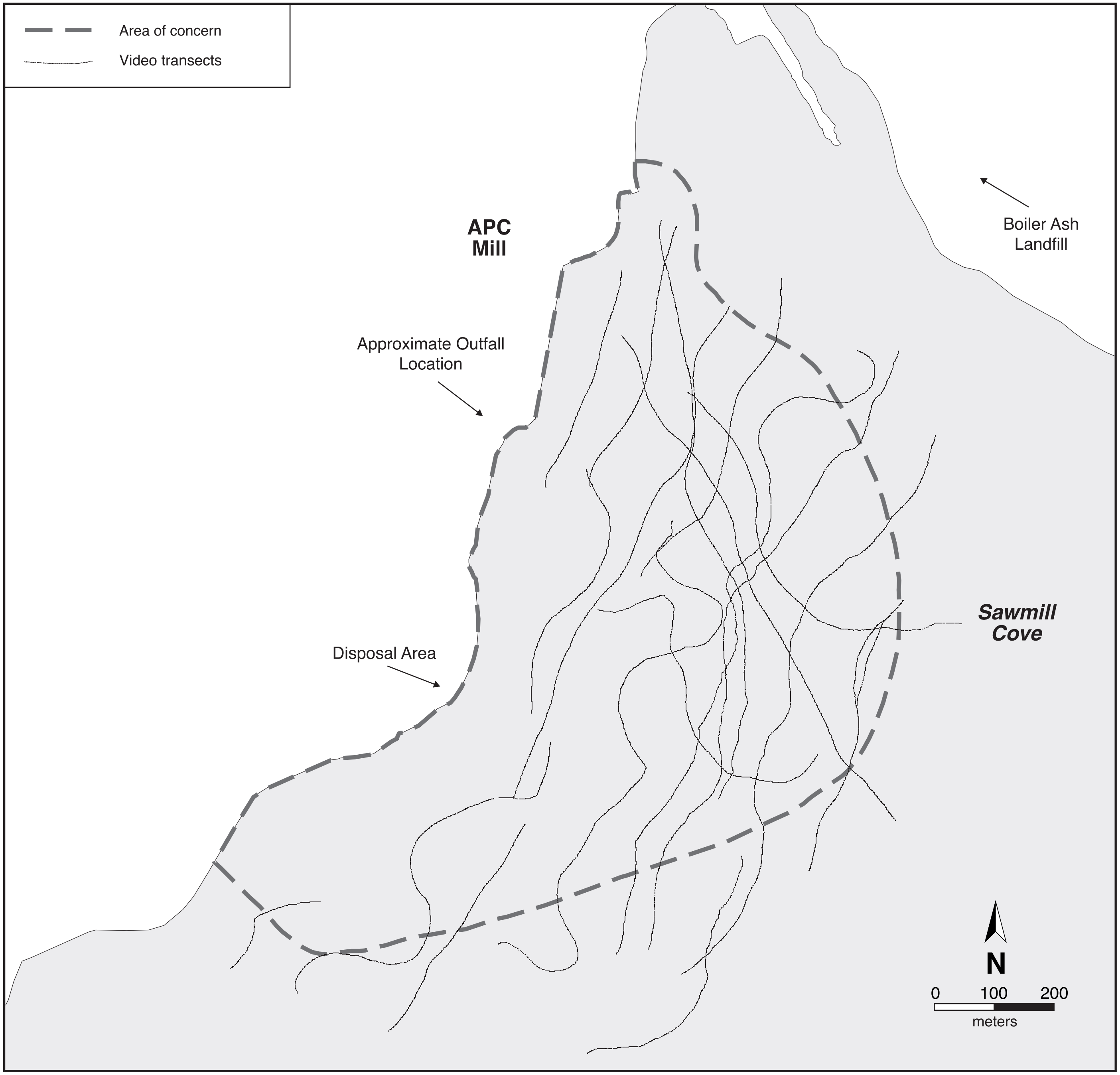

Figure 2-2. Actual video transects.

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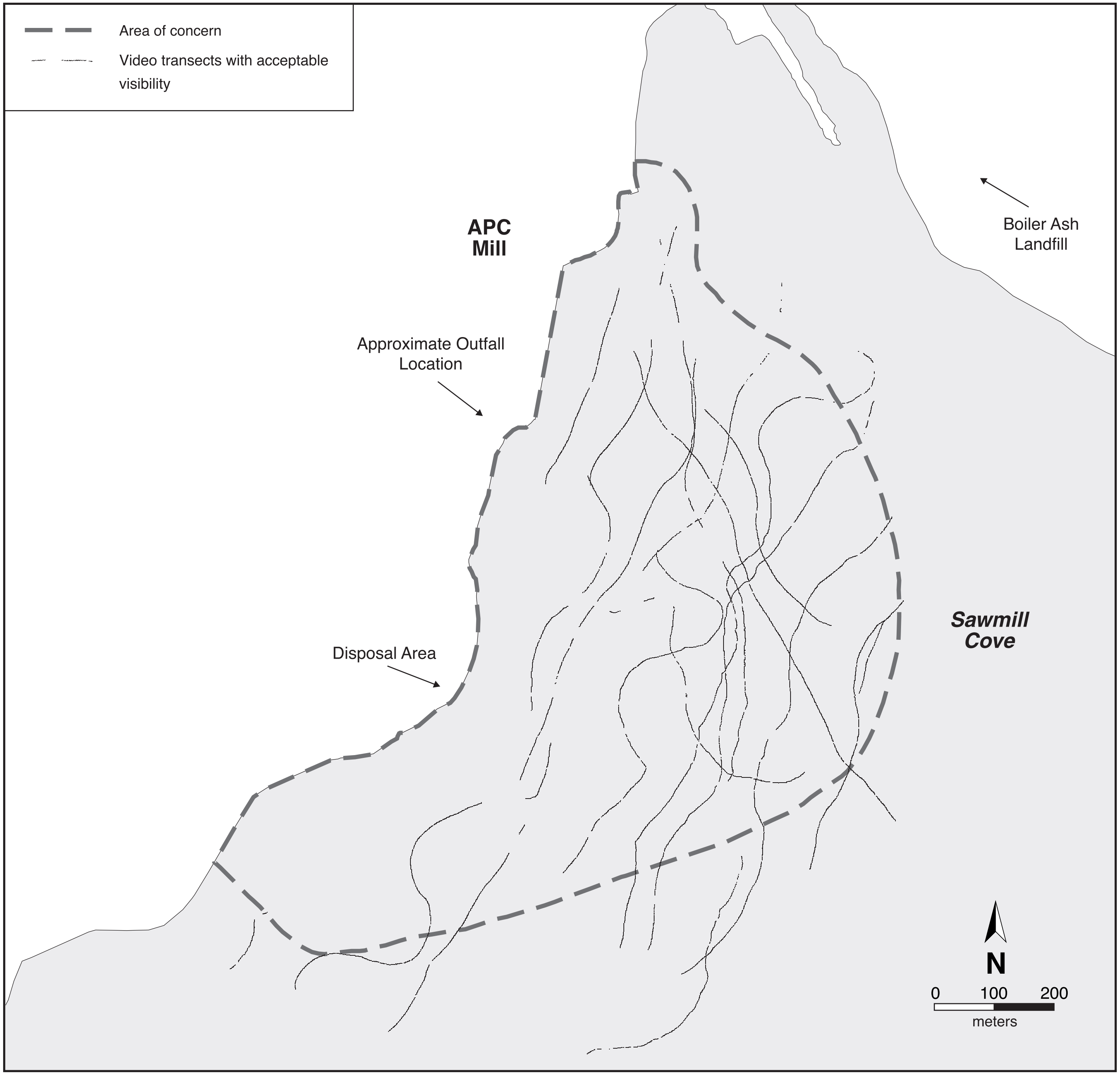

Figure 2-3. Video transects with acceptable visibility.

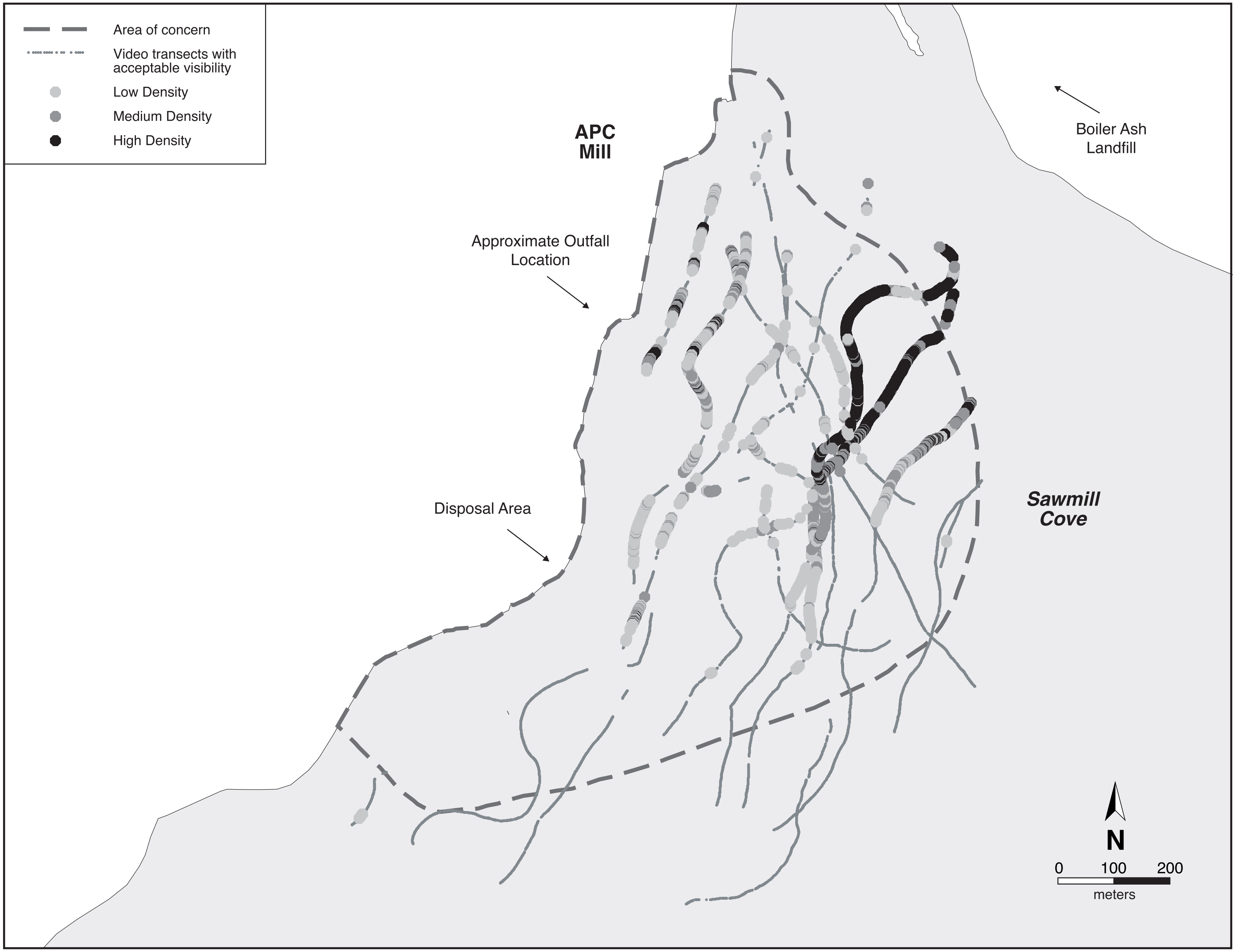

Figure 2-4. Video results for *Beggiatoa.*

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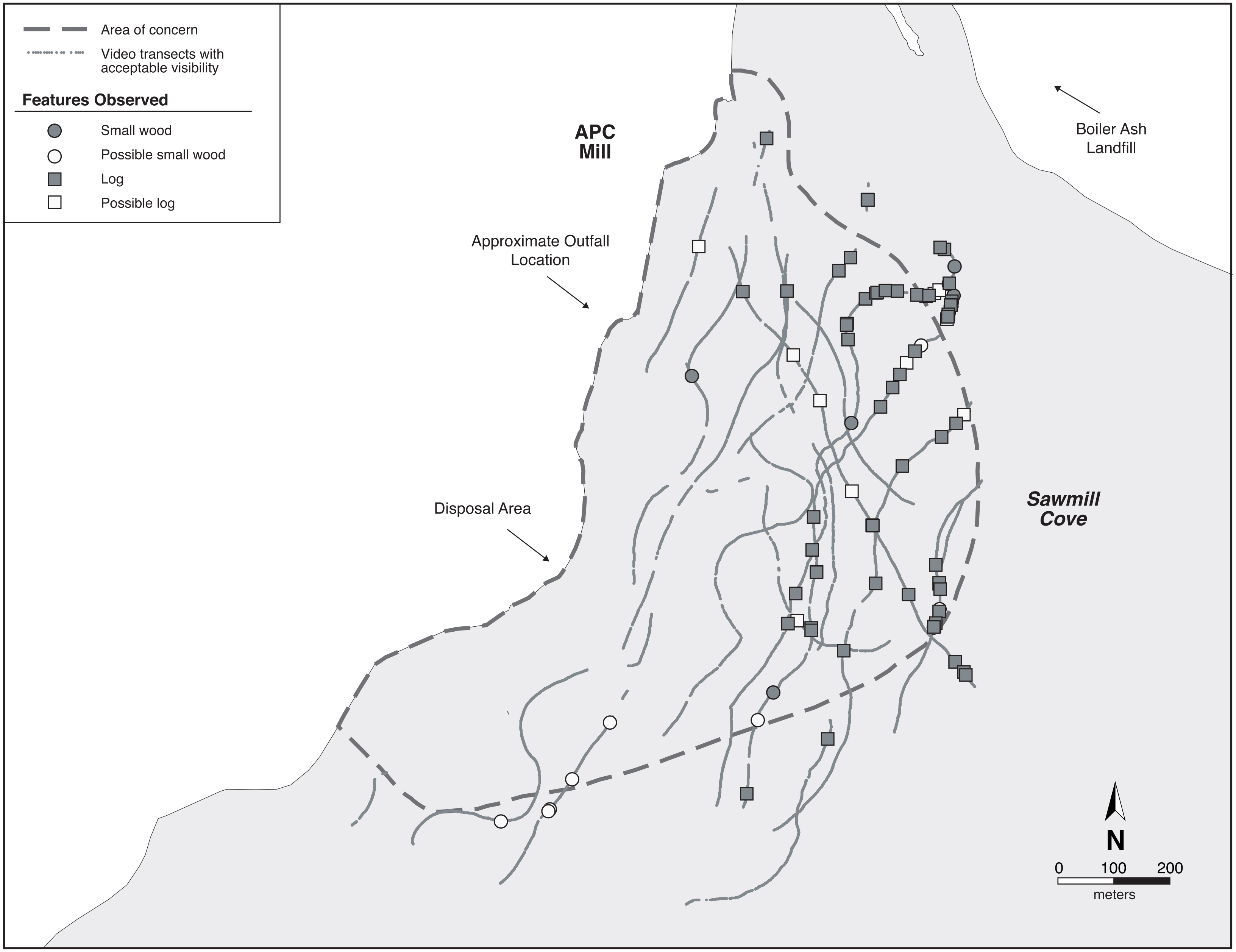

Figure 2-5. Video results for log and wood debris.

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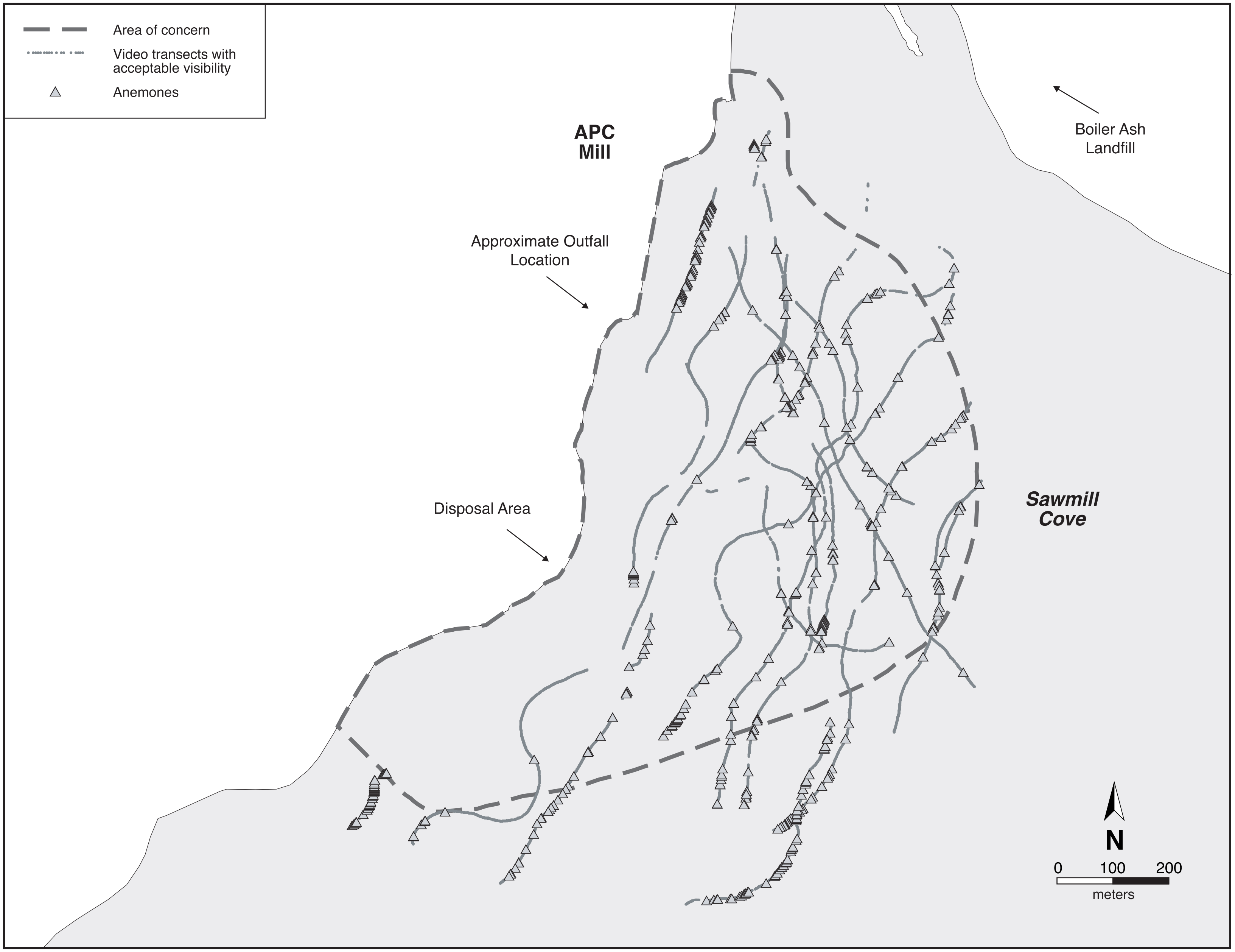

Figure 2-6. Video results for anemones.

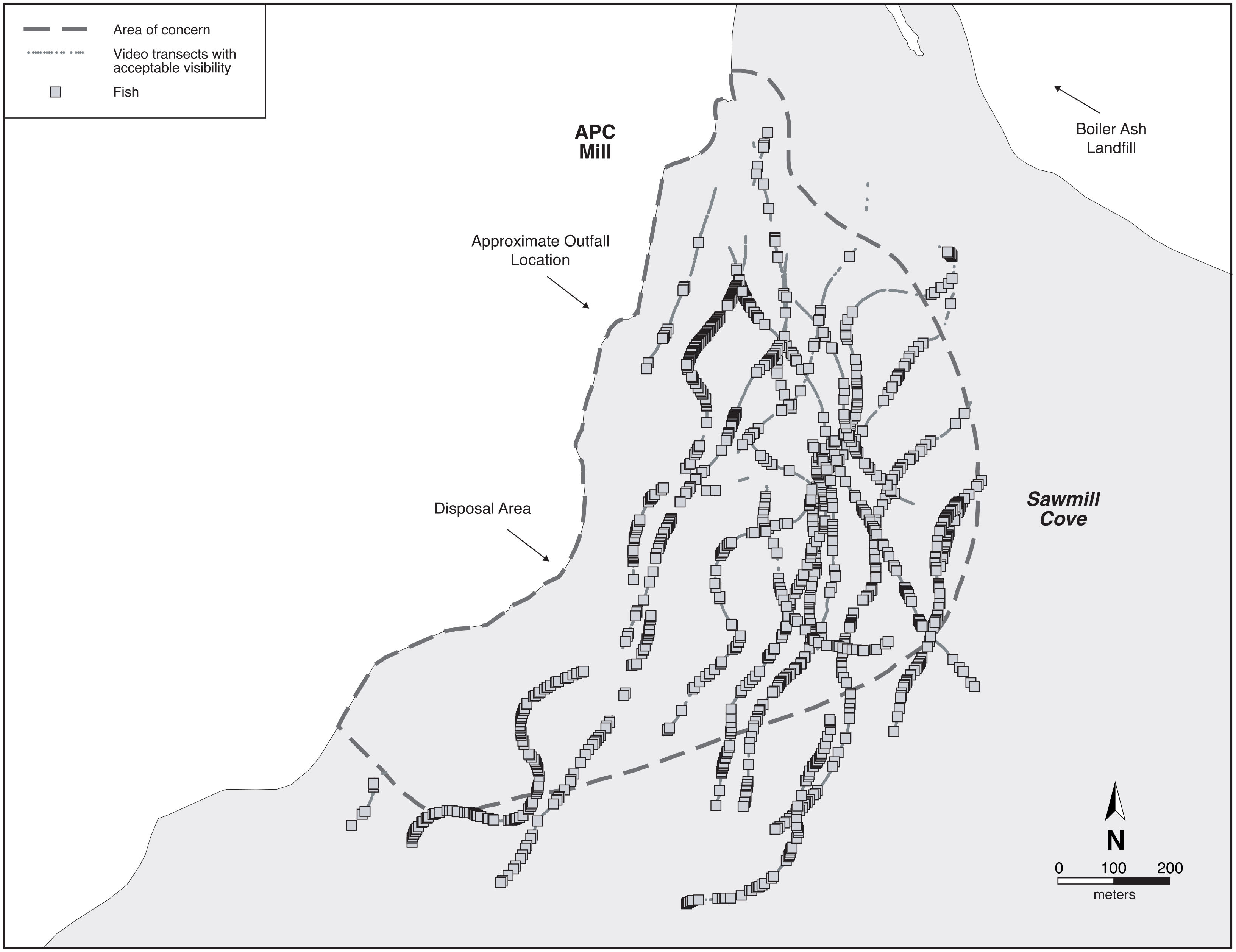

Figure 2-7. Video results for fish.

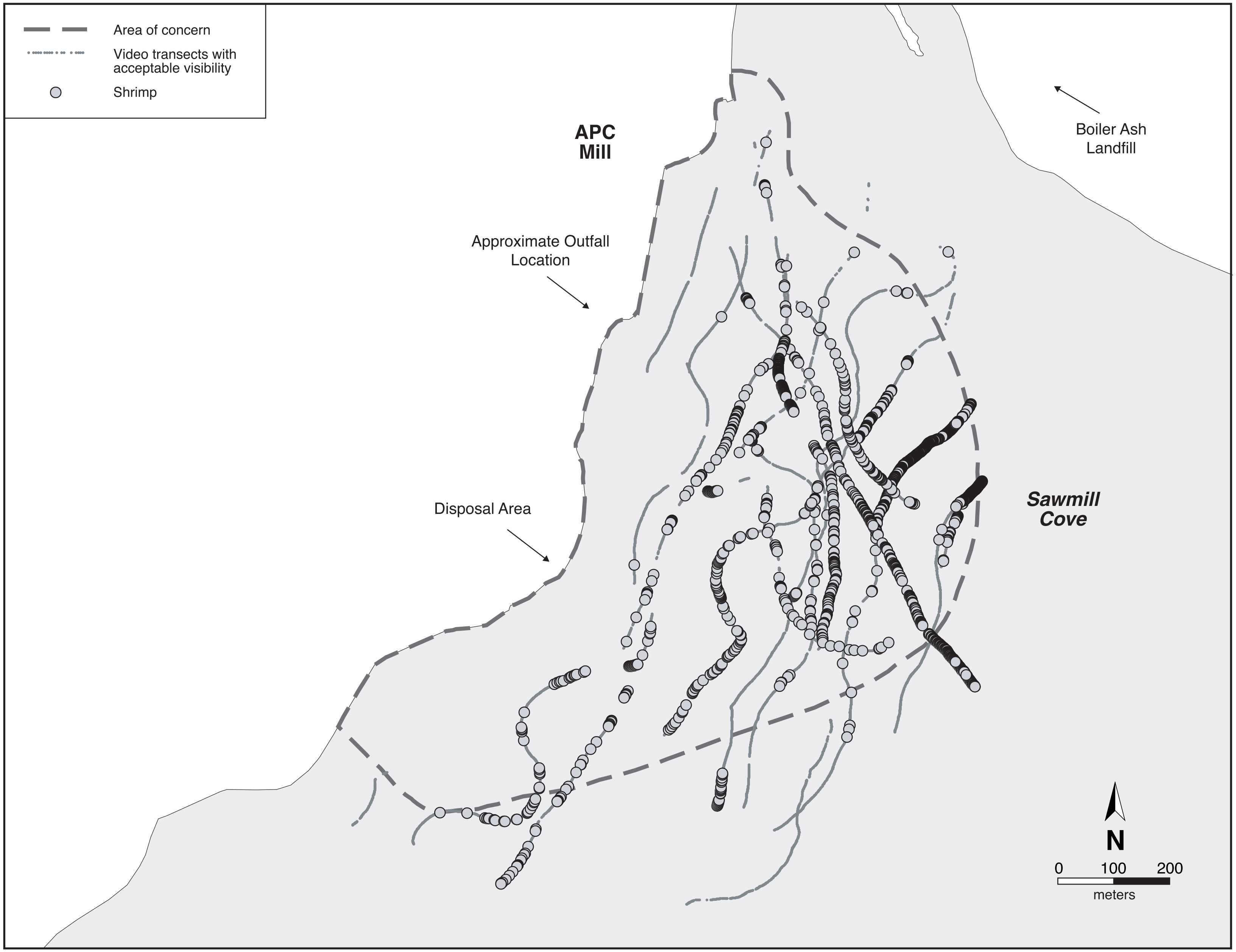

Figure 2-8. Video results for shrimp.

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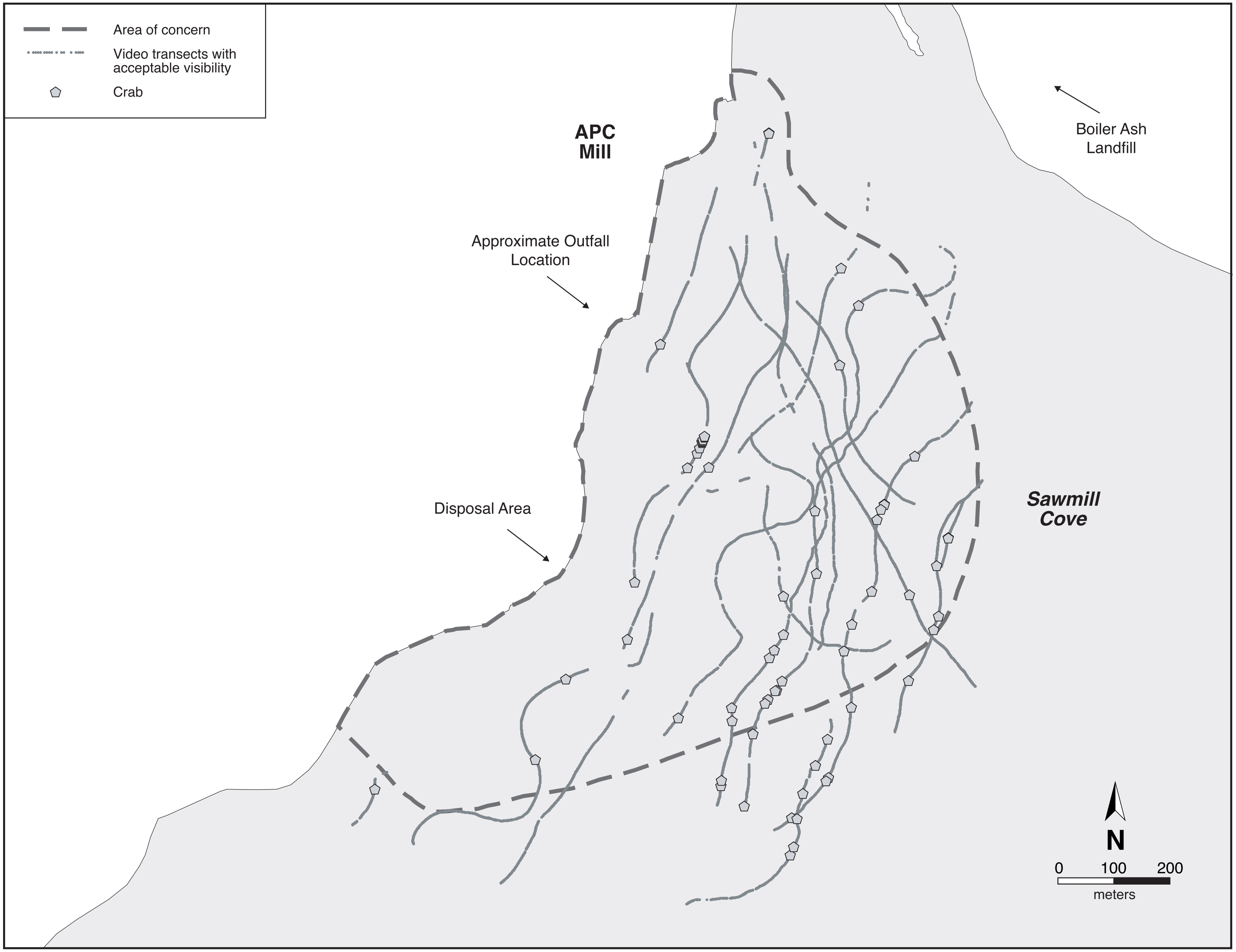

Figure 2-9. Video results for crab.

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Benthic Infauna Successional Stages

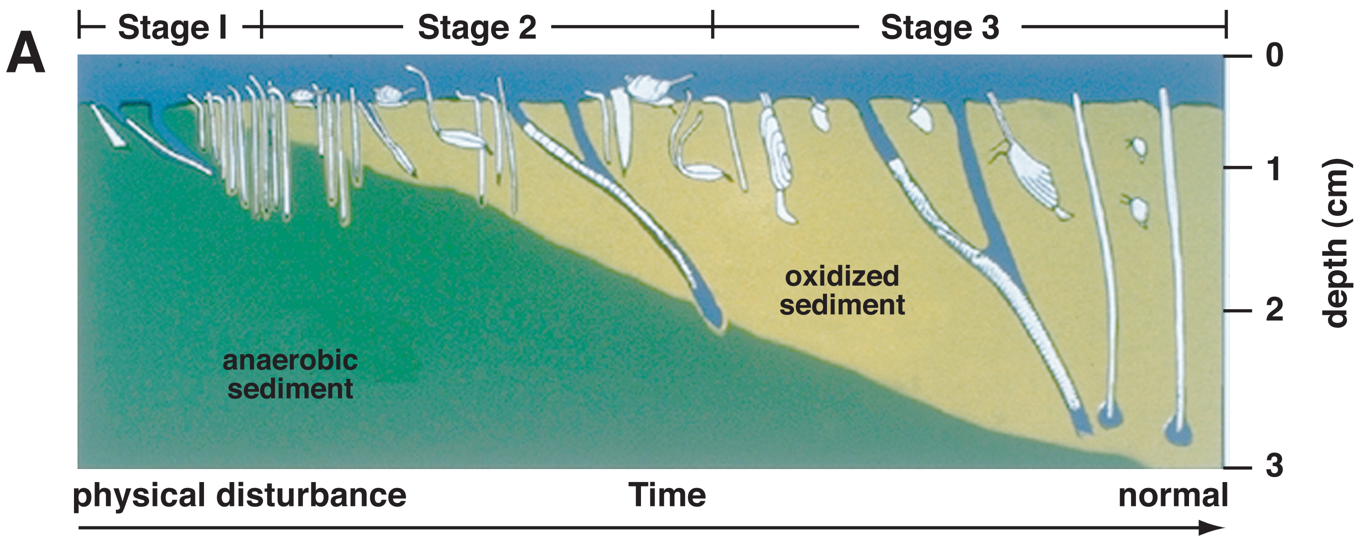


Figure 2-10a. Development of organism-sediment relationships over time following a physical disturbance (from Rhoads & Germano 1982).

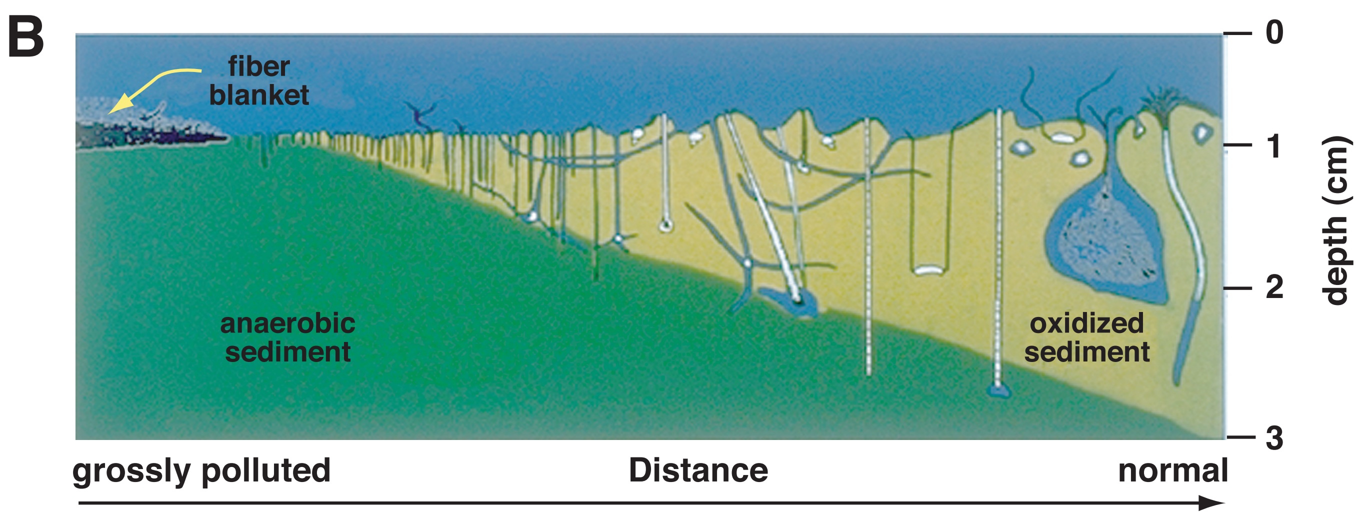


Figure 2-10b. Organism-sediment relationships over space along a pollution gradient associated with a pulp-mill effluent (from Pearson and Rosenberg 1978).

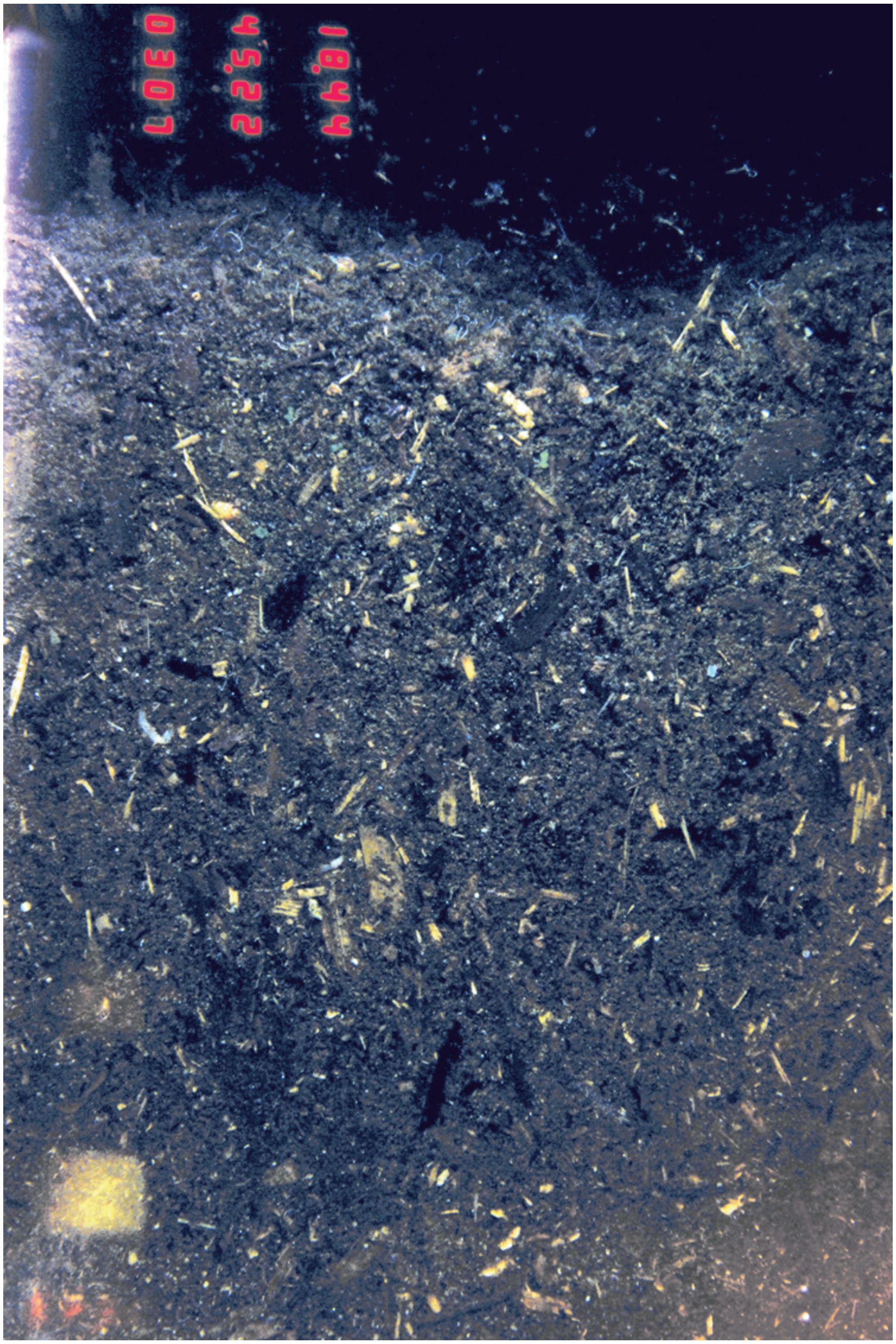
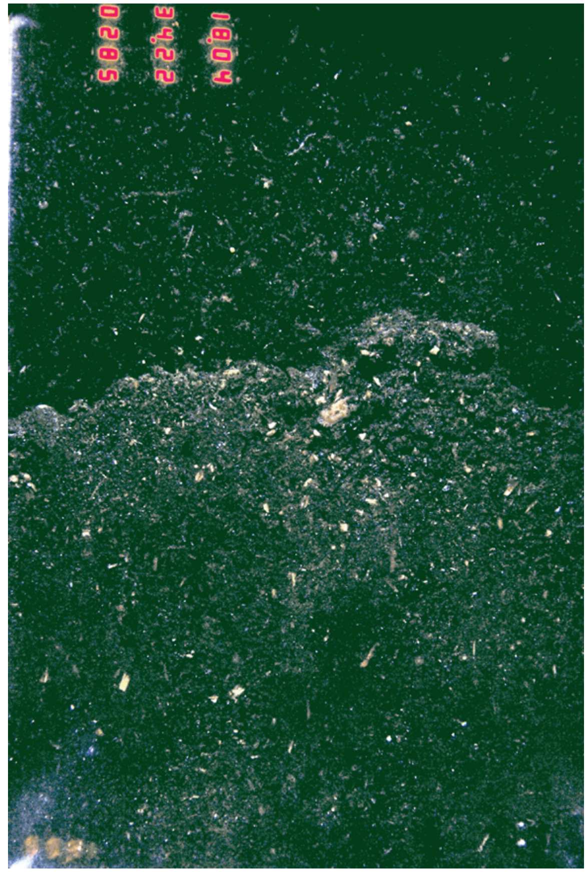


Figure 2-11. SPI image from Station 21 showing wood particles ranging in size from granule (-1 ϕ) to silt-sized (≥ 4 ϕ). Scale: width of image = 15 cm.

(A) Station CD shows relatively large chips embedded in the fiber matrix that have not decomposed all that much.



(B) The refractory nature of the organic carbon pool can be easily seen at Station 16 where the larger wood particles retain their original color.

(C) The wood waste at Station 95 has a grain-size major-mode in the silt-clay range (> 4 ϕ).

Figure 2-12. SPI images showing the size distribution of decomposing wood particles. Scale: width of image = 15 cm.

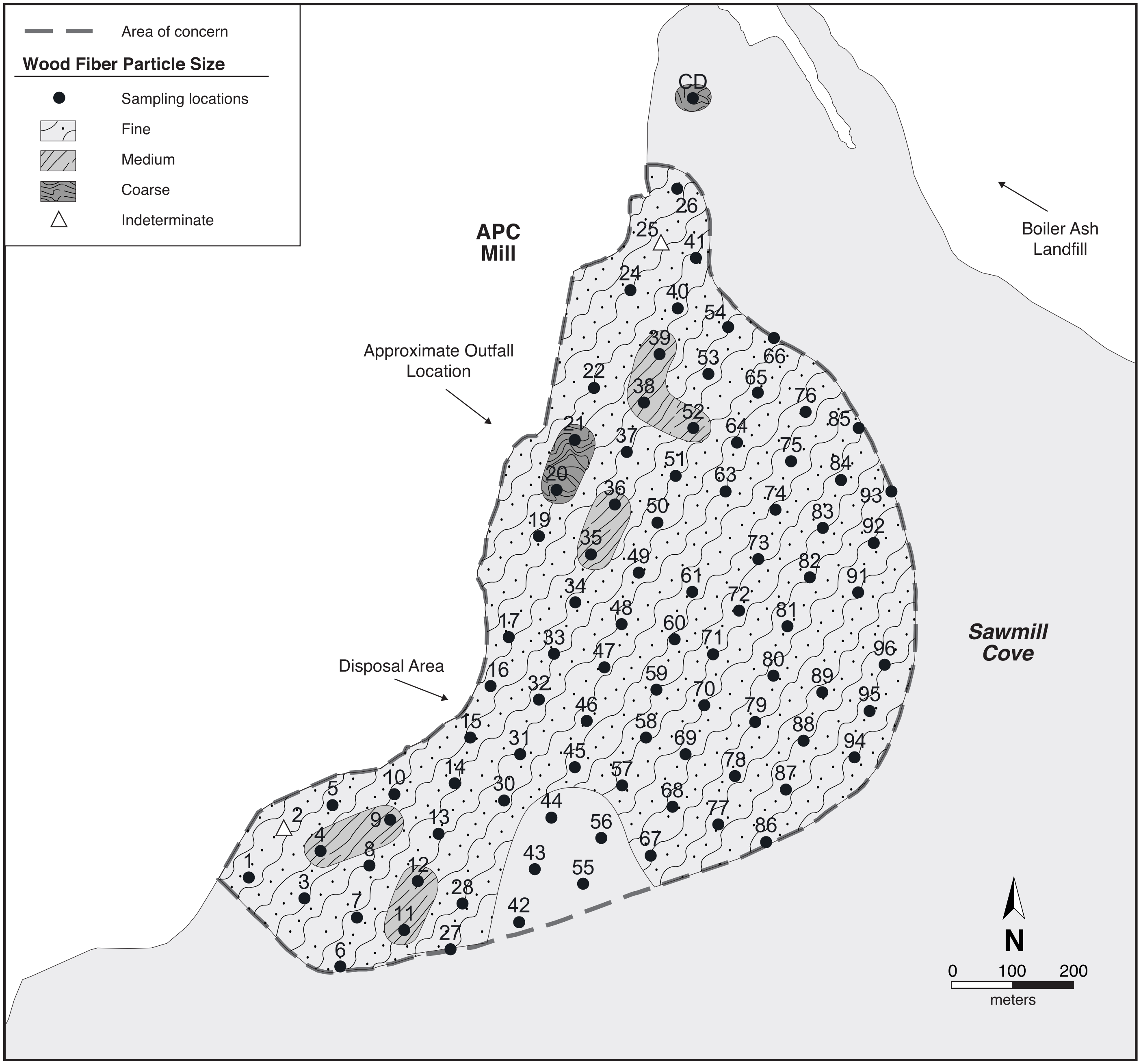


Figure 2-13. Map of wood fiber/waste distribution throughout the AOC.

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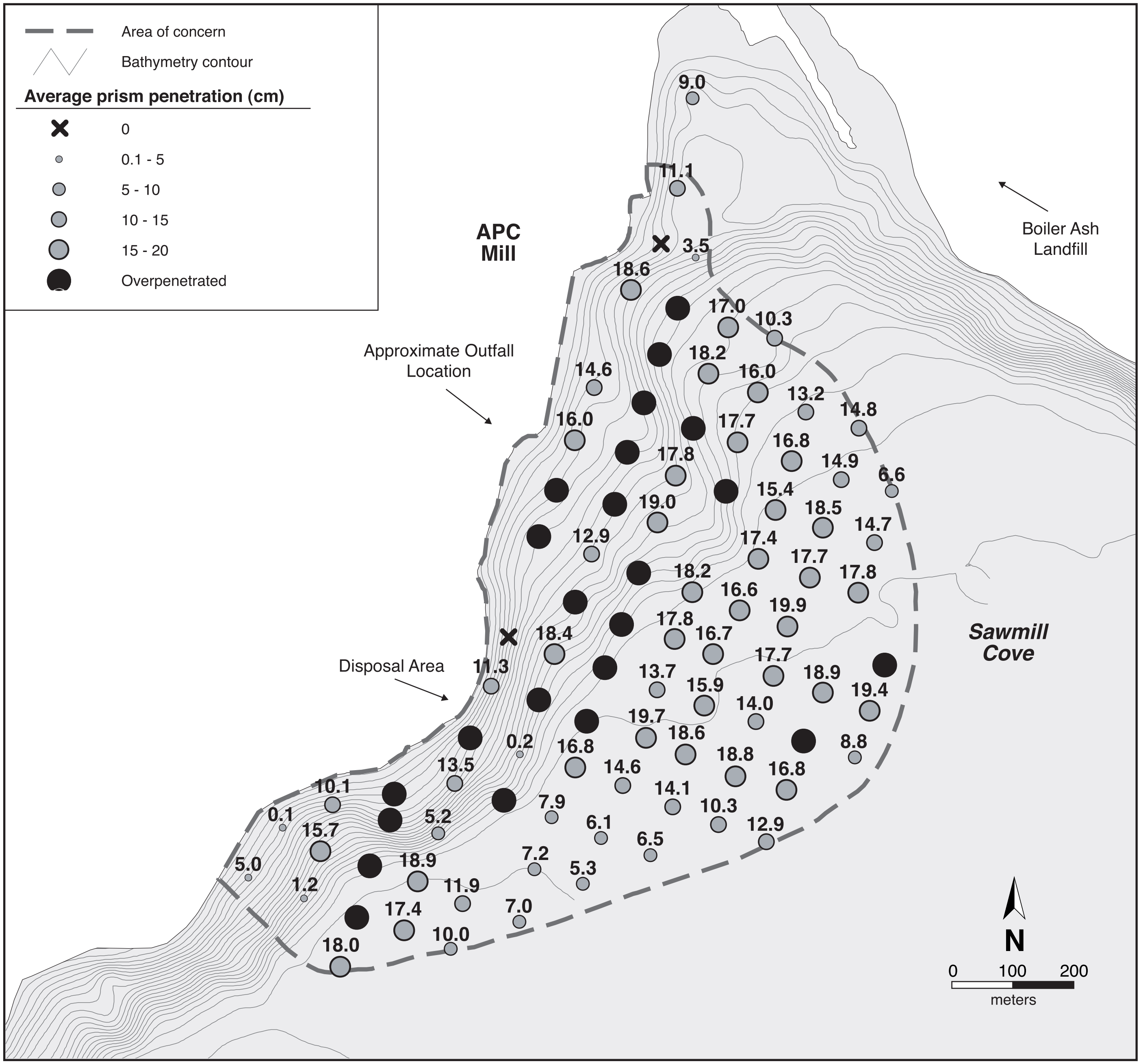

Figure 2-14. Distribution of mean prism penetration depth (cm) throughout the AOC.

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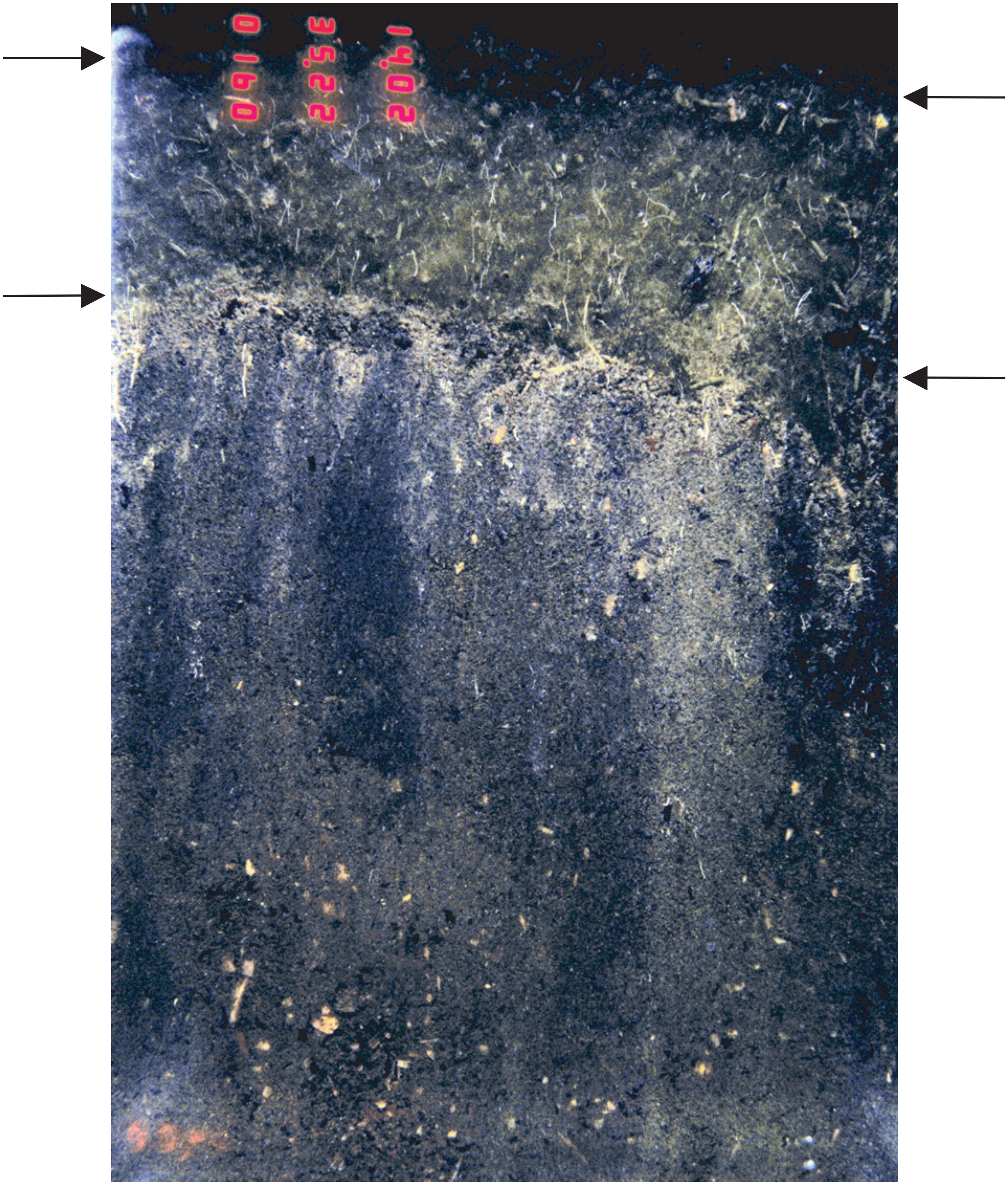

Figure 2-15. SPI image from Station 59 showing a 4-6 cm layer (arrows) of floccular phytoplankton detritus on the sediment surface. Note presence of white "fibers" (sulfur-reducing bacterial colonies). Scale: width of image = 15 cm.

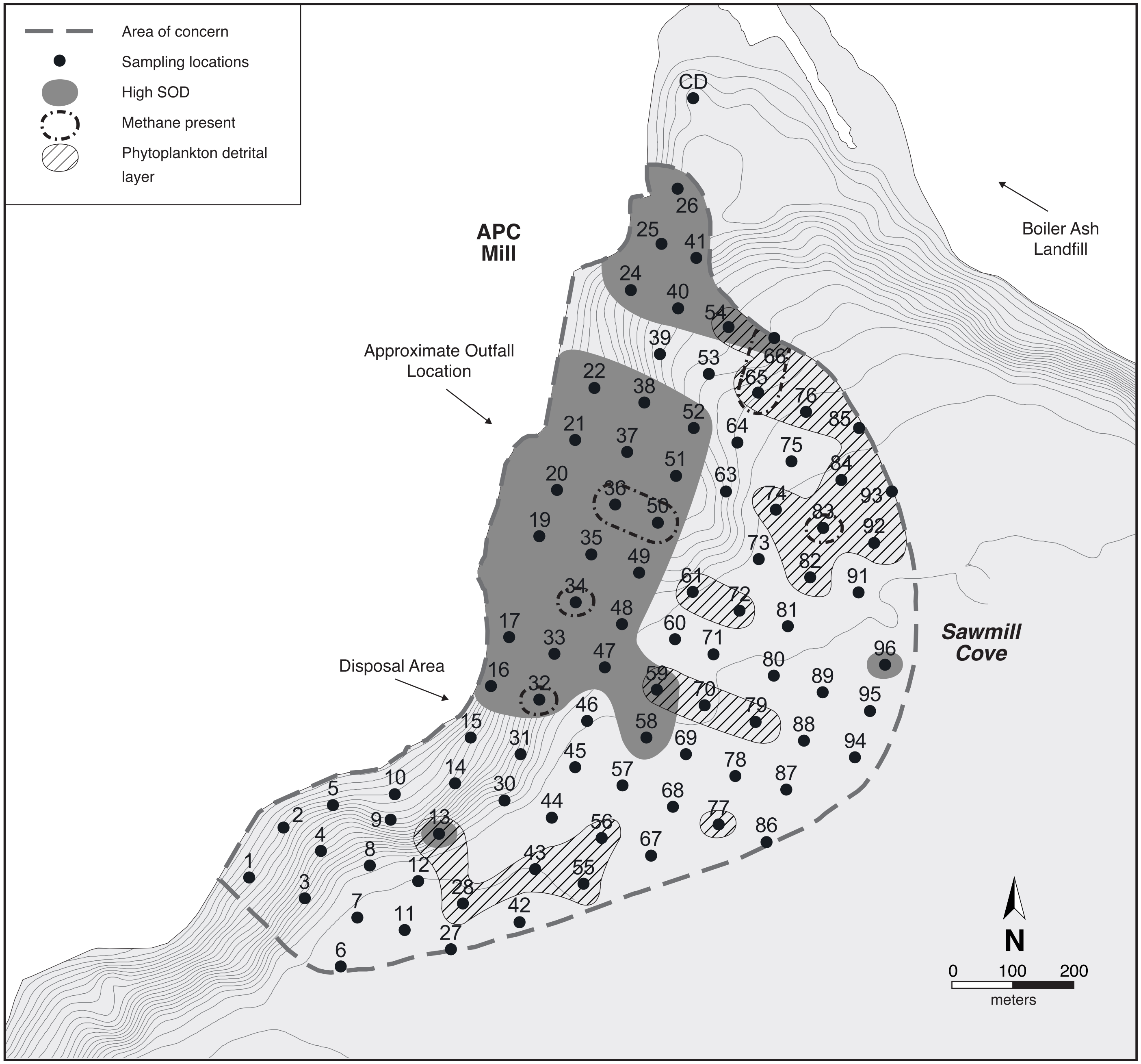

Figure 2-16. Stations showing evidence of excess organic enrichment and high SOD.

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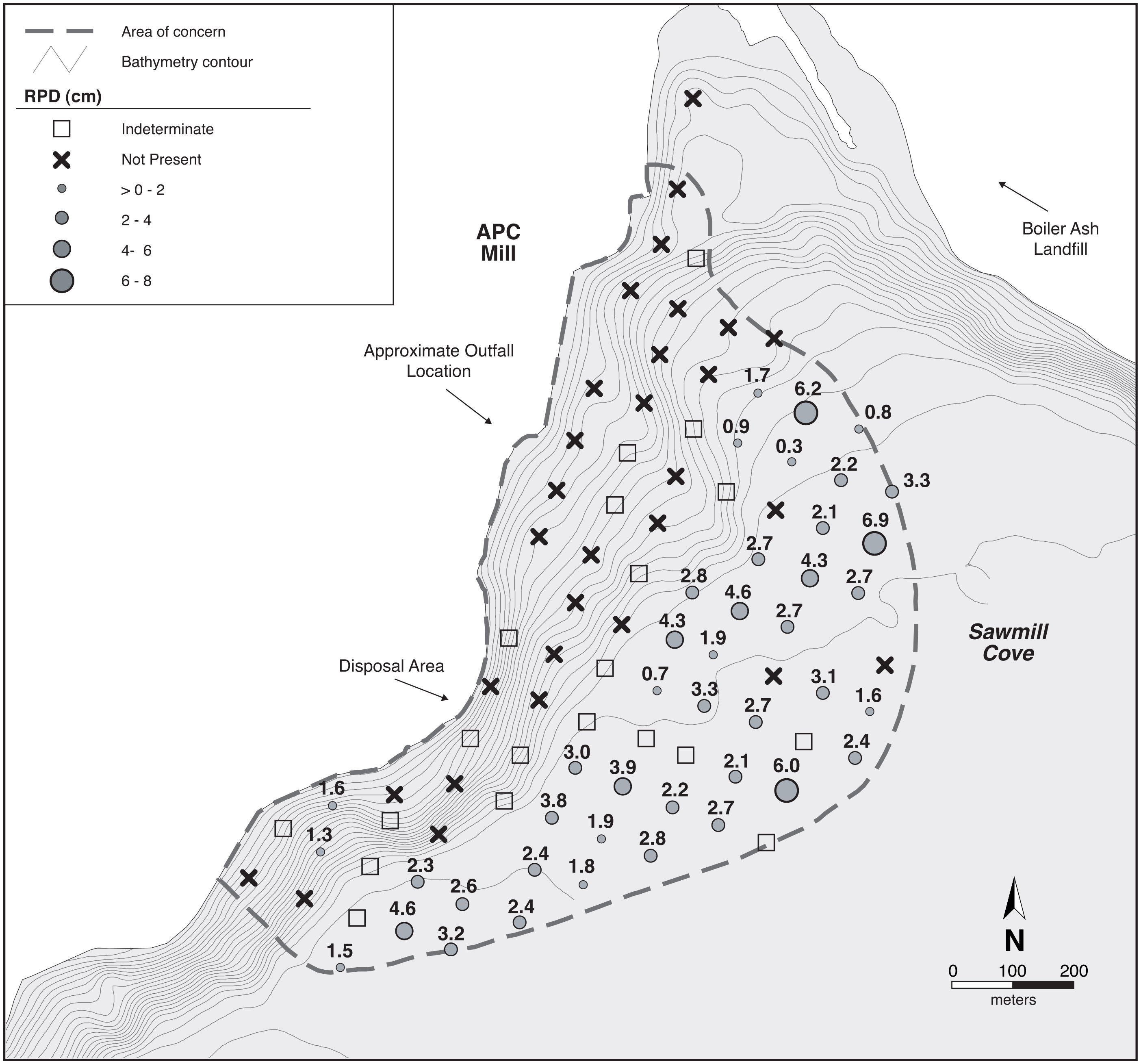
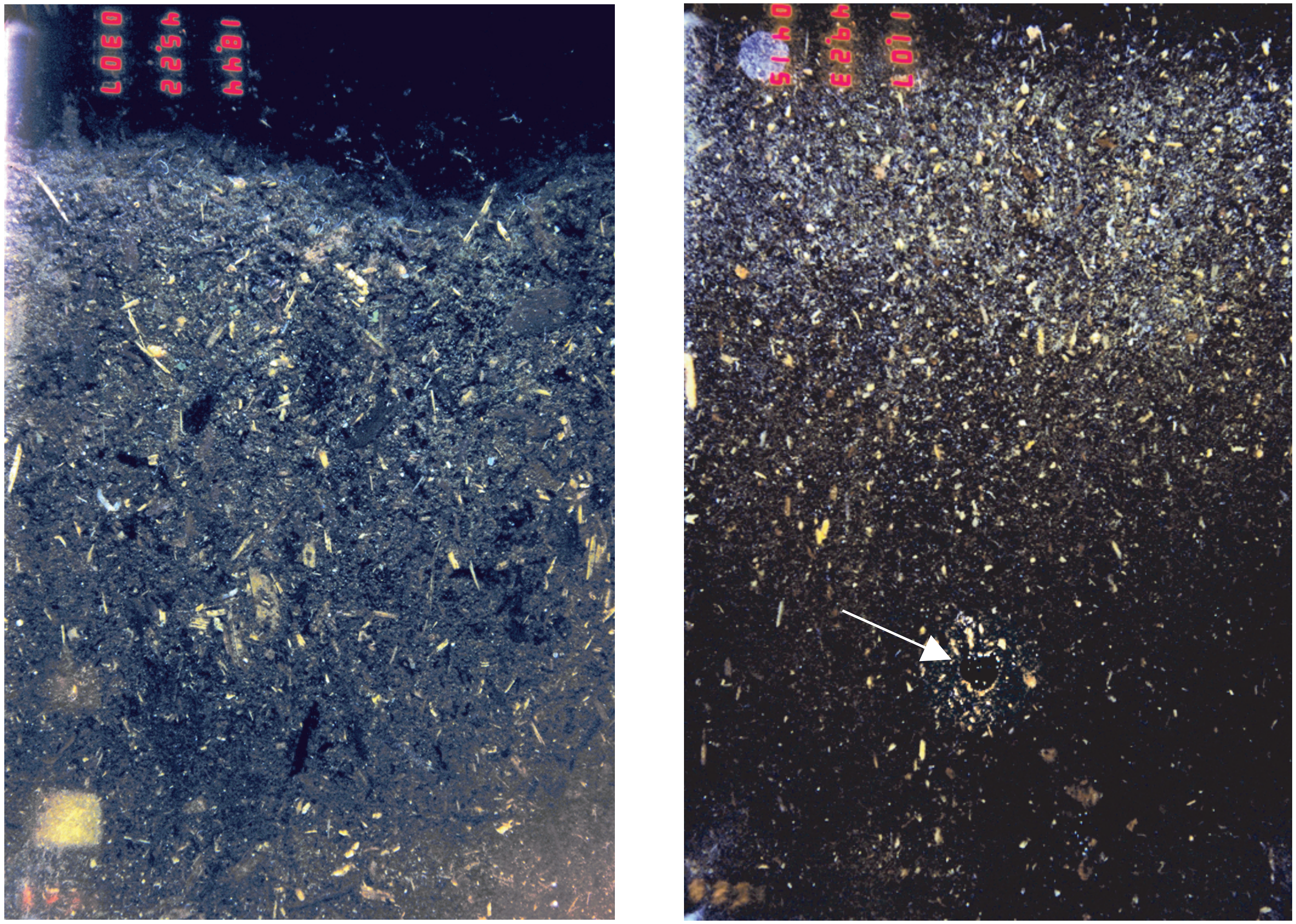


Figure 2-17. Distribution of mean apparent RPD depths (cm) within the AOC.



(A) While the sediment-water interface is clearly visible at Station 21, there is no visible oxidized layer in the cross-sectional profile of wood waste.

(B) The sediment-water interface is not visible at Station 36 due to excessive prism penetration, but the presence of methane gas (arrow) indicates excess organic loading; the lack of an apparent RPD is inferred.

Figure 2-18. SPI images from areas with high sediment-oxygen demand. Scale: width of image = 15 cm.

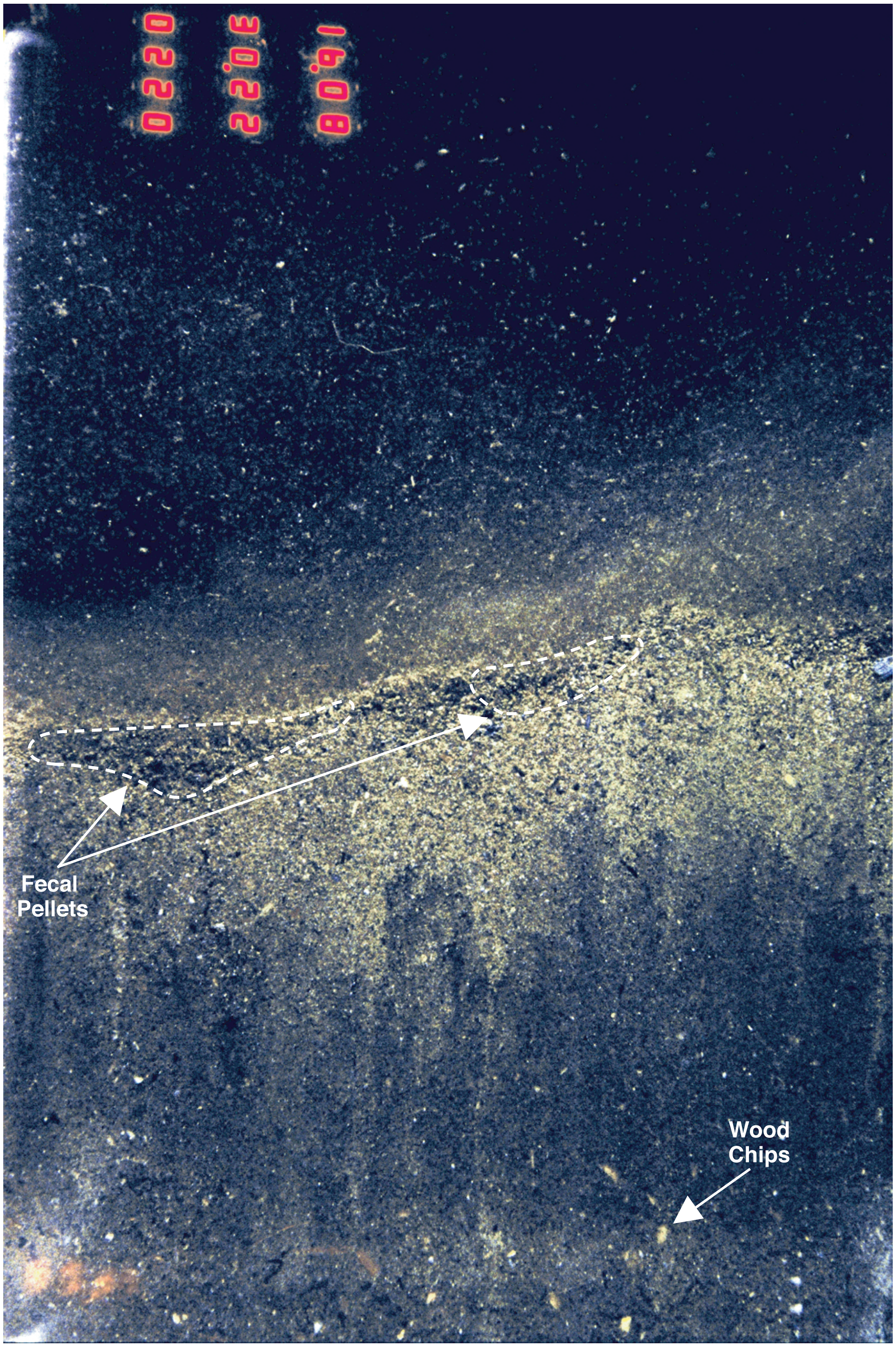


Figure 2-19. SPI image from Station 27 showing wood chips at depth with an apparent RPD in excess of 3 cm; note fecal pellets from subsurface deposit feeders at the sediment surface. Scale: width of image = 15 cm.

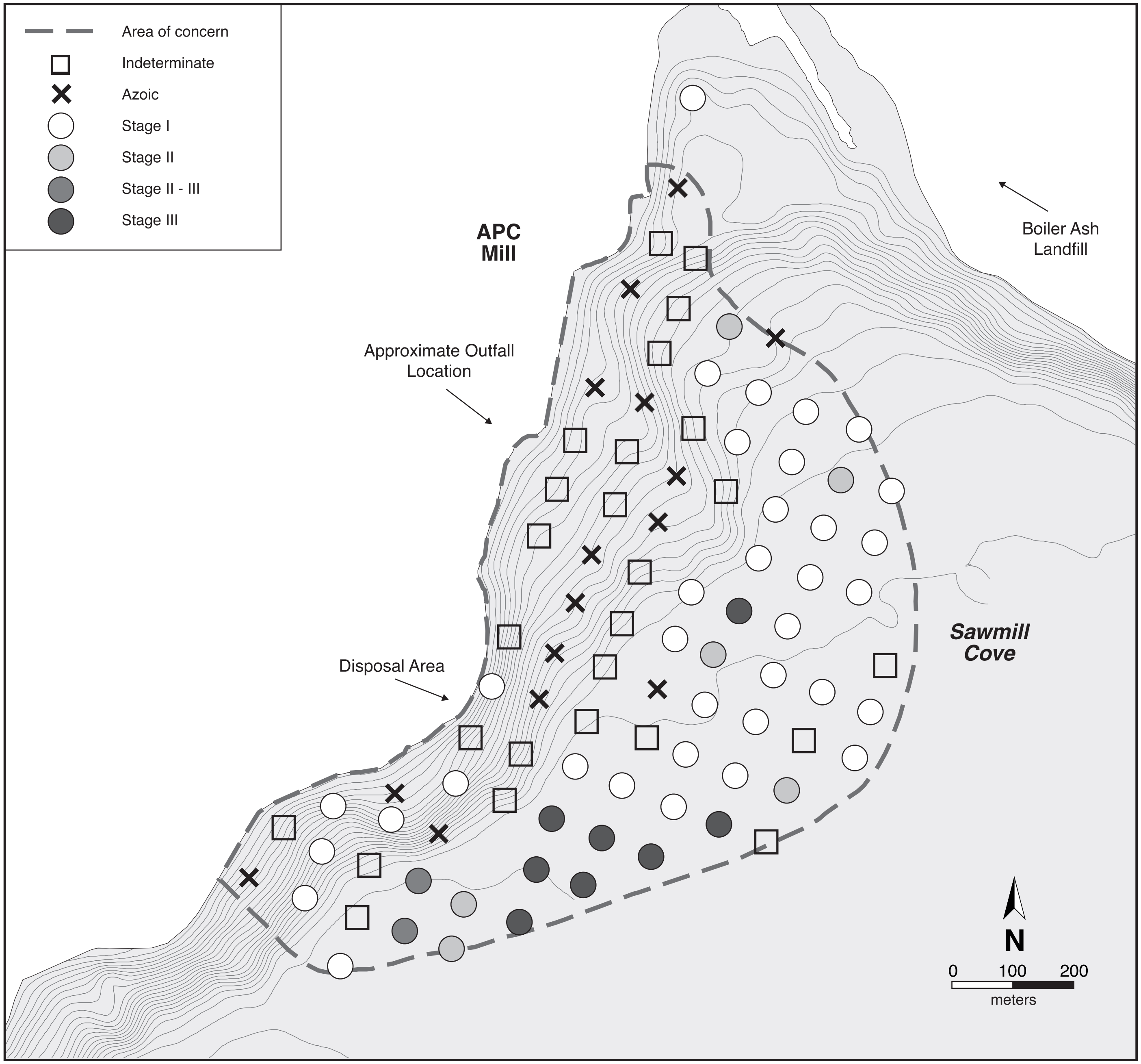


Figure 2-20. Distribution of infaunal successional stages within the AOC.

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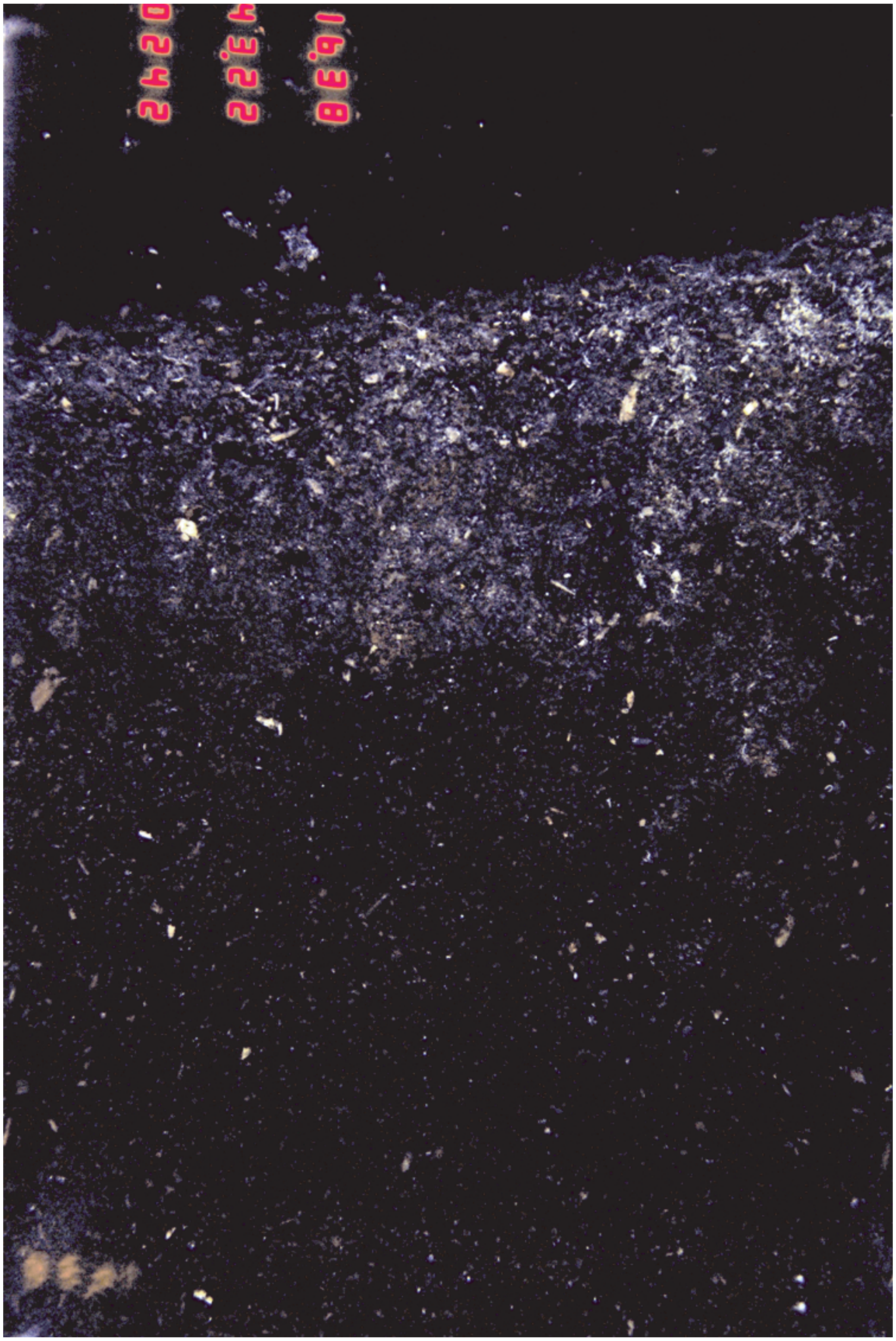


Figure 2-21. SPI image from Station 34 showing high SOD wood fibers with no signs of any apparent infauna. Scale: width of image = 15 cm.

Figure 2-22. SPI image from Station 6 showing the initial stages of recolonization. Stage I polychaetes are visible at the sediment-water interface (arrows). Scale: width of image = 12.5 cm.

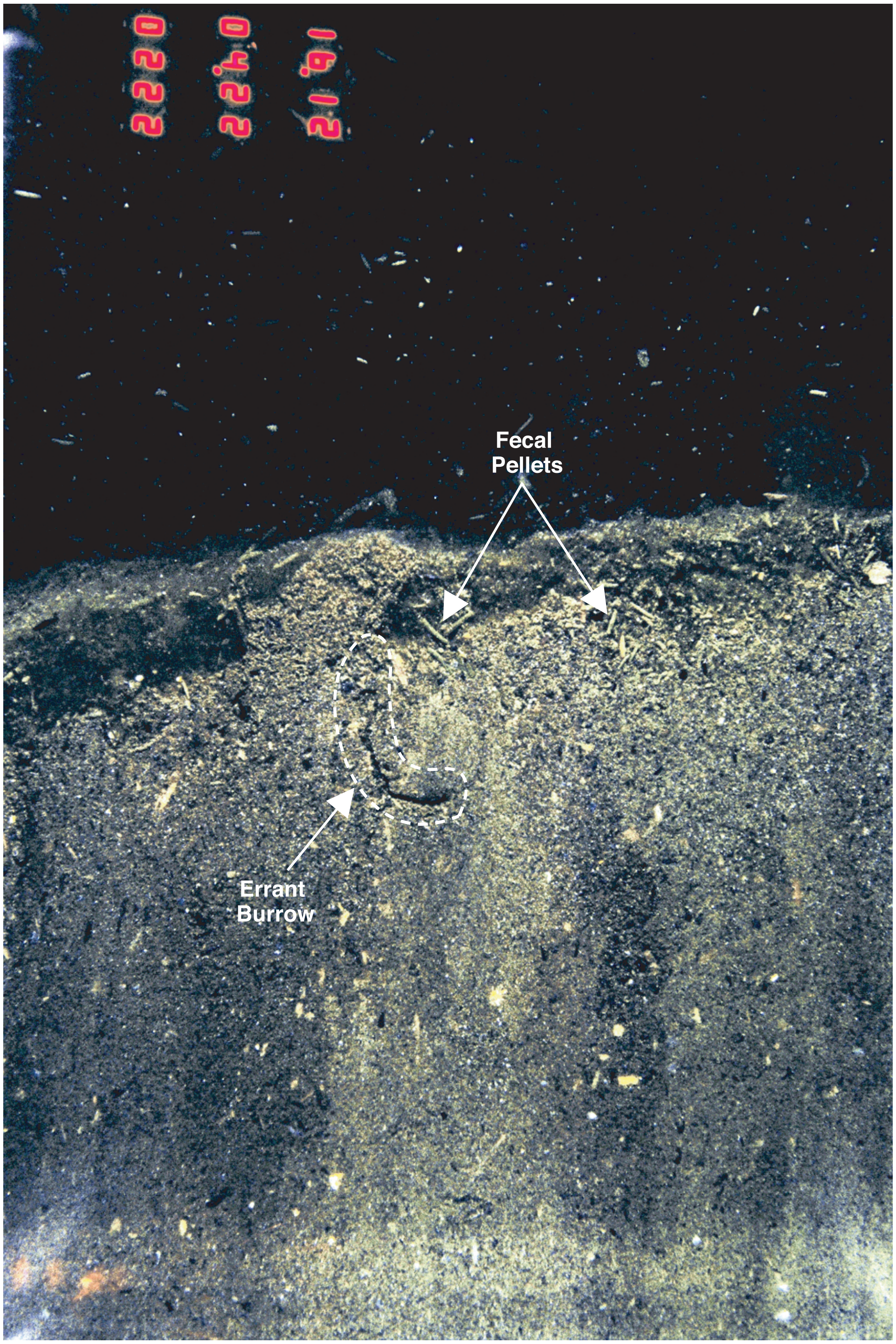


Figure 2-23. SPI image from Station 28 showing evidence of shallow deposit-feeding assemblages (errant burrow and collections of fecal pellets on the sediment surface). Scale: width of image = 15 cm.

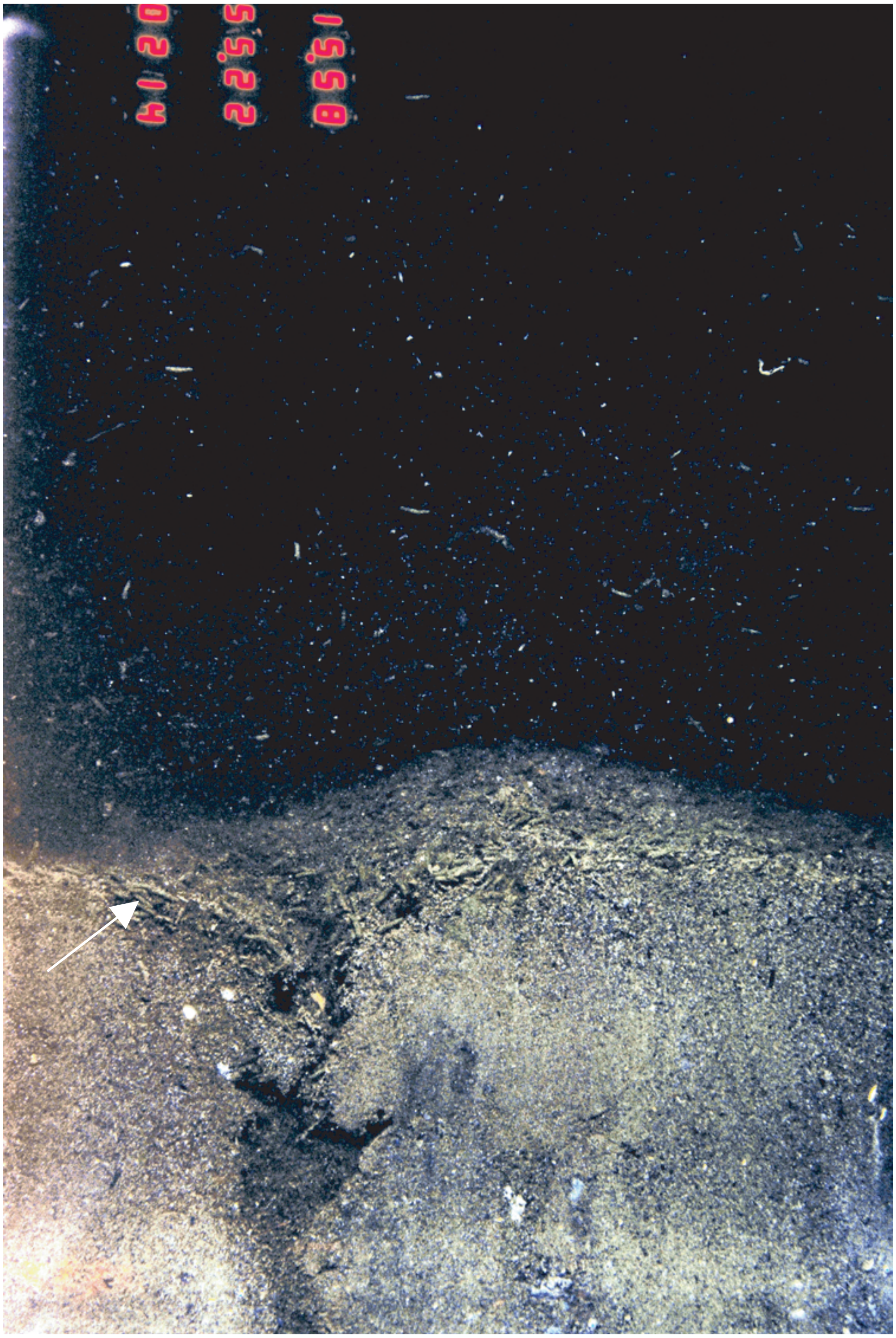
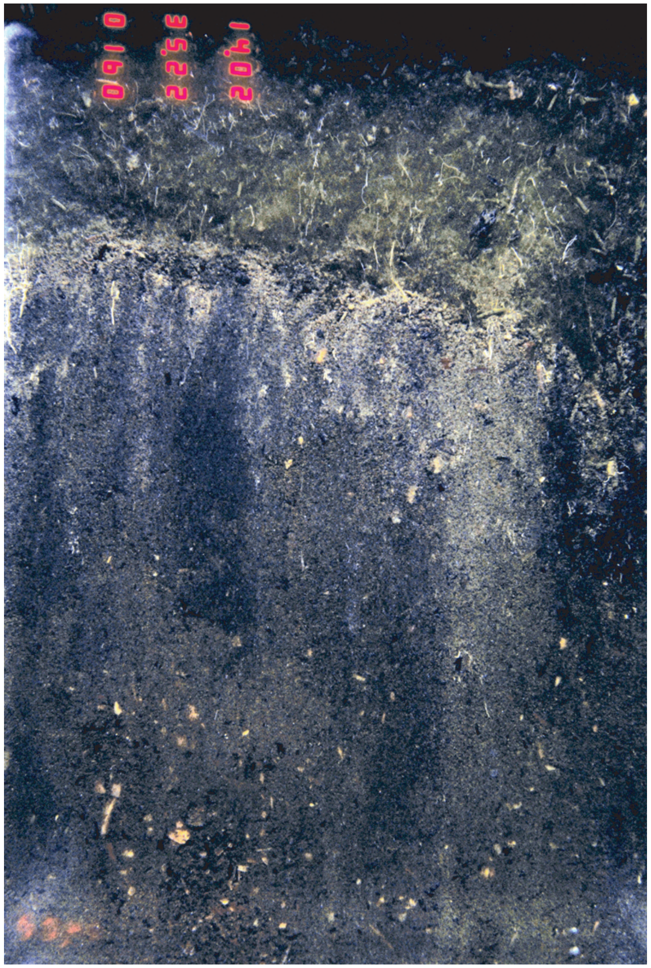
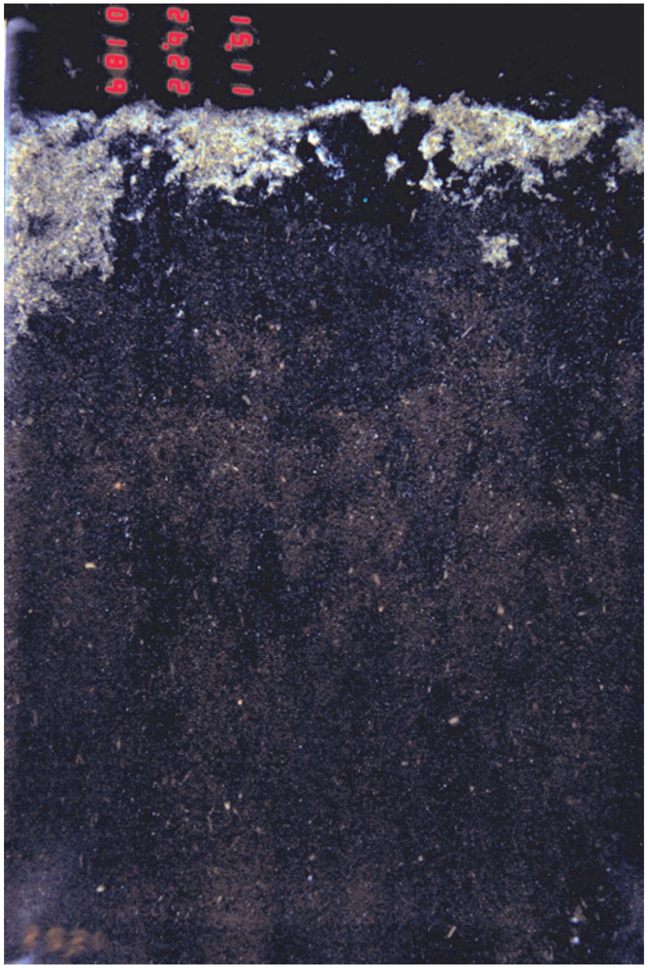


Figure 2-24. SPI image from Station 44 showing a well-developed RPD, the burrow of a large deposit-feeder, and fecal casts (arrow) from subsurface deposit-feeders at the sediment-water interface. Scale: width of image = 15 cm.



(A) Individual strands of bacterial colonies can be seen both on the sediment surface and in the floccular plankton layer present at Station 59.



(B) Dark, reducing sediment with high SOD can be seen beneath the white bacterial mat covering the surface of the seafloor at Station 51.

Figure 2-25. SPI images showing low (A) and high (B) densities of sulfur-reducing bacterial colonies. Scale: width of image = 15 cm.

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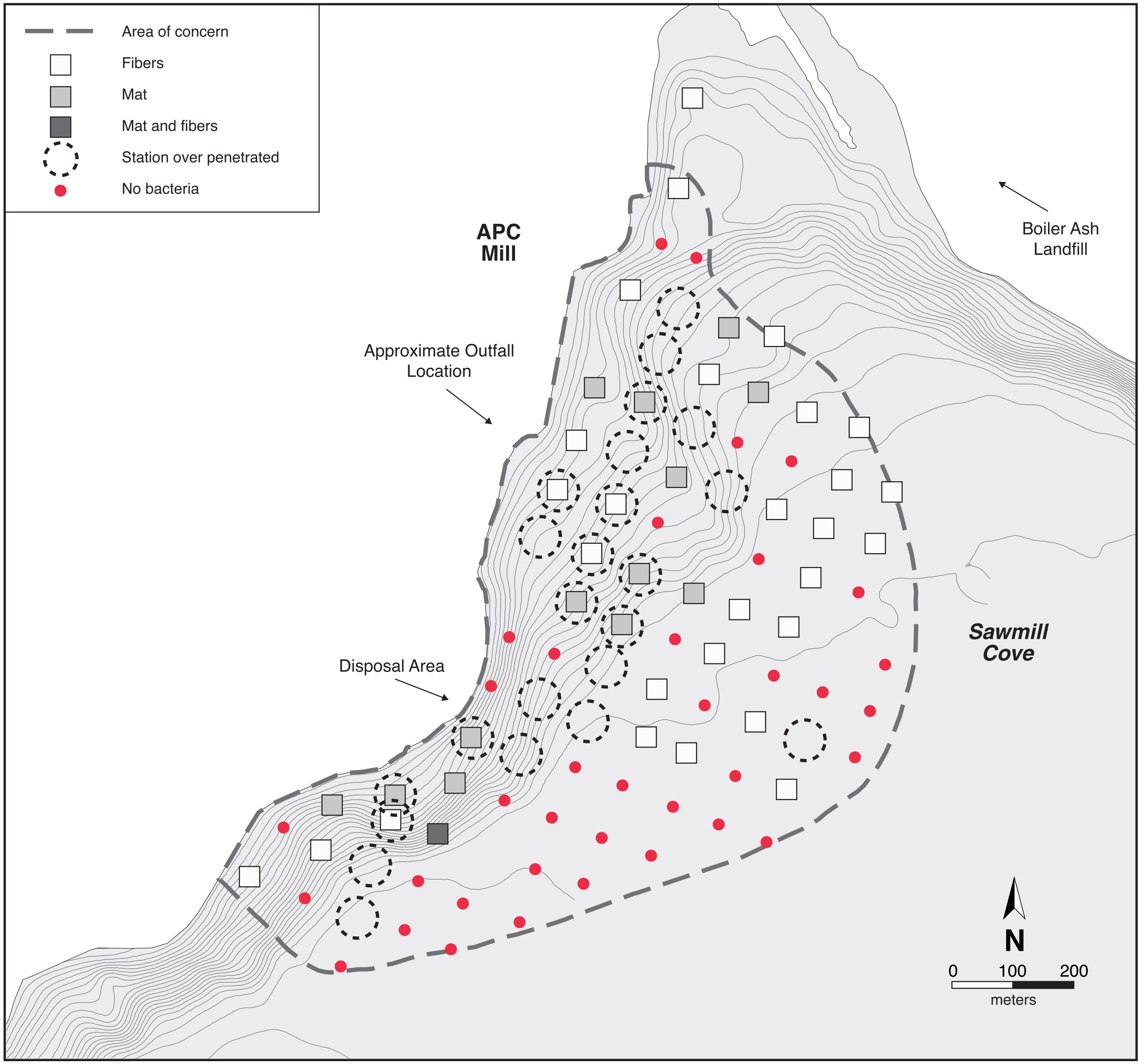

Figure 2-26. Stations where sediment oxygen demand was high enough for anoxic, sulfur-reducing bacterial colonies to grow on the seafloor.

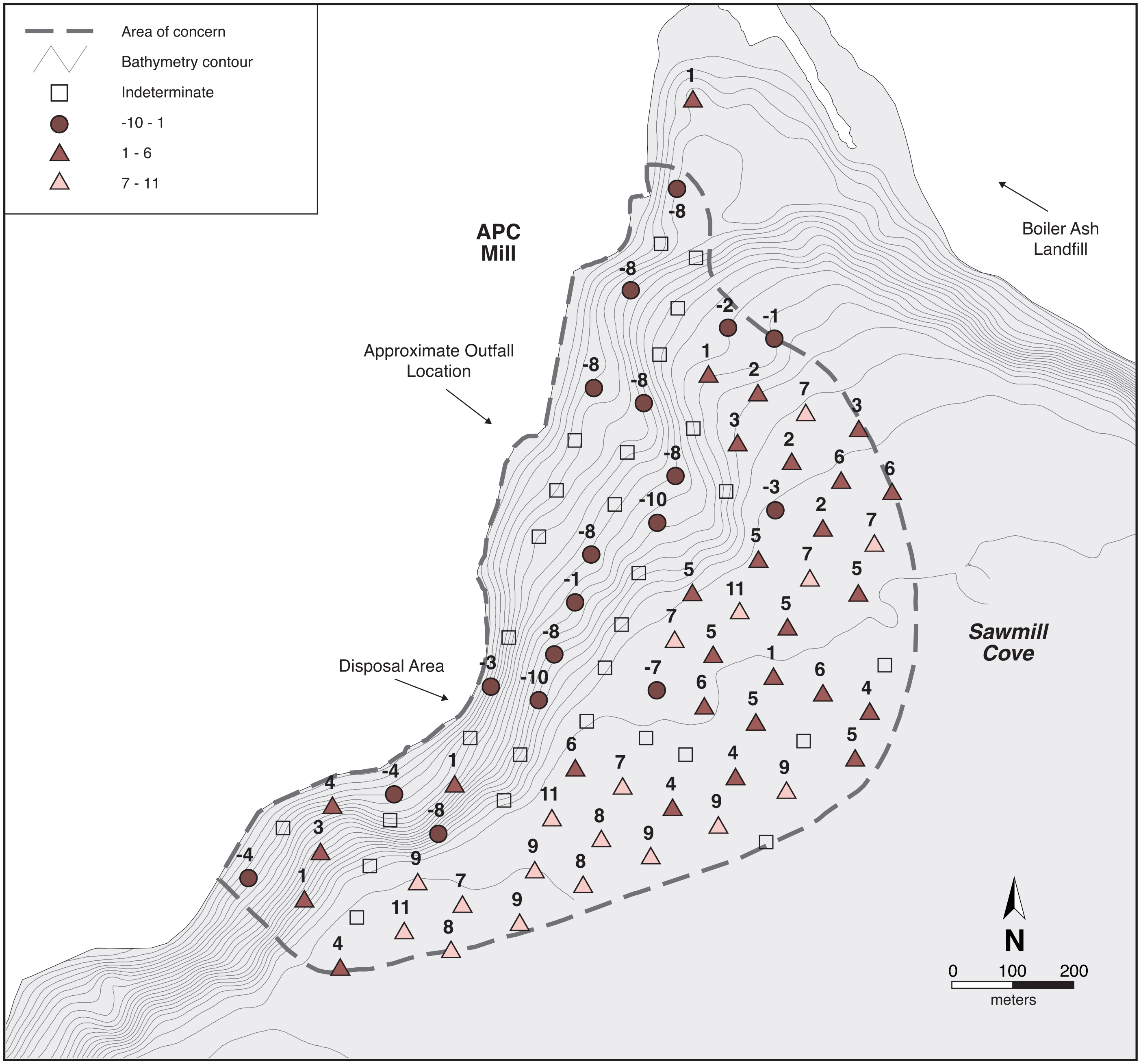

Figure 2-27. Distribution of OSI values within the AOC.

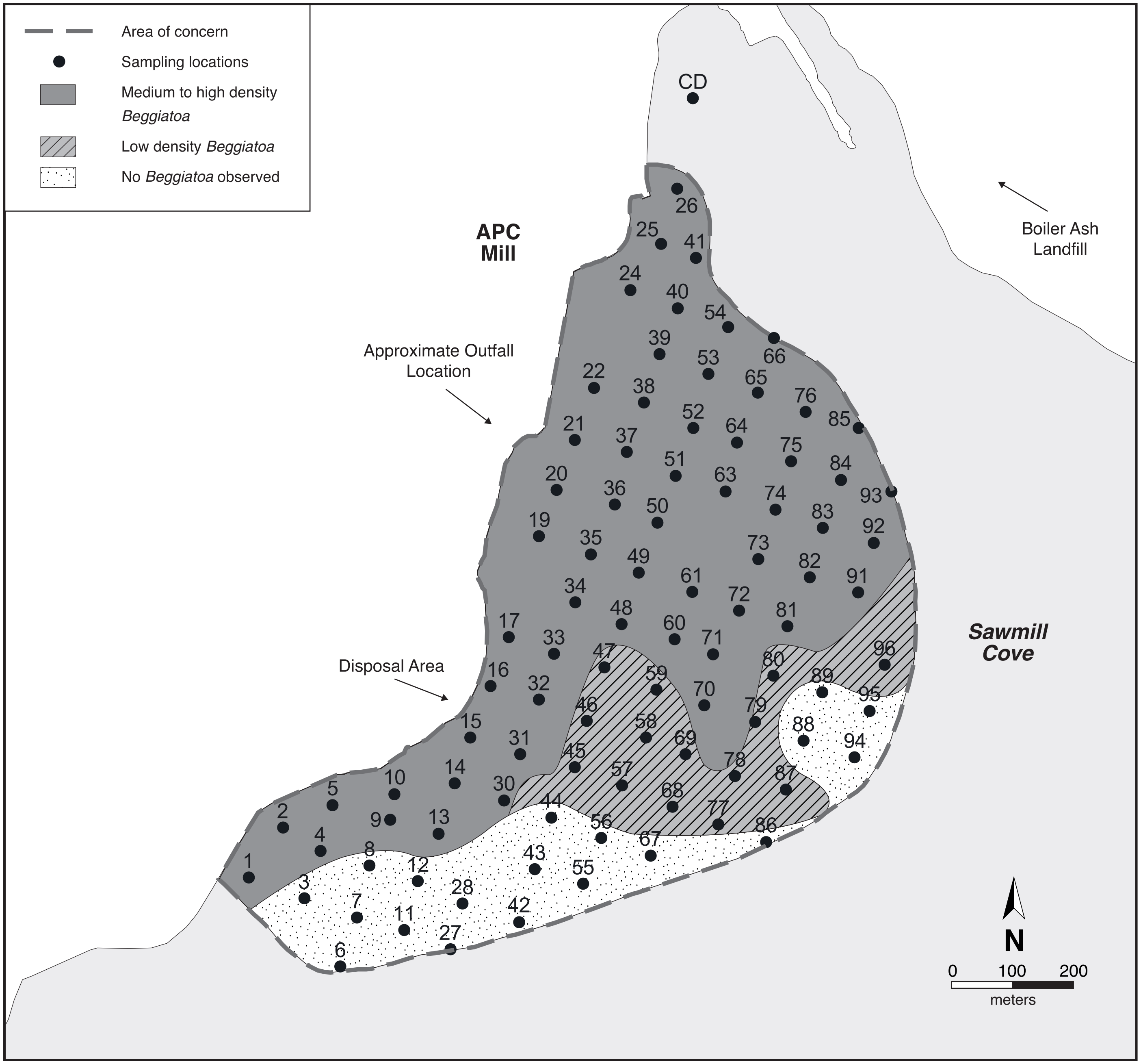

Figure 2-28. Combined *Beggiatoa* results.

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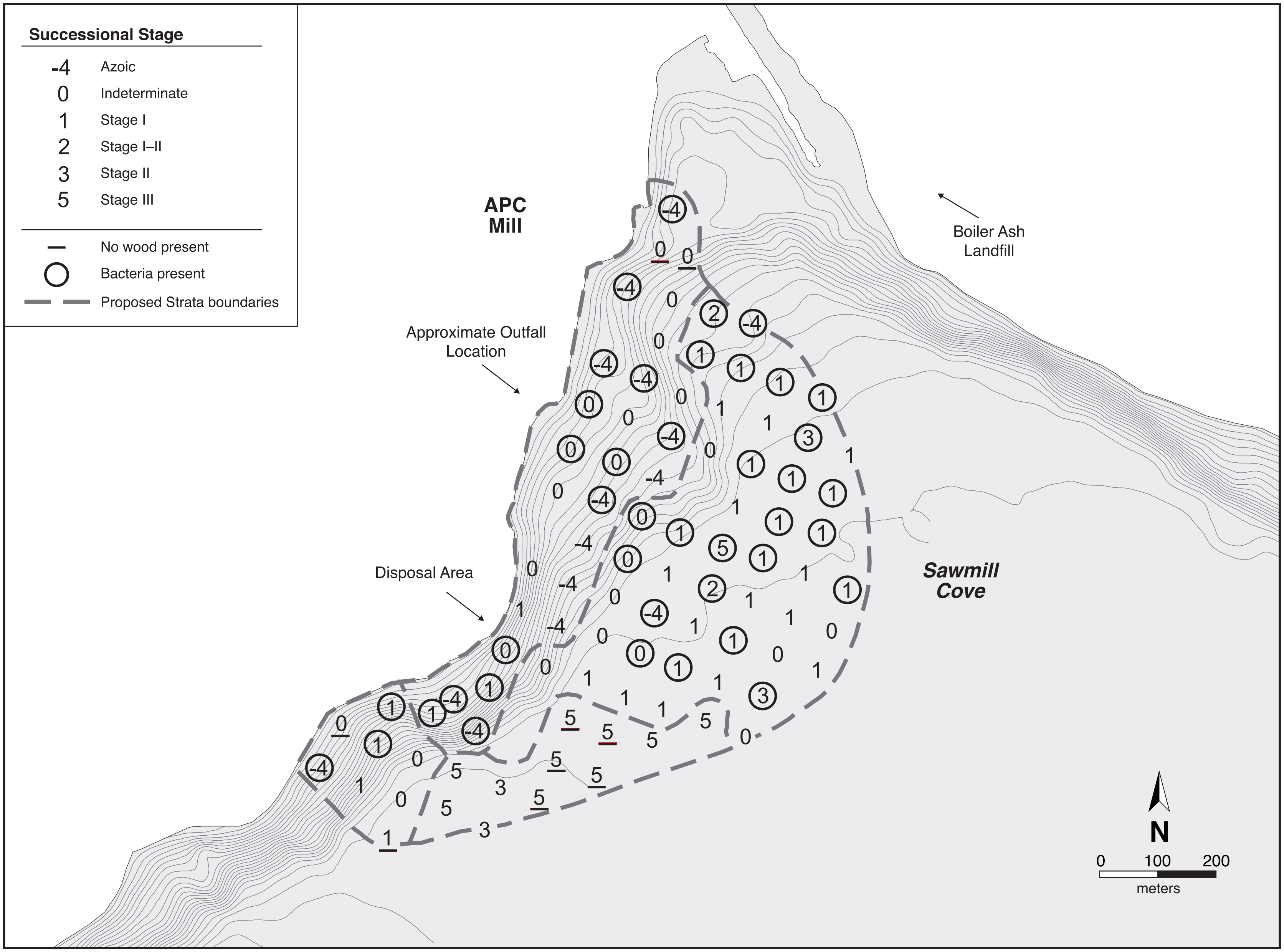

Figure 2-29. Proposed Phase II strata with SPI results.

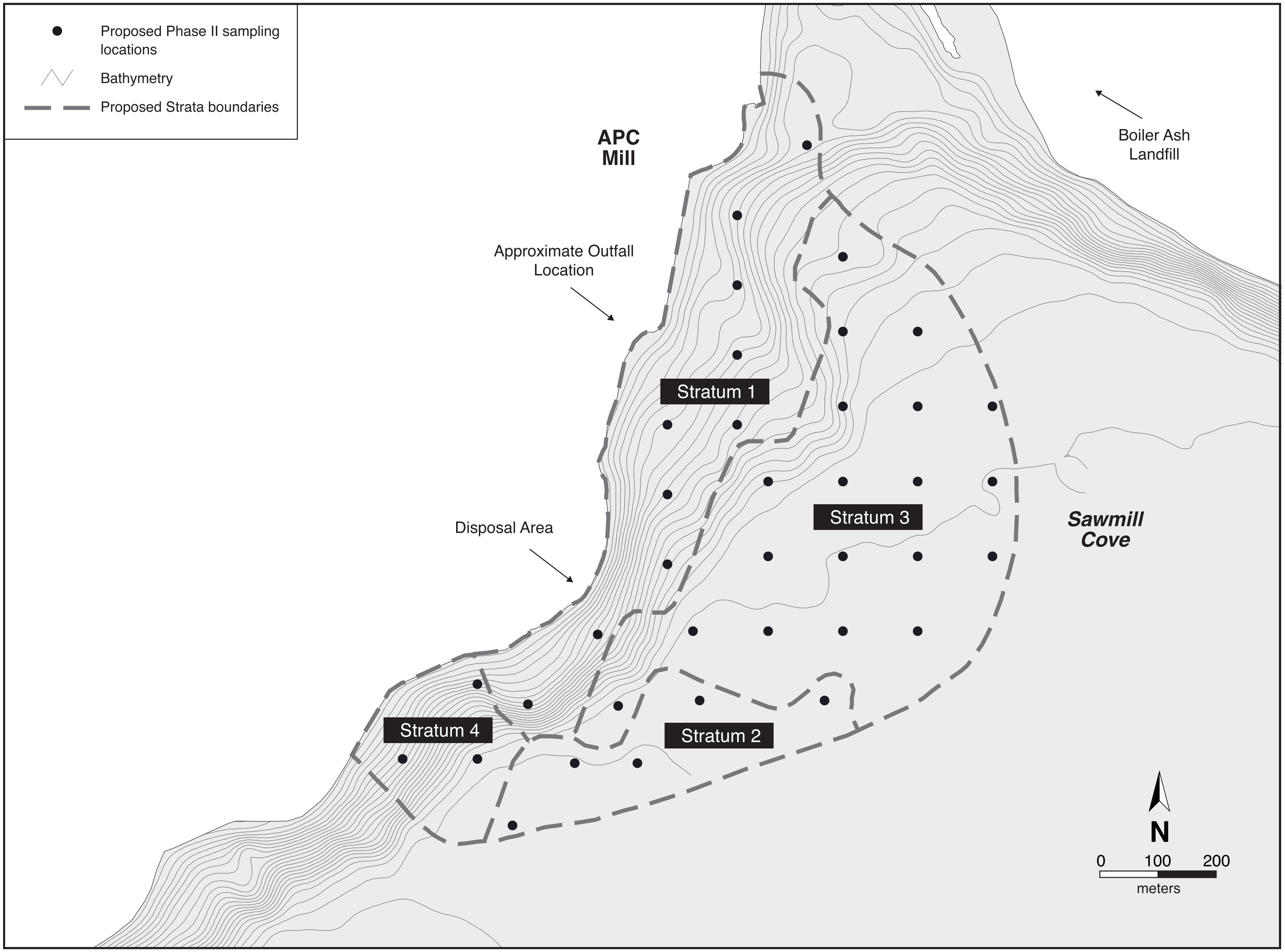

Figure 2-30. Proposed sampling locations for Phase II.

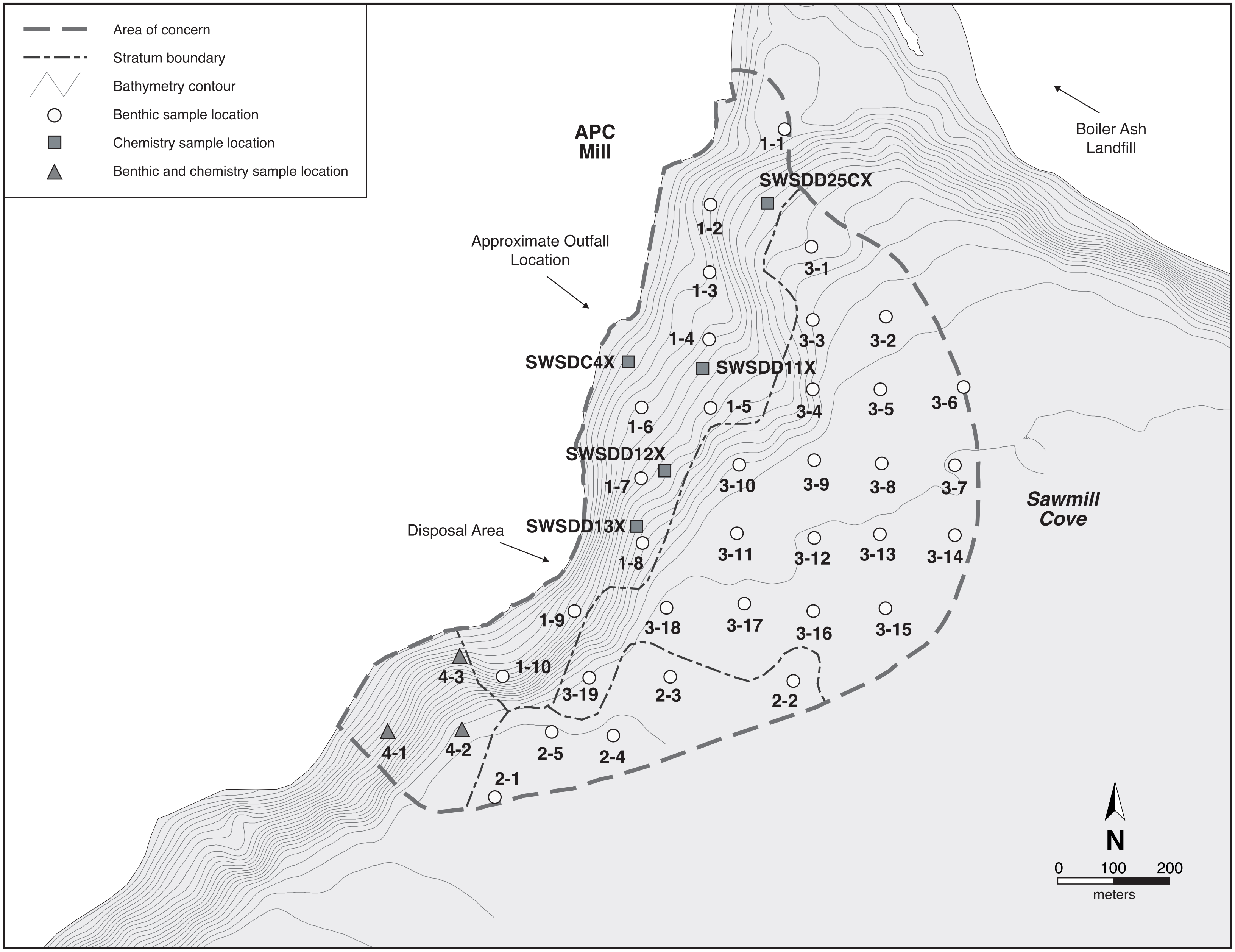

Figure 3-1. Benthic station locations.

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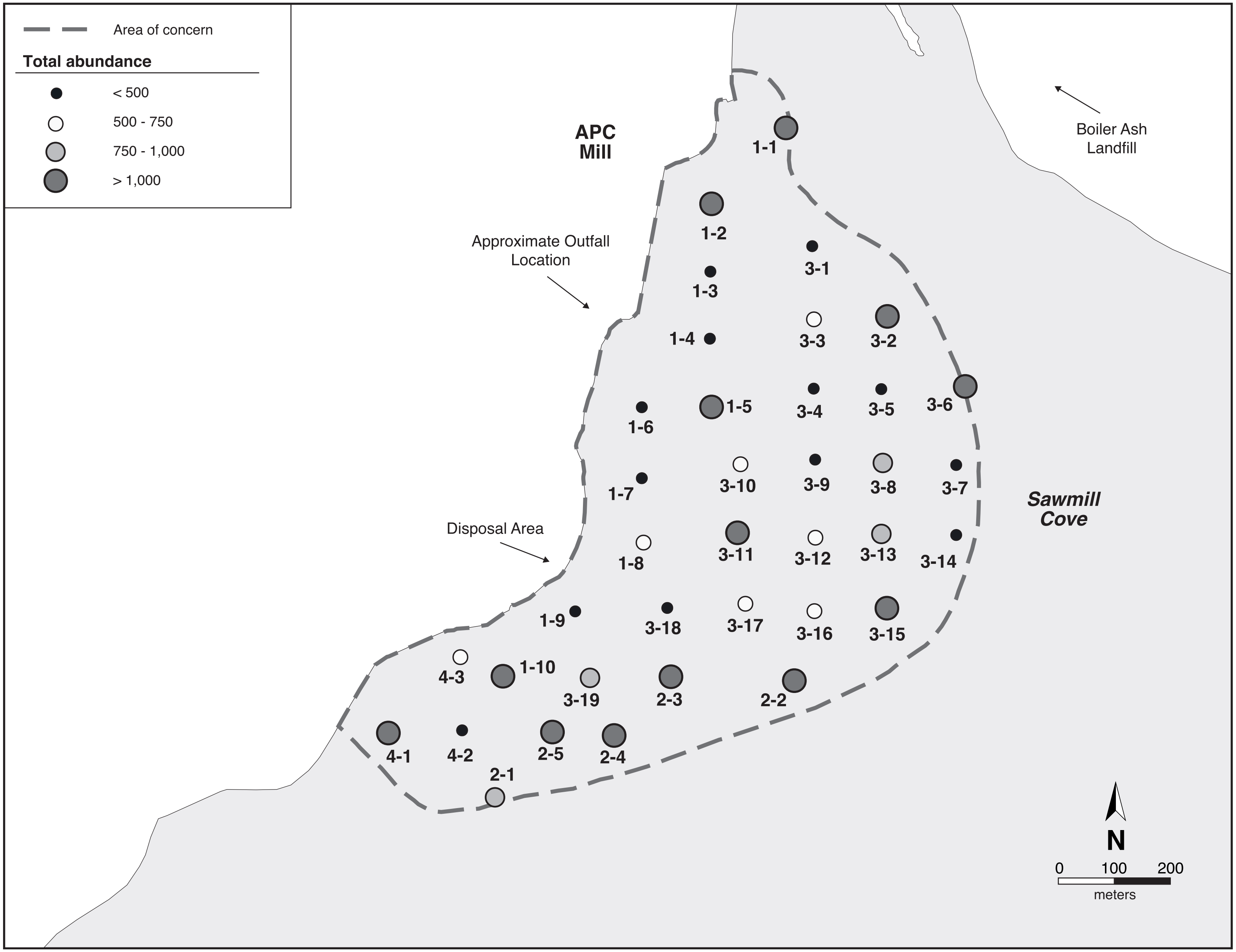

Figure 3-2. Total abundance counts per m^2.

Figure 3-3. Biomass grams per m^2.

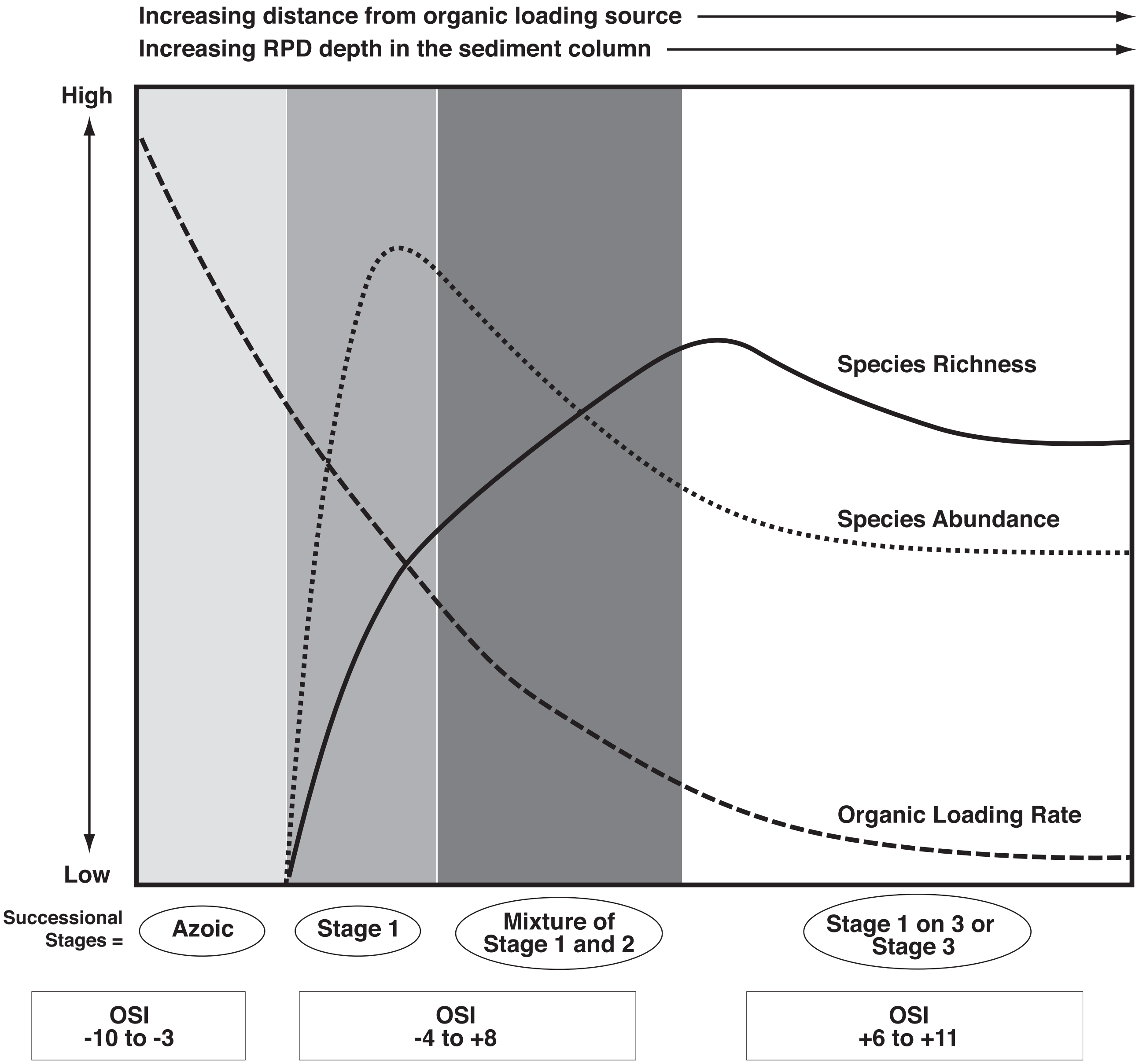

Figure 3-4. Relationship between SPI parameters (boxes along x-axis) and traditional benthic measures of species richness and abundance along a hypothetical organic enrichment gradient.

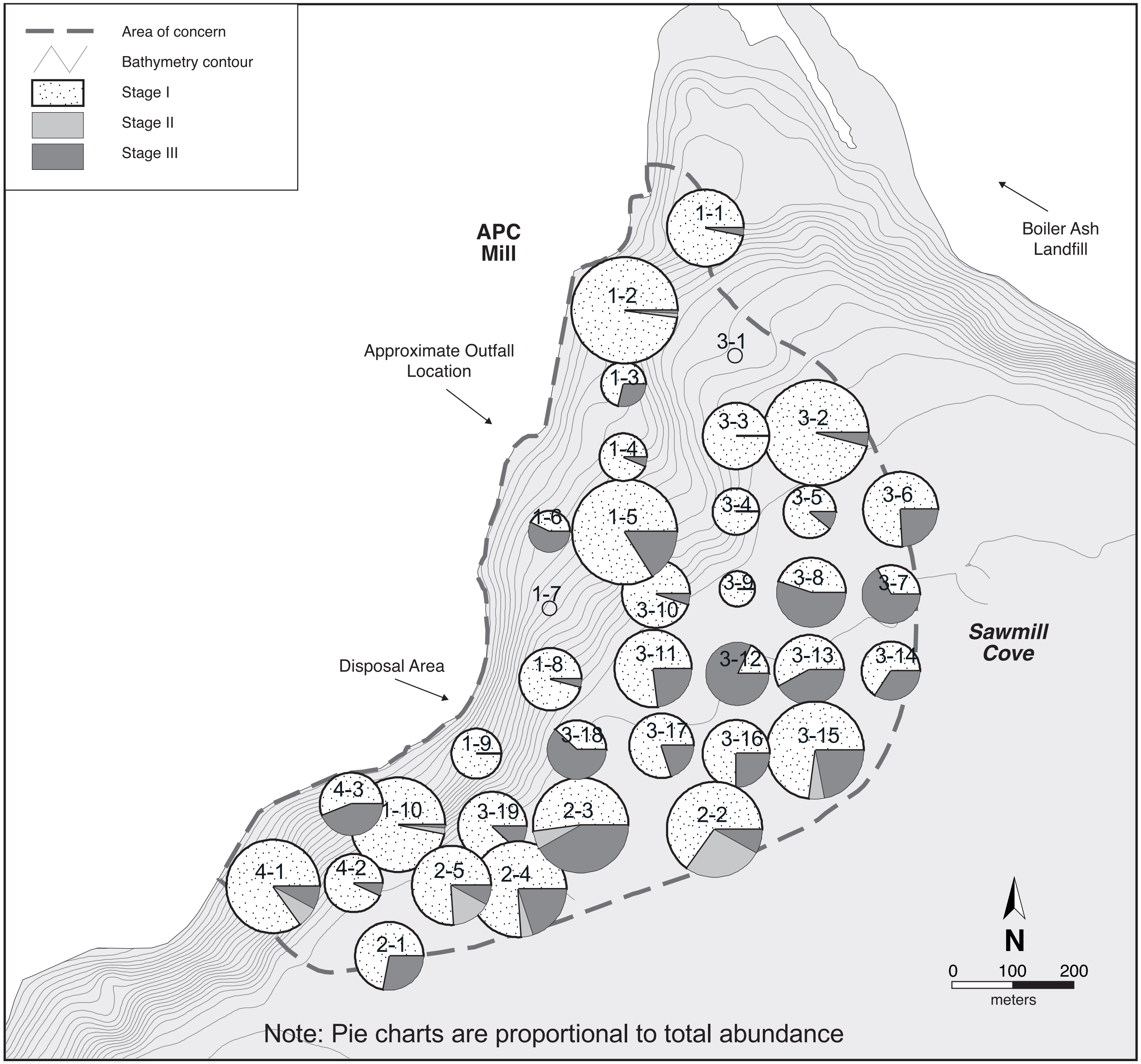

Figure 3-5. Distribution of benthic taxa by successional stage and abundance.

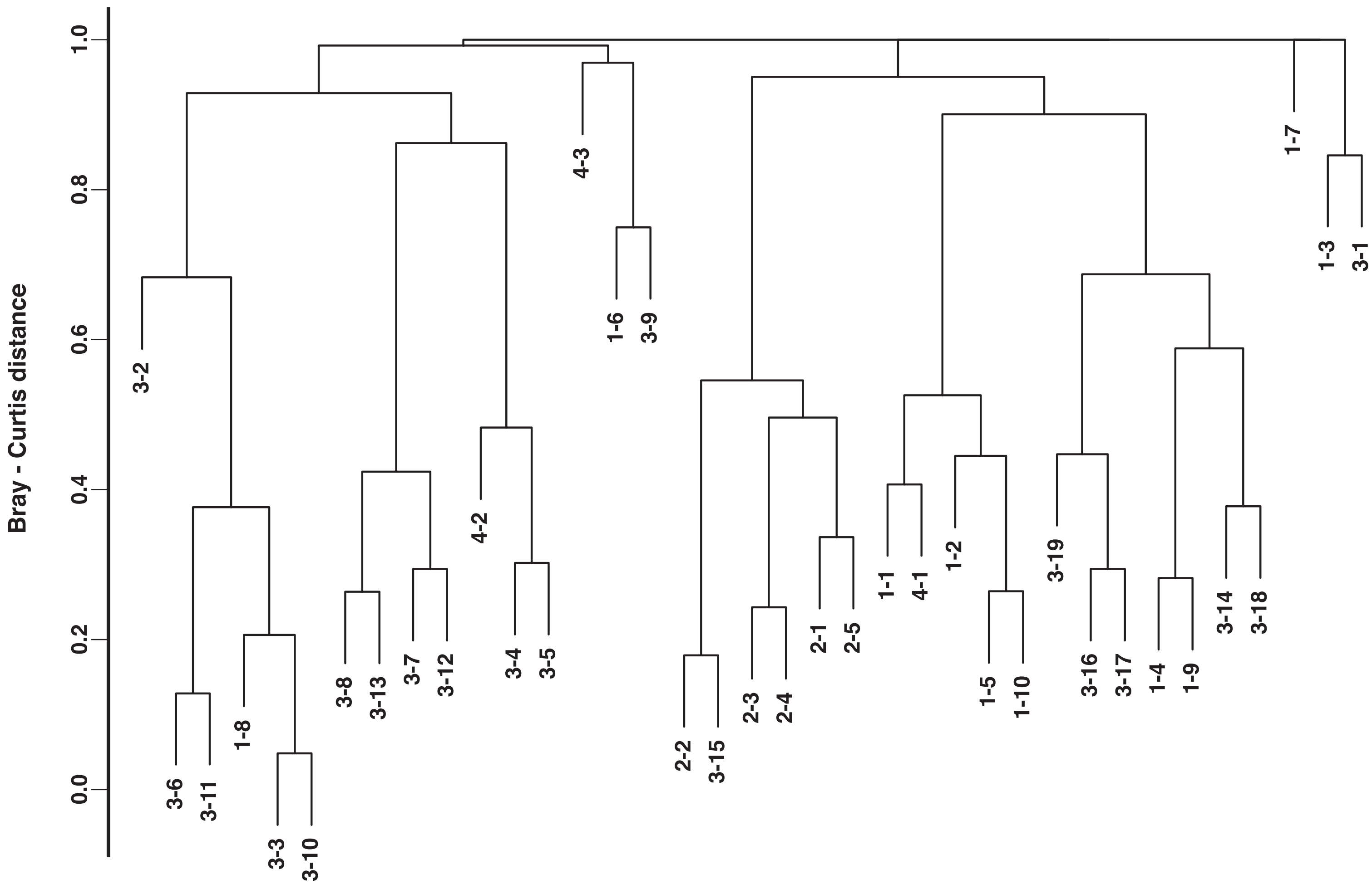

Figure 3-6. Dendrogram of results based on Bray-Curtis distance metric of family abundances for Sawmill Cove 2000 survey.

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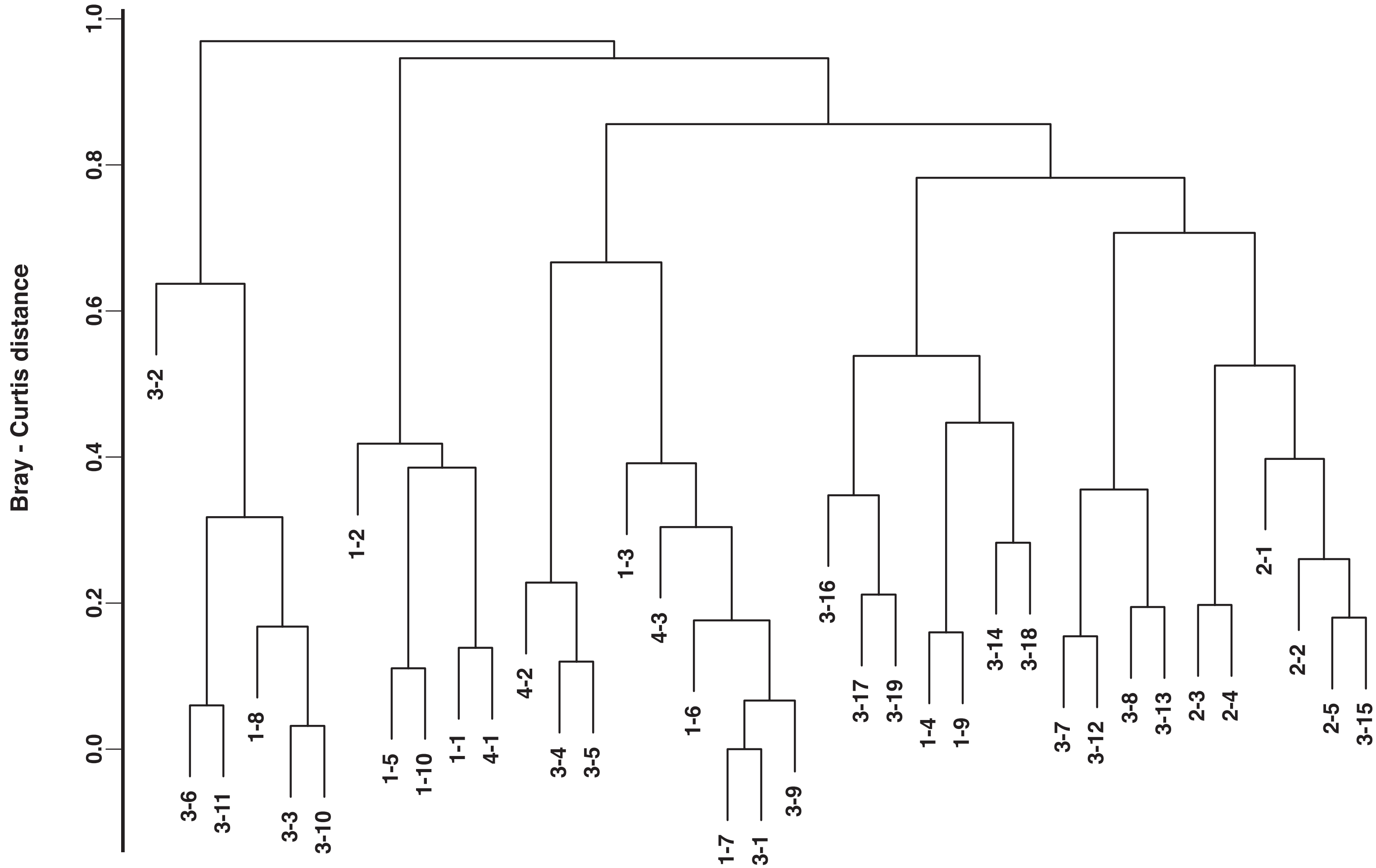

Figure 3-7. Dendrogram of results based on Bray-Curtis distance metric of dominant families for Sawmill Cove 2000 survey.

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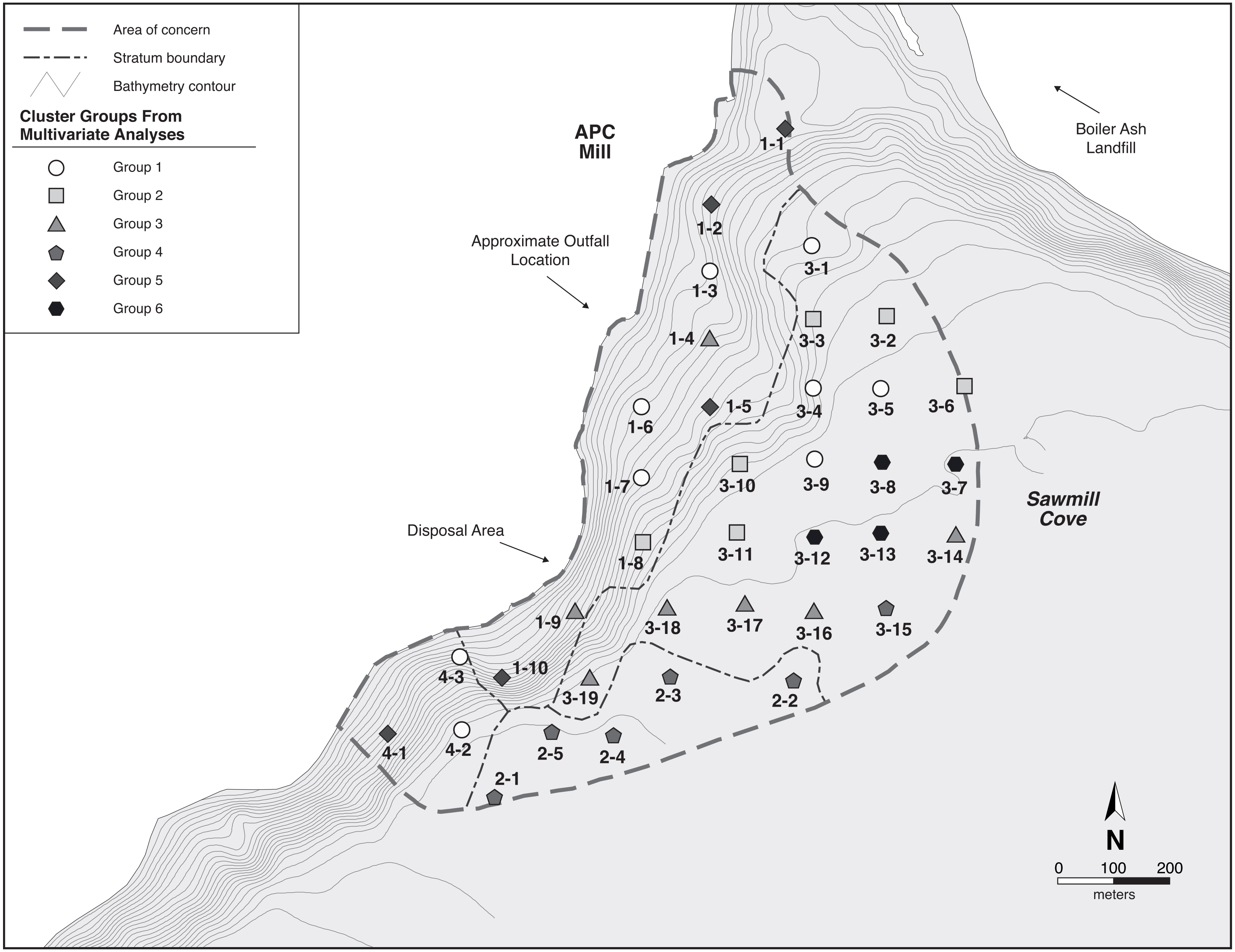

Figure 3-8. Station groupings with original strata.

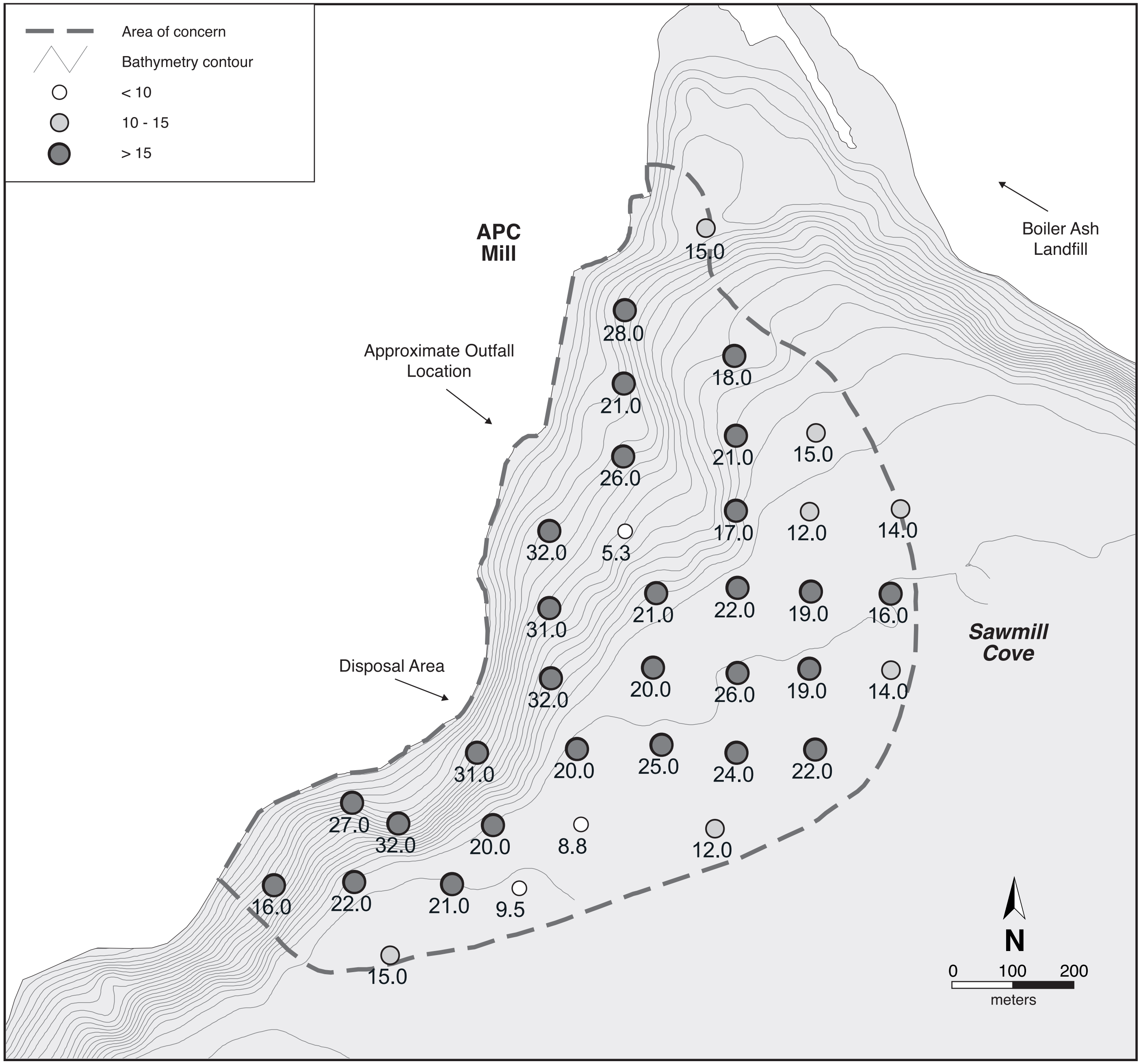

Figure 3-9. TOC concentrations.

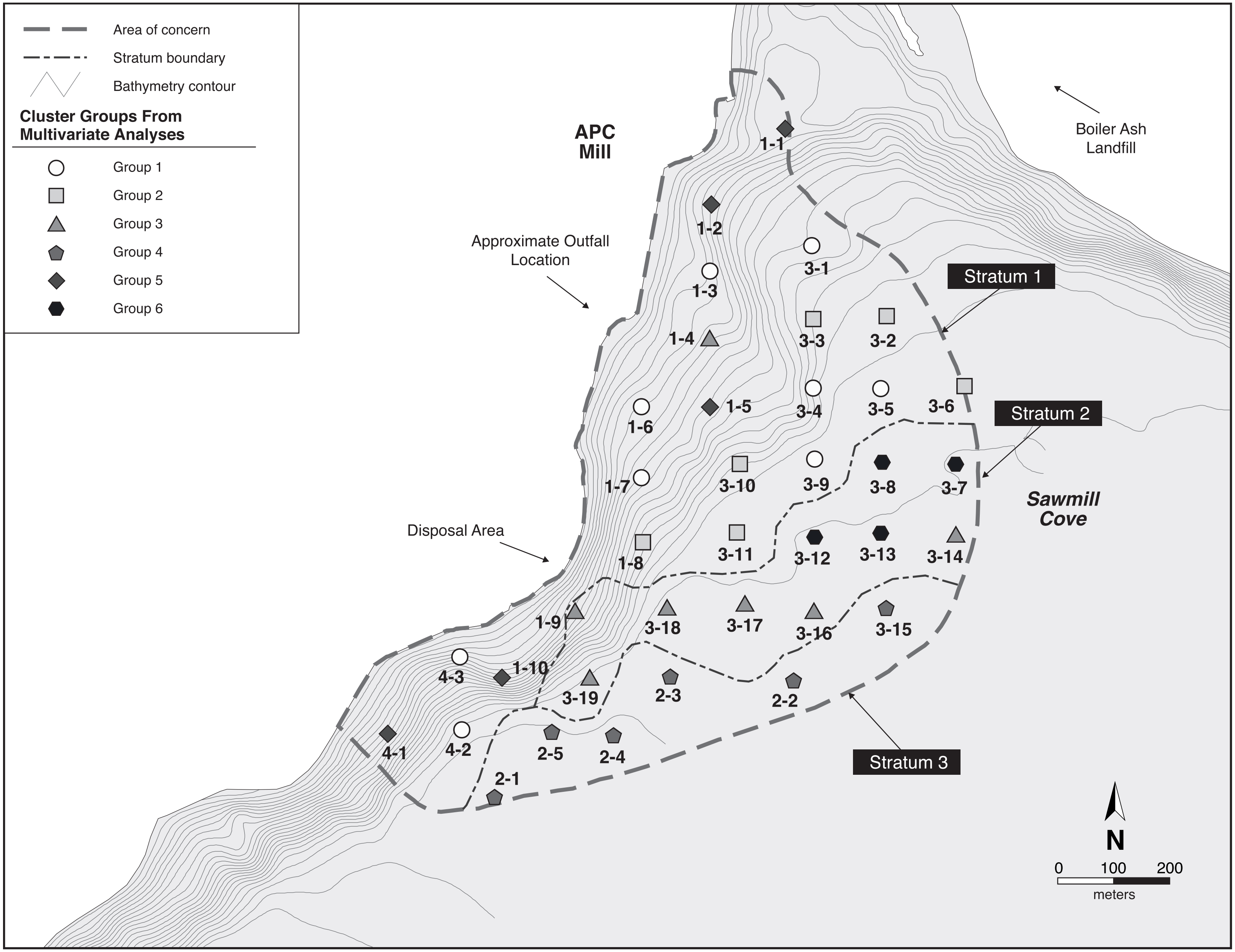

Figure 4-1. Station groupings with new strata.

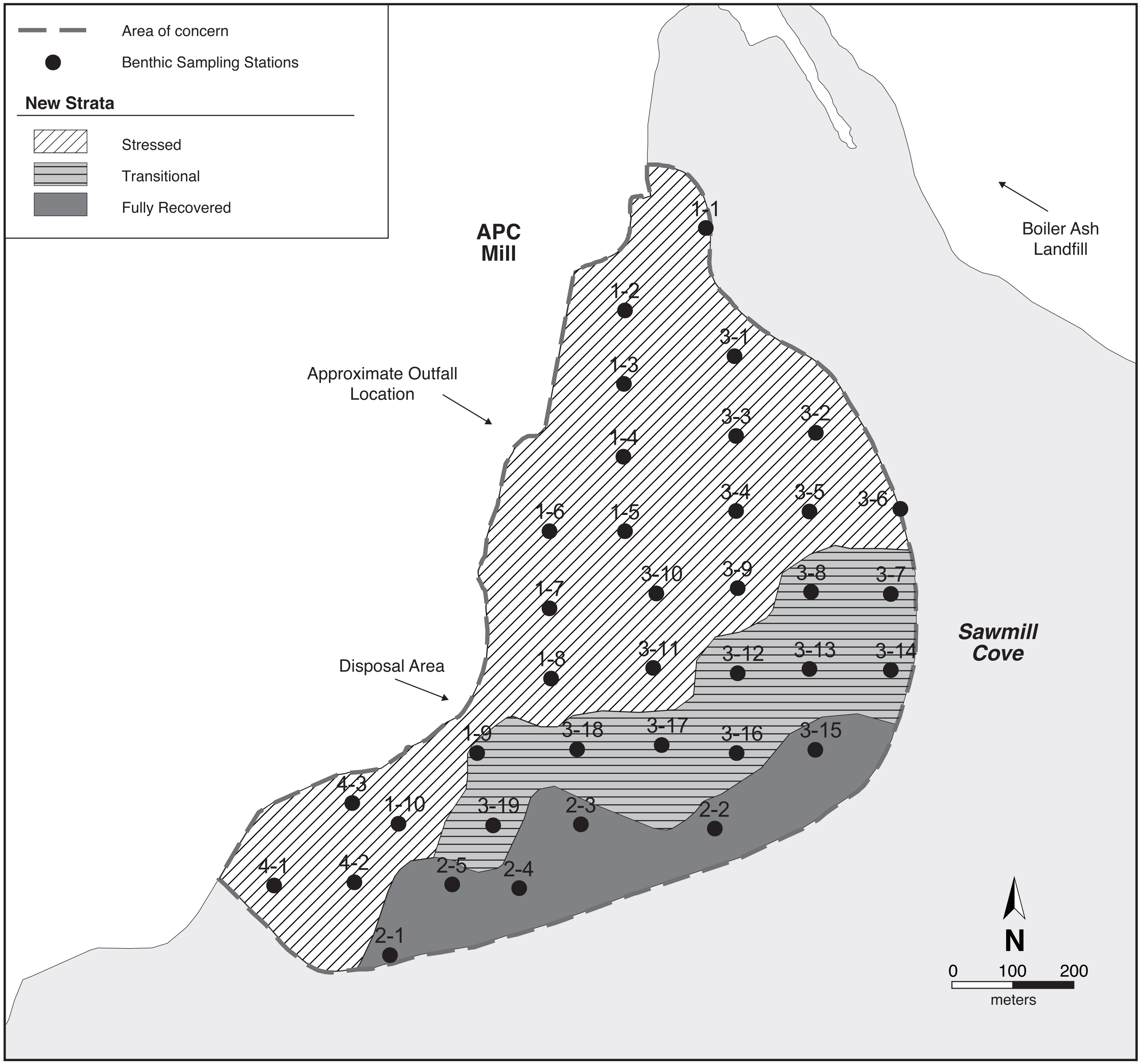

Figure 5-1. Revised AOC strata based on grab sampling and SPI survey results.

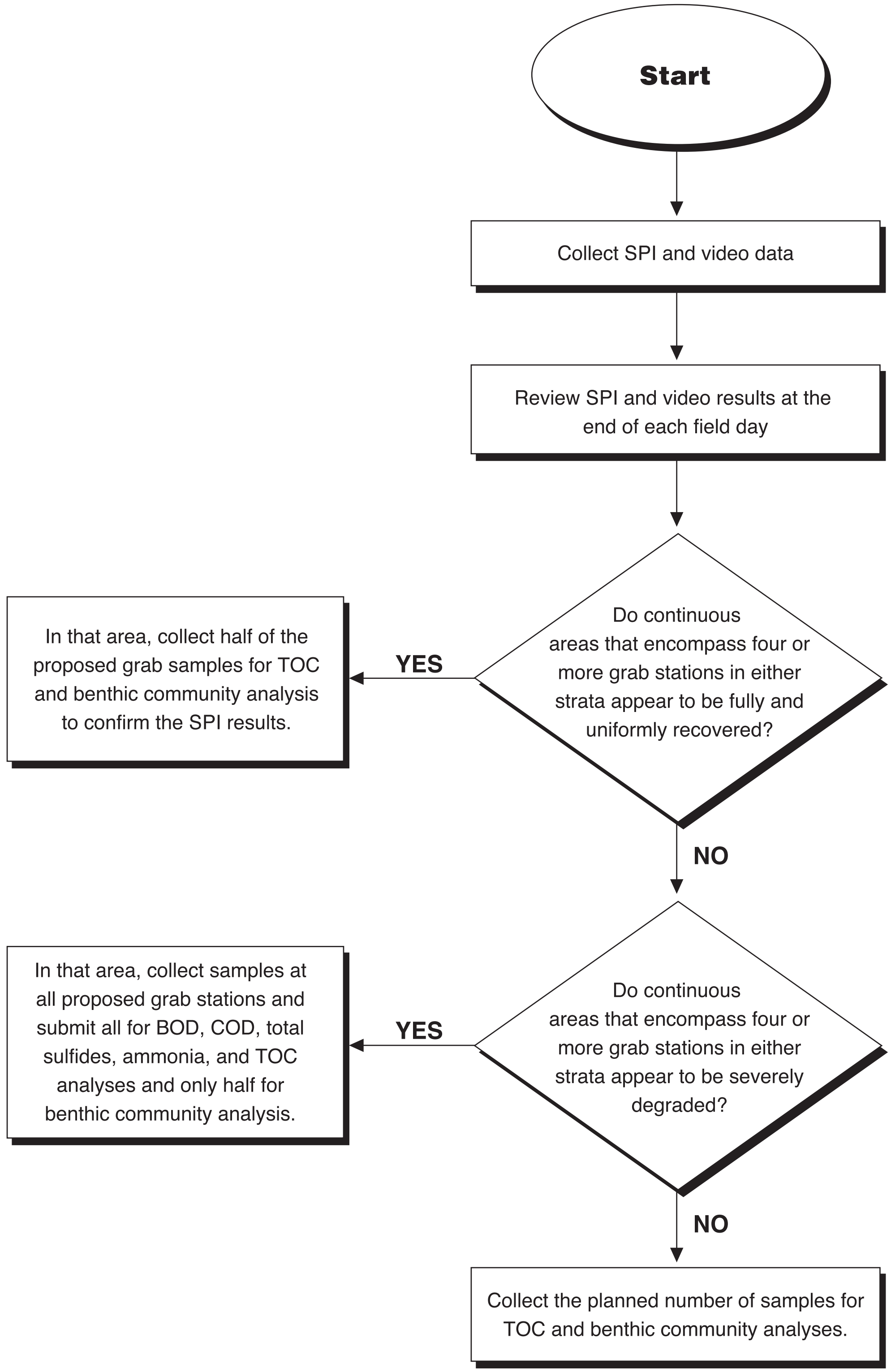

Figure 5-2. Flow diagram for execution of proposed sampling plan.

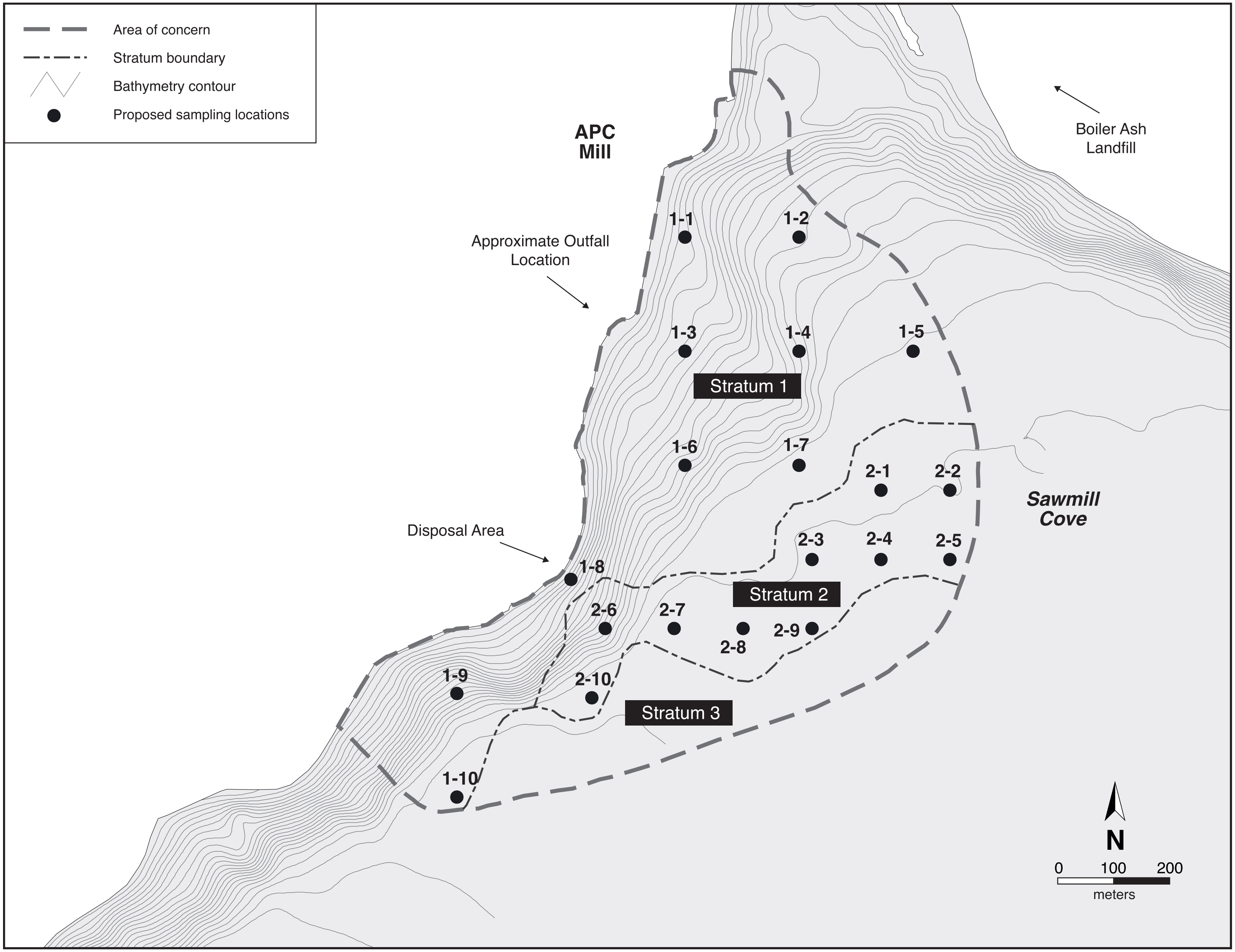

Figure 5-3. Proposed benthic sampling locations for next monitoring survey.

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