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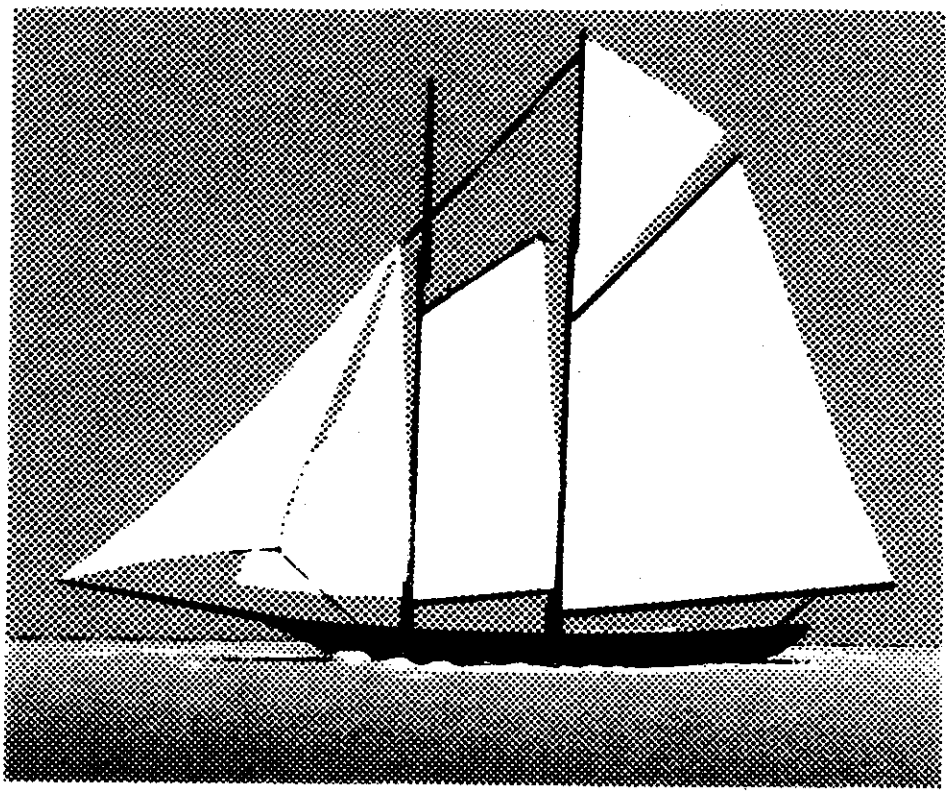

OCEANOGRAPHIC INSTITUTE OF OREGON

A Summary of the Benthic Invertebrate Information in the Region of Existing Offshore Disposal Sites Off of the Mouth of the Columbia River

September 1997

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A Summary of the Benthic Invertebrate Information in the Region of Existing Offshore Disposal Sites Off the Mouth of the Columbia River.

-by-
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September 1997

Introduction

This report was commissioned by the Corps of Engineers (COE), Portland District to assist the working groups of the Columbia River Offshore Disposal Site Workshop. This report reviews and evaluates the knowledge from numerous benthic studies which have been completed in the vicinity of the Mouth of the Columbia River (MCR), during the years 1973 to 1995, and characterizes the marine communities offshore of the Columbia River to assist in the evaluation of dredged material disposal options. This report also displays graphically (Geographic Information System, GIS) the areal extent of this information. The study evaluated research conducted within the boundaries 46°.00' to 46° 25' N Latitude by 123° 55'W to 124° 20'W longitude. The specific locations of the sampling, density (number per unit area) of the fauna and sediment particle size and organic content are also graphically illustrated.

This report also considers and addresses questions that the participants identified as being useful to them. Specifically, the participants to the Fisheries and Biological Resources Work Group in their meeting on July 23, 1997 requested that this report address the following:

- The history of dredging and disposal at MCR
- A review of the adequacy, validity, and representativeness of samples.
- A summary/description of all available studies
- A discussion of the correlation between benthic and fish data
- A discussion of whether the dominant species sampled are important food chain species or not important at all.

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Structure of the Report

Section 1 summarizes the history of dredging and disposal at the MCR. Section 2 presents an outline of benthic ecology and describes sampling methods and principles relevant to our inquiry. It outlines concepts underpinning sampling and data analysis including validity and representativeness. Section 3 discusses benthic infauna off the MCR, Section 4 summarizes the information contained in the the research studies of the the benthos of the MCR and Section 5 provides a summary of the research studies reviewed.

Section 1: History of Dredging and Disposal at the Mouth of the Columbia River

The US Army Corps of Engineers, Portland District has removed substantial quantities of sediments from the navigational channel in the Columbia River and its estuary since 1885 when dredging was initiated for a 30 foot deep channel across the entrance bar. In order to maintain a consistent 30-foot channel across the bar, the south side of the river entrance was jettied between 1885-1889. Additional deepening to 40 feet was begun in 1905. The north jetty was built in 1913.

The project was deepened to 48 feet between 1954 and 1956 and further deepened to 52 feet in 1979. In 1984 the northern 2000 feet of the 2640 foot wide MCR channel was deepened to a maximum depth of 59 feet (including over dredging).

The use of open water sites for disposal of dredged material became standard practice after 1945 and has continued to the present. Before 1977, the COE had identified several offshore areas on the navigational charts where dredged material was routinely disposed. These were described by approximate location and the disposal within the sites was not strictly controlled. In 1977, the Environmental Protection Agency (EPA) issued the final Ocean Dumping Regulations (40 CFR 228), requiring established disposal sites. At this time the MCR ocean disposal sites A, B, E and F received interim designations. The interim sites were rectangular in shape and smaller in size than many of the other interim sites around the country. Final site designation of sites A, B, E, and F occurred in 1986. With stricter enforcement to insure disposal within the sites, and because navigational precision had improved significantly over the years, the small rectangular sites were unable to disperse the sediments quickly enough. Mounding has occurred at some of the final designated sites and the COE has received interim approval from EPA to enlarge sites B and F.

In 1973 the COE Waterways Experiment Station, (WES), initiated and contracted studies to identify and determine the significance of physical, chemical and biological factors that govern the rate at which open-water dredged material disposal sites are colonized by benthic communities. Additional monitoring studies of specific disposal sites were

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subsequently undertaken by the Portland District between 1983 and 1996. Technical aspects of the studies reviewed in this report are summarized in Table 1.

Section 2: Benthic Communities, Sampling and Data Analysis

2.1 Infauna
- **2.1.1 Characteristics of the Benthic Infauna**
- **2.1.2 Infauna and their Importance to Impact Assessment**
- **2.1.3 Infauna Sampling and Analysis**

2.2 Epifauna
- **2.2.1 Epifauna and Their Importance To Impact Assessment**
- **2.2.2 Epifauna Sampling and Analysis: Limitations and Concerns**

In this report, we focus on benthic data because benthic populations tend to integrate all of the physical and chemical attributes of the environment. They have been shown to be sensitive to impacts such as direct burial, organic loading and changes in sedimentary characteristics, hydrography and water quality. It is this feature which allows ecologists to make interpretative and predictive assessments.

The benthos consists of organisms that live on or in the bottom. For convenience they are categorized into two groups –infauna and epifauna. It is important to note that organisms may fall in different categories at different stages of their life histories. Infauna and epifauna are discussed below. In the context of these sections we also discuss sampling and data analysis issues that were raised by the participants in their questions.

2.1 Infauna

2.1.1 Characteristics of the Benthic Infauna and Importance for the Food Chain

Benthic infauna are those organisms which live in the sediments either attaching to the substrate, living in tubes, or burrowing through the sediments. Infaunal communities are widely used in the scientific community for ecological assessments as they tend to be more stable (less motile) than epifauna such as crabs or bottom fish. Furthermore, infauna have been shown to provide an important ecological role in the breakdown and mineralization of nutrients, and serve as important prey items for larger organisms. The infaunal assemblages consist of worms, amphipods, small clams, anemones and small crustaceans.

2.1.2 Infauna and their Importance to Impact Assessment

The sedentary nature of the infauna makes sampling quantifiable and therefore aids in the sample to sample (between sample) and habitat to habitat (between habitat) assessment of ecological change and aids in determining impact assessment. Even though they are often

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TABLE 1

Summary of Bottom Invertebrate and Fish Data

from the Mouth of the Columbia River

Reference	Years Sampled	Number of Sites	No. Samples	Navigation	Disposal Status	Realm Sampled	Sampling gear/screen	Statistical Reporting	Disposal sites	Comments
M. D. Richardson, A.G Carey Jr. & W.A. Colgate, 1977	1974,1975 & 1976	12 cruises, 25 stations for distribution and density, 20 stations for benthic assemblages	2190 total 1,657 for infauna 73 beam trawls 369 sediment	Del Norte & Loran A	pre and post	infauna, macro meiofauna epifauna	Smith-Mcintyre (0.1m2) 1.0mm screen metered beam trawl (3m)	Density, diversity Cluster analysis	B, exp E	Baseline and seasonal information on invertebrates throughout the ZSF including pre and post disposal.
J.T. Durkin and S.J. Lipovsky, 1977	1974,1975, &1976	5	151 (5m & 8 m)	Loran A	Pre and Post	epifauna, fish crabs	Semi-ballon shrimp net (otter trawl)	Density, diversity	exp E	Companion to Richardson 1977 but areal coverage reduced.
G.T. McCabe Jr., R.L. Emmett and R. J. McConnell, 1986	1983-1985	6 ocean 22 estuarine				Dungeness Crab	Semi-ballon shrimp net, (8 m) (otter trawl)	Distribution, density age class	none	Six offshore stations sampled Primary emphasis was in the estuary
M.D. Slipola, 1993	1989,1990, 1991, 1992	13 infauna 3 trawl	trawls (12)	Loran C	Pre and Post	infauna epifauna	Gray O'haraBox Core (0.1 m2) 0.5mm sieve Semi-ballon shrimp net (otter trawl) - 8 m	Density, diversity Principal Component Analysis	H F	Study of offshore disposal for Tongue Point Sediments
Hinton and Emmett,1994	1992	51 infauna 4 Trawl	45 infauna singles 30 replicates at 6 stations	GPS	Existing sites	infauna epifauna /fish	Gray O'haraBox Core (0.1 m2) 0.5mm sieve Semi-ballon shrimp net (otter trawl) - 8 m	Density, diversity Cluster Analysis	A,F,B	Study of offshore disposal site with comparisons to Richardson 1977
Emmett and Hinton 1995	1993	28	140	GPS	Existing sites	Infauna	Gray O'haraBox Core (0.1 m2) 0.5mm sieve		A,F,B	with comparisons 1989-1993 Five station groupings with six which did not cluster. Density increased from '89 to '91, leveled off in '02 decreased in '93
Hinton and Emmett,1996	1994	29	145	GPS		Infauna	Gray O'haraBox Core (0.1 m2) 0.5mm sieve	Density, diversity, equibility Cluster Analysis	A,F,B	with comparisons 1989-1994 Five station groupings with six which did not cluster. Density increased from '89 to '94, except in 1993 when it decreased .
Hinton and Emmett , 1997? (By FAX)	1995	36	180	GPS		infauna	Gray O'haraBox Core (0.1 m2) 0.5mm sieve		A,F,B	No information

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small in size, and exhibit some seasonal cycles in abundance, some species are often long lived and are known to be good indicators of the health of their habitat. Since they cannot move away easily, the infaunal assemblages (groups of different taxa and species living together) have been shown to provide a good indicator of changes in the health of an ecosystem.

2.1.3 Infauna Sampling and Analysis

Quantitative sampling of infauna requires a sampling device whose cutting area and depth of penetration are known in order to determine the surface area and volume of a sample which is used for the calculation of density. The sampling characteristics of the sampler can be determined by repetitive sampling. Richardson et al. 1977, collected twenty replicate infaunal samples from a single site and calculated a mean Bray-Curtis dissimilarity index for each of 190 sample pairs to determine how many replicates were needed to have a statistically representative sample. The results indicated that a single sample was not a good estimate of the relative proportion of individuals of dominant species at a site. The results indicated that that five grab samples were necessary to characterize each site. Five replicates samples were therefore taken at each site for the baseline study and also in all subsequent studies we reviewed.

Similarly, comparing the variance of a population at a single site (within station variability) with the variation at another site (across station variability) can be used to determine if differences between sites are significant. An individual station can thus be compared against itself over time (temporal) to determine seasonal or trending differences or with distant stations. In addition natural variability can be evaluated with other events such as disposal of dredged materials.

2.2 Epifauna

The epifauna consists of the larger more mobile bottom dwelling forms of invertebrates and vertebrate organisms which are usually only captured by trawl nets or baited bottom traps. Typically the epifauna in the Pacific Northwest is represented by organisms such as crabs, sea cucumbers, sea urchins, flatfish, black cod, shrimp and scallops. Many of the epifauna are commercially or recreationally important species.

Feeding studies on epifauna indicate a variety of dietary patterns; preying directly on the benthos, scavenging on organic and decaying tissue and deposit feeding (ingesting sediment). Numerous food habit studies have been conducted on Pacific Northwest species, particularly flatfish. These provide the best evidence for understanding the role infauna play in important commercial fisheries.

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2.2.1 Epifauna and Their Importance To Impact Assessment

Epifauna are less amenable for use in impact assessments than infauna because of the difficulties in quantification. Quantitation of epifaunal samples is much more difficult than for the infauna.

2.2.2 Epifauna Sampling and Analysis: Limitations and Concerns

Sampling for epifauna is normally achieved by trawling a large net with a weighted bottom or foot rope and a buoyant head line to create an opening. The sides are spread by the water pressure created by pressing on large bottom hydrofoils (doors, otter boards). The nets are fishing both on the way down to the bottom as well as on the way up thereby contaminating samples with pelagic (free swimming) organisms. It is sometimes difficult to separate the pelagic and epifaunal species when this occurs.

It is also difficult to know the precise time a trawl begins to reach bottom, or if it is fishing the entire duration of the tow. Weather conditions affect trawl speed and thus catch rate. Some studies used a constant time on the bottom such as a 5 minute tow. Since the actual distance covered varies with currents and ship speed, the distances traveled over the ground in a given unit of time can be quite variable. Many of the larger faster swimming organisms can avoid the nets.

Quantification of trawl samples is usually reported by calculating the area trawled from the width of the net opening by the distance traveled or the time of the tow. Because of these variables, trawl information for density (number/hectare), tends to be much more variable. Trawl information however, is valuable to determine species composition, the age class and seasonal occurrence of the epifauna. It complements quantitative infaunal data in demonstrating presence and absence of important species, and areas frequented by juveniles and adults.

Since the information on sampling and quantification of infauna are quite different from the epifauna, the discussion of adequacy of information is treated separately when the results of studies in the MCR are presented below.

Section 3.0: Summary and Description of Available MCR Benthic Studies

In an effort to provide information useful to the overlay process as well as respond to the participants request to provide a summary and description of available MCR studies, available studies regarding the benthos were reviewed. Although many of the research studies were performed with somewhat different specific goals and objectives, there are elements, which each of the studies have in common, that allow some comparisons. Comparisons are especially useful in the case of the benthic infauna studies. Similarities

of past studies which allow comparison are:

- Each study focused on baseline benthic information or dredge material disposal, either for site location, or monitoring of specific disposal areas or projects.
- All but the 1977 study uses the identical quantitative sampler
- All but the 1977 study use the same mesh size
- The same group of professional taxonomists made identifications for all of the studies; as a result, there is taxonomic consistency in the data
- The sampling areas covered are within the overall MCR study area.
- All used quantitative sampling for infauna.
- All studies report areal concentrations in numbers of organisms (or density) and are directly comparable (except for the 1977 study which is approximately comparable).
- All had sample replication information (either published or available from authors).

In our review, we aggregated the data from the epifauna and infauna studies, where possible, to provide a more complete data base for the MCR area. This information provides information helpful to the overlay process as well as helps us respond to questions raised by the participants including responding to their request that this report summarize and describe available studies for the MCR.

Since our goal was to summarize the benthic invertebrate data (infaunal and epifaunal) in a manner consistent with determining differences in "standing stock" throughout the study area, normalizing the abundance information to a common denominator such as the number of organisms per unit area would be the most appropriate method of comparing these data sets. Density or concentrations of benthic invertebrates per unit area are therefore used in the GIS summaries. Higher detail community measures such as diversity, species richness and clustering algorithms are presented in the original studies.

Table 1 identifies the individual research studies, the period the sampling occurred, the equipment used and provides a tabular summary of the pertinent information used as the basis of this report. Although the theoretical aspects of the field of benthic ecology has not changed dramatically during the periods in which these studies of the MCR were undertaken, certain changes in navigational accuracy, statistical techniques for displaying the information and sampling protocols have changed. We do not believe these changes in anyway hinder the inter-comparison of studies for sample coverage in the study area, or faunal type and abundance.

Station locations reported in each study were digitized and entered into the GIS with latitude and longitude co-ordinates. When station information was reported as Loran C navigational units it was converted to latitude - longitude on a base map of the Study area.

All abundance information was converted to number of organisms per meter square (no./m^2). The information was then graphically displayed to show: the sampling coverage

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of the study area using : the sampling coverage of each study individually, the infauna and epifauna sampling separately, and the coverage of the combined studies.

Figure 1 shows the combined sampling locations of all grab and trawl sampling conducted in the study area. Many of the sites represent multiple years of sampling the same location. Figure 2 combines just the infaunal sampling locations and figure 3 all of the trawl sampling which was reported in the research studies.

Section 4.0 Summary and Findings of the Review of Studies -

4.1 GENERAL FINDINGS
4.2 Infaunal Study Findings
4.3 Epifaunal Study Findings

4.1 GENERAL FINDINGS

The review of studies of the benthos off of the mouth of the Columbia River, indicate both some general as well as many specific characteristics which are useful in describing the biology of the study area. The following discussion collectively summarizes the general and specific findings of the research.

Figure 2 indicates extensive sampling coverage of benthic infauna throughout the study area in both time and space. Although the active disposal sites had a higher concentration of infaunal sampling, the areal coverage of the overall region is quite broad in both the temporal and spatial aspects and is adequate to characterize the benthos of the study area.

Sampling of epifauna, Figure 3 while not as extensive as infauna research studies, can be considered representative of the area if coupled with the agency records of trawling efforts and catch information, and the information from the crab fishing industry. While the information is qualitative rather than quantitative, it can provide the distributional information necessary to locate productive fishing and crabbing areas.

4.2 Infaunal Study Findings

The infaunal studies reviewed, conducted sampling utilizing 1) accepted sampling protocols, 2) accepted sampling replication (five replicates) and 3) organism extraction and preservation techniques. The only exception was the 1977 Richardson study; which d a Smith-McIntyre grab sampler. A Gray O'Hare box corer was used to collect benthic infauna in the other studies. Five replicates were taken at each station during each sampling period.

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In analyzing the results of these studies it is important to recognize that benthic infauna populations generally spread by larval dispersal. Some of these species are opportunistic colonizers and thus are effective in repopulating a disturbed area, such as non-dispersive disposal sites. Many of these opportunistic species are abundant members of mouth of the Columbia River area.

Sediment type is a critical habitat parameter which correlates highly with infauna. Some forms are known to be tolerant of fine grained sediment with high organics while others prefer fine to coarser grain sands.
Study comparability -- With the exception of one study (Richardson et. al. 1977), all of the infaunal studies are directly comparable with many of the stations being revisited in succeeding sampling efforts to be able to evaluate trends (changes over time). The sampling device and taxonomic methodology are of the highest quality. These data allows comparisons of density and species composition between studies.

Sampling validity--The benthic infaunal sampling in all studies followed the most rigorous scientific standards available with the exception of the earliest study which used too large a screen mesh to capture the smaller and more difficult to identify organisms. This study thus underestimates the population density.

Infaunal community of the Mouth of the Columbia River. The off shore area closely resembles the nearshore shallow water sand bottom community typical of the Oregon and Southern Washington coast. The infauna are characterized by species whose evolutionary history has adapted them to high energy environments. These environments typically contain high wave energy, which produces high fluxes of sediment deposition, erosion and transport of sand. Large storms with large waves occur off the MCR which, when combined with the large fresh water output from the Columbia River, and the semi-diurnal tides produce suspended material containing both sediment and organic particulates. The bottoms of high energy environments tend to exhibit sand waves or ripples caused by bottom transport of sand. Organisms have adapted to these hi-energy environs by being highly motile (crabs, fish) rapid burrowers, quick tube builders or rapid colonizers. Nutrients come into the MCR system from the rivers ("outwelling"), from the deep ocean ("upwelling"), and from the surface ("downwelling").

With one exception, the nearshore wave swept zone exhibits the lowest densities, seasonal variability and pachiness. The exception was in 1994, when the nearshore shallow water stations exhibited both the highest and lowest density. The two shallow water stations with the highest densities (stations #39 & 54) were low in diversity and dominated by two species, *Diastylopsis spp.* (very mobile cumacean) and *Owenia fusiformis* (an opportunistic polychaete). These species are rapid colonizers and highly tolerant of disturbed areas such as caused by currents, wave surges and shifting sediments. The studies reviewed, however, indicate that in general, invertebrate densities increased with distance from shore. and the nearshore shallow water benthos tends to have fewer taxa and lower densities than quieter offshore habitats especially in areas with sediments of finer grain size and higher organic content.

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The combined results of the studies indicate the benthic assemblages off the MCR exhibit community patchiness , year to year variations in density and species composition, seasonal variability and responses to disposal impacts. Such characteristics of the infauna are typical of areas of high disturbances and the species found in these habitats tend to be rapid colonizers, high energy tube dwellers and rapid burrowers. The variation in density for eight MCR stations are compared in Figure 19.

Variations in the densities of benthic infauna as reported in the individual studies reviewed are consistent with observations reported from other high energy nearshore shallow sandy environments.

Sandy shallow water marine systems typically exhibit larger spatial and temporal variations than deeper water low energy areas which tend to have more stable hydrography. The lessening of wave and current action allows finer grained sediments to settle and produces muddier bottoms.

Two kinds of fluctuations are reported in these studies, Sudden increases in the abundance of one or two species at a single or a few stations and fluctuations in the overall trends in populations (in abundance or density) at most all stations throughout the study area.

The sudden increases between station or seasonal variations which were reported on several occasions can be correlated with natural population fluctuations such as mass recruitment . For example, in 1992 some of the highest densities ever observed in Oregon and Washington were found. A large set of juvenile razor clams were responsible for the high values. In 1994 *Diastylopsis spp.* (very mobile cumacean) and *Owenia fusiformis* were found to produce a very high density at two inshore stations which normally have lower density than the offshore sites. Bottom disturbances are though to create micro habitats which allows these opportunists to invade momentarily.

The trending type of population fluctuations, such as seen by making overall comparisons over several years generally reflect changes in natural oceanic conditions. All studies seem to indicate population fluctuations in the benthic infauna resulting from changes in primary productivity brought about from oceanic conditions such as upwelling, downwelling, and outwelling which bring nutrients. In addition large storm events and spring freshets as well as site specific disposal of dredged material introduce variability and seasonal change.

The studies of actual disposal of dredged material show a decline in infaunal populations immediately after disposal but that rapid recovery and repopulating occurs Recovery from disposal impacts for benthic invertebrates and dungeness crab appears to begin after disposal and often exhibits higher densities within a year. The recovery levels of benthic invertebrates often exceed the pre-disposal conditions because the disturbed area is

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invaded by opportunistic species which are highly mobile or otherwise adapted to colonizing disturbed areas.

The participants asked about the correlation between benthic and fish data. The relationship between benthic infauna, macrofauna and fish is evident through many food habit studies. Benthic invertebrates are important prey for many species of demersal fish and shellfish, especially juveniles, which are abundant off the Columbia River and the Central Oregon Coast (Durkin and Lipovsky, 1977, Pearcy and Hancock, 1988). The increase in demersal fish and shellfish densities corresponds with the observed overall increase in benthic invertebrate densities from 1989 to 1992 off of the MCR.
The general sediment characteristics in the study area are quite uniformly a fine grained sand, however, the studies consistently found a lobe of finer grained (silt) sediments trending to the west and northwest of disposal site "B"toward Willapa Submarine Canyon. The studies also indicate both annual and diurnal transitory fine-grained deposits occur in the offshore study area particularly near the river mouth.

Based only on infauna, the area of finer sediments lying west and northwest of ODMDS "B" has been identified as dissimilar from the rather uniform sandy bottom area found throughout the rest of the study area. The finer sediments and different species components identified consistently throughout the study efforts suggest it is an area which should be considered for exclusion from ODMDS considerations.

4.3 Epifaunal Study Findings

Although adequate information exists to understand the general occurrence of the demersal fish and crab populations off the MCR. The information is less quantitative due to the limitations of oceanographic and fishery sampling techniques for capturing large motile species. Presence and absence information, total capture and catch per unit effort (CPU) information from commercial fishing logs indicate that the region receives a relatively high and sustained level of fishing for crab and demersal fish.

Epifauna and fish are highly motile and can generally avoid or withstand high suspended sediment loads found in the study area. The mobile nature of these species also produces a very high level of sample variation and tremendous effort is required to estimate population stocks.

Sampling of epifauna is not as extensive as infauna studies, but is representative of the area because there are extensive records of past trawling efforts and catch information, as well as information from the crab fishing industry.

Shallow water areas seem to warrant further investigation for new (or potential) dredged material disposal sites for two reasons: they have relatively low benthic invertebrate densities, and the sediment transport material deposited could potentially be redistributed by nearshore currents.

As reported in the report's conclusions, densities increased in the experimental disposal site "G" after disposal. One might, therefore, expect that if an unused site with low infaunal density were to be selected for future disposal, density may increase. This is consistent with knowledge that when marine bottoms are physically disturbed whether by natural or man made forces, organics and detritus are resuspended and organisms who can withstand high-energy environments (opportunistic species) invade. Based on these data, large variations in density (orders of magnitude) were found in the study area. Seasonal differences were thought to account for much of the variability. The shallow (17-20 m) sandy stations lying south of the entrance were found to exhibit the lowest densities and have little seasonal variation .

Section 5.0 Description of MCR Individual Studies

5.1 Benthic Infaunal Studies
5.2 Epifaunal Studies

5.1 Benthic Infaunal Studies

Michael D. Richardson, Andrew G. Carey Jr. and William A. Colgate (1977)
Richardson et al.(1977) began benthic sampling of the MCR in December, 1974 in what turned out to be a two phase study lasting until January 1976 "The objectives of this study were to identify and determine the significance of physical, chemical and biological factors that govern the rate at which open-water dredged material disposal sites are colonized by benthic communities". This was the earliest benthic sampling in the MCR study area and collected over 2,190 samples total. Included in these were 73 metered beam trawls, 369 sediment samples and 1,657 Smith McIntyre 0.1 m^2 grab samples. The work included a pilot study of 100 sites which covered most of the MCR study area with a single un-replicated grab sample. Also taken were repetitive samples at five sites in order to develop a statistically valid sampling strategy and determined the amount of replication necessary for the quantitative baseline sampling conducted in the second phase. It was determined that 5 replicate grab samples from each site during each sampling period were necessary to be able to statistically compare the between sample variation with the between station variation. The second phase included infaunal baseline studies of 22 sites prior to the controlled disposal of 4.6×10^5 m^3 dredged material and the continued collection of seasonal baseline information.

The study provided important baseline biological information prior to, and subsequent to the disposal of 450,000 m^3 of dredged material at experimental site G in July and August of 1975, as well as determining the distribution of species, the community structure and seasonality of macro-benthos. The study was able to relate species groupings to the distribution of sediments and organic matter, the stability of the sediments, and changes in sediment characteristics due to the deposition of fine grained dredged material from the Columbia River. The study also provided information on the meio-benthos (infauna which passes through a 0.42 mm sieve). The major problem with the Richardson study is the use of a 1.0 mm sieve for removal of organisms in all of the Phase II sampling.

Subsequent studies have utilized a 0.5 mm sieve and therefore the Richardson results will comparatively under estimate infaunal density for organisms smaller than 1.0 mm.

The baseline study results indicated that areas exposed to direct disposal of dredged material had higher diversity and evenness values and lower density of macro-benthos than unaffected areas. There was a significant reduction in the abundance of 11 of the 33 most abundant species at the areas of direct disposal. Recolonization of the affected area was mostly by active means (burrowing and migration) with reproduction and recruitment contributing less.

Except for the southern inshore sand assemblage the species composition, biomass and density of benthic assemblages off MCR were different (lower) than values calculated from other benthic assemblages reported for the Oregon-Washington continental shelf.

Figure 4 shows the sampling locations and Figure 5 shows the relative densities for the Richardson et al. 1977 study. The areal coverage is the most extensive of all the studies reviewed.

As reported in the report's conclusions, densities increased in the experimental disposal site "G" after disposal (due to recolonization with different species. The immediate impact was reduced density). One might therefore expect that if an unused site with low infaunal density were to be selected for future disposal, density may also increase. This is consistent with knowledge that when marine bottoms are physically disturbed whether by natural or man made forces, organics and detritus are resuspended and organisms who can withstand high-energy environments (opportunistic species) invade. Based on these data, large variations in density (orders of magnitude) were found in the study area. Seasonal differences were thought to account for much of the variability. The shallow (17-20 m) sandy stations lying south of the entrance were found to exhibit the lowest densities and have little seasonal variation .

The National Marine Fisheries Service (NMFS) conducted a three year sampling of the benthos of the Ocean Dredged Material Disposal Site (F) during the period 1990-1992. These data are reported in Siipola et.al., 1993. In addition, in 1992 NMFS, began benthic studies covering a broader area off the Mouth of the Columbia River. To date, four reports have been produced which cover the benthic sampling program carried out by NMFS between 1992 and 1994. Two additional reports are "in progress". The identical 51 sampling stations covered during the period were constant until 1996 when six additional stations were added. Possibly the studies could have been treated as a single temporal benthic infaunal sampling program covering the period 1992 to 1995 however, we think individual treatment provides a clearer picture. Comparative results for density are found in the reports Only the sediment data for the 1996 information is available.

<u>Siipola, Mark D. et.al., 1993</u>
The Tongue Point monitoring program focused on determining bathymetric, sediment, contaminant and benthic invertebrate community changes in and adjacent to ODMDS F

and sediment and contaminant changes in and around the Tongue Point dredge site. Both the dredge site and the disposal site were sampled. Only the disposal site data is reviewed herein.

A pre disposal baseline survey of 29 stations centered around disposal site F was conducted (May 1989) Thirteen stations, 5 in the disposal site and 8 surrounding site F were sampled for sediment, and benthic infauna. Trawls were made at three stations for demersal fish/invertebrates. After disposal, the site was sampled four times (March 1990 - July 1992), the last being 30 months after disposal. The sampling locations for each year are shown in Figures 6a-c shows and the relative densities are shown in Figures 7a-c. The dredged material deposited at ODMDS F consisted of sediments finer than the ambient material, and formed a relatively stable and recognizable mound. The overall mean density of benthic invertebrates for all stations combined changed significantly during the four survey years. Benthic invertebrate densities doubled each survey year and the number of taxa also increased. Increased density related to increases in many different taxa rather than just one or a few species. One station in the middle of the site did appear to be affected by the disposal in 1990, but appeared recovered in subsequent sampling. Benthic invertebrate densities during 1989, 1990, and 1991 generally resemble previous benthic surveys off the Columbia River. The high density observed in 1992 are unusual with respect to densities and species compositions. Other Pacific Northwest nearshore ocean areas where high benthic invertebrate densities have been reported include off Tillamook Bay and Willapa Bay. The high densities in these areas was thought to be from "outwelling" of large amounts of organic material from adjacent estuaries.

The conclusions in this study were that no significant contamination, toxicity or bioaccumulation impacts due to disposal could be documented at site F. Dredged material affected sediment grain size in the disposal site but did not appear to impact the biological community. Recolonization of the mound was very rapid. Six months after disposal ceased invertebrate densities were higher than recorded prior to disposal. Although the presence of dredged material altered the benthic community structure through changes in species composition and equibility (J').it did not reduce densities.

Susan.A. Hinton, and Robert.L. Emmett 1994 (1992 data)

The study objectives were to identify benthic invertebrate species composition, abundance and sediment characteristics over a large area offshore from the Columbia River. Benthic invertebrates and sediments samples were collected at 51 stations extending 16 km north and 17 km south. Eight stations from the 1977 study were re-sampled and data compared. A limited survey of fishes and epibenthic invertebrates was included.

In 1992, benthic invertebrate densities were higher at all stations except for Station 39 (near disposal site B) where densities had been higher in April and June 1975. Figure 8 shows the sampling locations and Figure 9 shows the relative densities for the study.

Benthic invertebrates varied widely throughout the study area in July 1992. The distribution of sediment types offshore from the Columbia River observed during this survey agrees with sediment distributions described in previous studies. South of the entrance to the Columbia River, sediment grain size decreases with depth. Cascade Channel receives sediment from the Columbia River through the Willapa Canyon, which has its head on the outer edge of the continental shelf 45 Km north of the mouth of the Columbia River. A NW offshore transport of coarse silt and very fine sand is required to supply Willapa Canyon with sediment. Both radionuclide and near-bottom current studies of fine-grained river borne particulate matter in the shelf sediments derived from the Columbia River show a net northward transport toward Willapa Canyon.

Robert L. Emmett, and Susan A. Hinton 1995.(1993 data)

The objective of the study was to assess benthic invertebrate communities at 28 stations and sediment characteristics at 30 stations in an area offshore from the MCR during July 1993. The study extended 16 km north and 17 km south. and 16 km west from the river mouth. The study area includes disposal sites A,B, and F. Sites B & F received dredged material in 1993. Figure 10 shows the sampling locations and Figure 11 shows the relative densities for the study.

The lobe of organically enriched fine-grained sediments to the west and northwest of site B was again reported and discussed as per Hinton and Emmett (1994).

Densities were found to vary widely throughout the study area. Stations near the mouth of the Columbia River in shallow water (<40 m depth) that are often disturbed by waves and currents, generally had lower benthic invertebrate densities than deeper water stations away from the Columbia River.

The importance of benthic invertebrates as prey for many species of demersal fish and shellfish especially juveniles was inferred from the previous studies of Durkin and Lipovsky (1977). Annual and long term fluctuations in invertebrate abundances were suggested to have a direct effect on fish and shellfish populations, but long term research was not available. Much of the biological fluctuations appear related to physical changes in habitat.

Eight stations at site F had been sampled during the 1989 - 1992 studies. Benthic invertebrate densities increased significantly between 1989 and 1992. Invertebrate densities in 1993 were high but second to 1992 values. Lower upwelling was given as the possible reason. The variability and complexity was thought to be the result of widely fluctuating environmental conditions, such as high currents, wave actions and shifting sediments. The harsh environmental conditions in shallow-water habitats near the mouth of the Columbia River appear to depress benthic invertebrate densities. A general trend toward higher benthic invertebrate densities with increasing distance westward from the river mouth seems to be a pattern consistent with earlier studies.

Susan A. Hinton, and Robert L. Emmett 1996 (1994 data)
The primary goal of the August 1994 study was to assess benthic invertebrate communities at 29 stations and sediment characteristics at 30 stations. The study extended 16 km north and 17 km south. and 16 km west from the river mouth. The study area includes disposal sites A, B, and F which had been expanded by the Portland District due to mounding. Figure 12 shows the sampling locations and Figure 13 shows the relative densities for the study.

For the 27 stations occupied in both 1993 and 1994, there were no significant differences between years for the number of benthic invertebrate taxa and densities. Species composition and densities vary widely in 1994 especially at shallow water stations. Unlike previous studies, benthic densities generally decreased with distance from the mouth of the river. At site F, the eight stations density and number of taxa increased significantly between 1989 and 1994, except in 1993 when it decreased.

The relatively large number of cluster groups and stations that did not cluster in such a small area indicates that a complex benthic invertebrate community exists off the mouth of the Columbia River. Harsh environmental conditions in shallow water habitats can depress benthic invertebrate densities. In this survey however, stations in shallow water had both the highest and lowest benthic invertebrate densities and some stations indicated a decrease in density with increasing depth. Two phenomena were suggested as possible explanations: First, widely fluctuating conditions (high energy) produce micro-habitats colonized by opportunistic organisms. and secondly, habitat conditions which may be in various stages of development.

"Recent offshore benthic invertebrate surveys suggest nearshore shallow-water (<40m) areas should be investigated further for use as ocean dredged material disposal sites. Benthic invertebrate densities were lowest at most shallow-water stations south of the Columbia River mouth during 1989-92 and north and south of the mouth during 1992-94".

Shallow water areas seem to warrant further investigation for new (or potential) dredged material disposal sites for two reasons: they have relatively low benthic invertebrate densities, and the material deposited could potentially be redistributed by nearshore sediment transport.

Unpublished (1995 partial data/no report) Only station, density and sediment data from the 1995 sampling were plotted during this summary. Figure 14 shows the sampling locations and Figure 15 shows the relative densities for the study.
Unpublished (1996 -sediment data only)

C27340

5.2 Epifaunal Studies

Joseph T. Durkin and Sandy J. Lipovsky, 1977

In a companion study to the OSU infaunal studies the NMFS conducted fishery investigations between October 1974 through April 1976 off the MCR. The purpose of the study was to determine the composition, spatial and temporal distribution of demersal finfish and decapod shellfish, to determine food habits of dominant species and to determine the impact of dredged material disposal on finfish and crabs at experimental site "E".

Trawl sampling of finfish and decapod shellfish benthic populations from October 1974 to April 1976 captured 184,291 organisms. Sampling was conducted at five stations on a monthly basis during the first phase of sampling (October,1974 through June, 1975). The second phase of the study (July, 1975 - August 1975 continued sampling at the four sites but was oriented primarily toward monitoring deposition of dredged material at disposal site "E". The final phase (September 1975-April 1976 was a continuation of sampling at the five stations. The trawl sample locations are shown in Figure 16 and the fish and shellfish total numbers captured are shown in Figures 17 and 18 respectively.

The food habit analysis indicated for invertebrate and one fish species are the most extensively consumed prey items off the MCR. These were the cumacean, *Diastylopsis dawsoni;* the mysid *Neomysis kadiakensis;* the amphipod, *Atylus tridens;* The shrimp, *Crangon* sp.; and the anchovy, *Engraulis mordax.* The feeding results also suggested that the consumption of small organisms such as cumaceans, copepods, mysids and amphipods decreased while consumption of shrimp and fish usually increased during and immediately following disposal. Following disposal, food consumption tended to be similar to that at the other sites.

The study indicated that substantially more finfish and decapod shellfish reside at north and central sites during the summer.

The disposal monitoring results showed a three to six month reduction in finfish diversity and species richness at the experimental site after disposal, however, seven months after disposal these indices were similar to those of the four comparative sites.

George T. McCabe Jr , Robert L. Emmett, Travis Coley and Robert J. McConnell., 1986.

A two year NMFS study of Dungeness crab which was conducted prior to the deepening of the Columbia River bar. The sampling was undertaken between Nov. 1983 through October 1985.. The study objectives were to describe the Dungeness crab's estuarine distribution, abundance, size-class, structure and the location and timing of movements across the bar (RM 0.7 to 2.8). Sampling was done with an 8m semi-balloon shrimp

C27341

trawl.. Figure 19 shows the trawl sampling locations and the distribution shown in Figures 20-22 shows the relative densities for the study.

A maximum of 28 estuarine and ocean sites were sampled each month in or near frequently dredged areas in the Columbia river estuary. Although much of the data reported is from inside the entrance channel in the estuary , it contains information from the Columbia River bar, and six ocean sampling sites located along a transect perpendicular to the shore. Only the ocean catches are reported in this summary.

The six ocean stations were sampled during 16 months of the two year study. The eastern most station, was in shallow water 5-12 meters, and the transect extended out to 91m . The report found that ocean densities in the first year were not significantly different from densities in the second year. Densities were greater in the estuary during both years. Size class were difficult to compare between ocean and estuary because of low ocean catches especially <50mm size class.

The limited sampling for epifauna especially juvenile commercial species in the offshore waters makes the small amount of information for the offshore area from this study valuable. Additional information from the commercial crabbing and groundfish fleet would be useful for at least filling in the adult distributions the commercially important species.

Although the crab densities do not represent absolute values due to the sampling efficiency of trawls which are inherently less quantitative than infaunal samplers , the results maybe roughly comparable with other trawl study information.

Siipola, M.D. et.al. 1993

The NMFS conducted five minute tows with a 26.5 foot semi-balloon shrimp trawl taken during the 1990 to 1992 pre and post disposal benthic invertebrate studies conducted at and adjacent to ODMDS F . Four trawling efforts were conducted during each survey, one in the disposal area and one each north and south of the disposal area. Trawling depth ranged from 109 to 148 feet. The locations were reported in Loran C co-ordinates which were hand plotted for the GIS representations.

The results indicated that excluding whitebait smelt (a schooling pelagic fish that often resides near the bottom) from the trawl catch analysis, that overall fish and shellfish densities were similar in 1989 and 1990 (1,855/ha. and 1,702/ha. respectively) and increased in 1991 (2,730/ha.) and 1992 (3,564/ha.). The increase in demersal fish and shellfish densities corresponds with the observed overall increase in benthic invertebrate densities from 1989 to 1992.

Although the authors reported that the trawl data it indicated that dungeness crab capture was reduced during the years when disposal was taking place and then recovered to above baseline values after disposal, no statistically valid analysis was presented. Generally trawl data is too variable to determine change let alone cause and effect.

List of Benthic References for Mouth of the Columbia River.

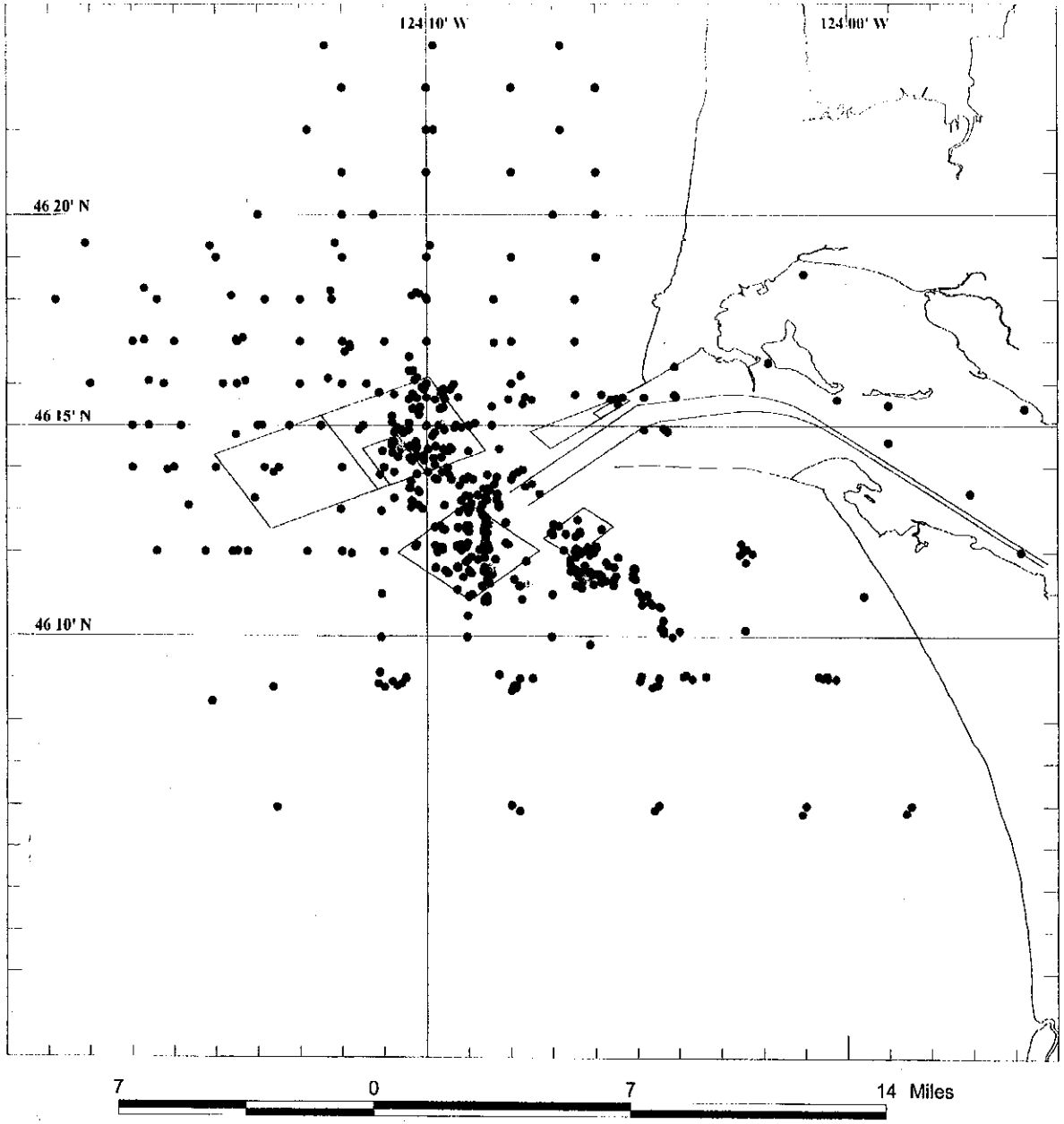
List of Benthic References for Mouth of the Columbia River.

1. Durkin, J.T., S.J. Lipovsky, 1977. Aquatic Disposal Field Investigations Columbia River Disposal Site, Oregon. (Appendix E: Demersal Fish and Decapod Shellfish Studies. USACOE Waterways Experiment Station, Vicksburg, Miss. 3 9180. Technical Report D-77-30.
2. Richardson, M.D., A.G. Carey Jr. W.A. Colegate, 1977. Aquatic Disposal Field Investigations Columbia River Disposal Site, Oregon. Appendix C: The effects of Dredged Material Disposal on Benthic Assemblages. Technical Report D-77-30. Contract No. DACW57-75-C-0137 & DACW5776-C-0092. USACOE Waterways Experiment Station, Vicksburg, Miss. 39180
3. Holton, R.L. , N. H. Cutshall, L.I. Gordon, L.F. Small (1978). Aquatic Disposal Field Investigations Columbia River Disposal Site, Oregon. Appendix B Water Coluirm, Primary Productivity and Sediment Studies. Technical Report D-77-30. Contract No. DACW57-75-C-0126 & DACW57-76-C0081. USACOE Waterways Experiment Station, Vicksburg, Miss. 39180
4. Columbia River: Evaluation of New Ocean Dredged Material Disposal Areas, USACOE (CR Coal Export Channel Study.
5. Siipola, Mark. D. R.L Emmett and S.A. Hinton (1993) Ton'gue Point Monitoring Program 1989-1992. Final Report, September 1993.
6. Emmett R. L. and Susan A. Hinton. 1995 Benthic Infauna and Sediment Characteristics Offshore from the Columbia River, July 1993. Coastal Zone and Estuarine Studies Division, NNWS, NOAA.
7. Emmett R. L. and Susan A. Hinton. 1994 Benthic Infauna, Sediment and Fish Offshore from the Columbia River, July 1992. Coastal Zone and Estuarine Studies Division, NNES, NOAA.
8. Emmett Robert L. and Susan A. Hinton. 1996 Benthic Infauna and Sediment Characteristics Offshore from the Columbia River, August 1994. Coastal Zone and Estuarine Studies Division, NNTS, NOAA.
9. Pearcy William.G and Danil R. Hancock 1978 Feeding Habits of Dover sole (Microstomus pacificus), rex sole (Glyptocephalus zachirus), slender sole (Lyopsetta exilis), and Pacific sandab (Citharichthys sordidus), in a region of diverse sediments and bathymetry off Oregon. Fishery Bulletin, Vol. 76, no. 3:641-652.
10.

Figures

Marine Fauna Sample Locations

Figure 1



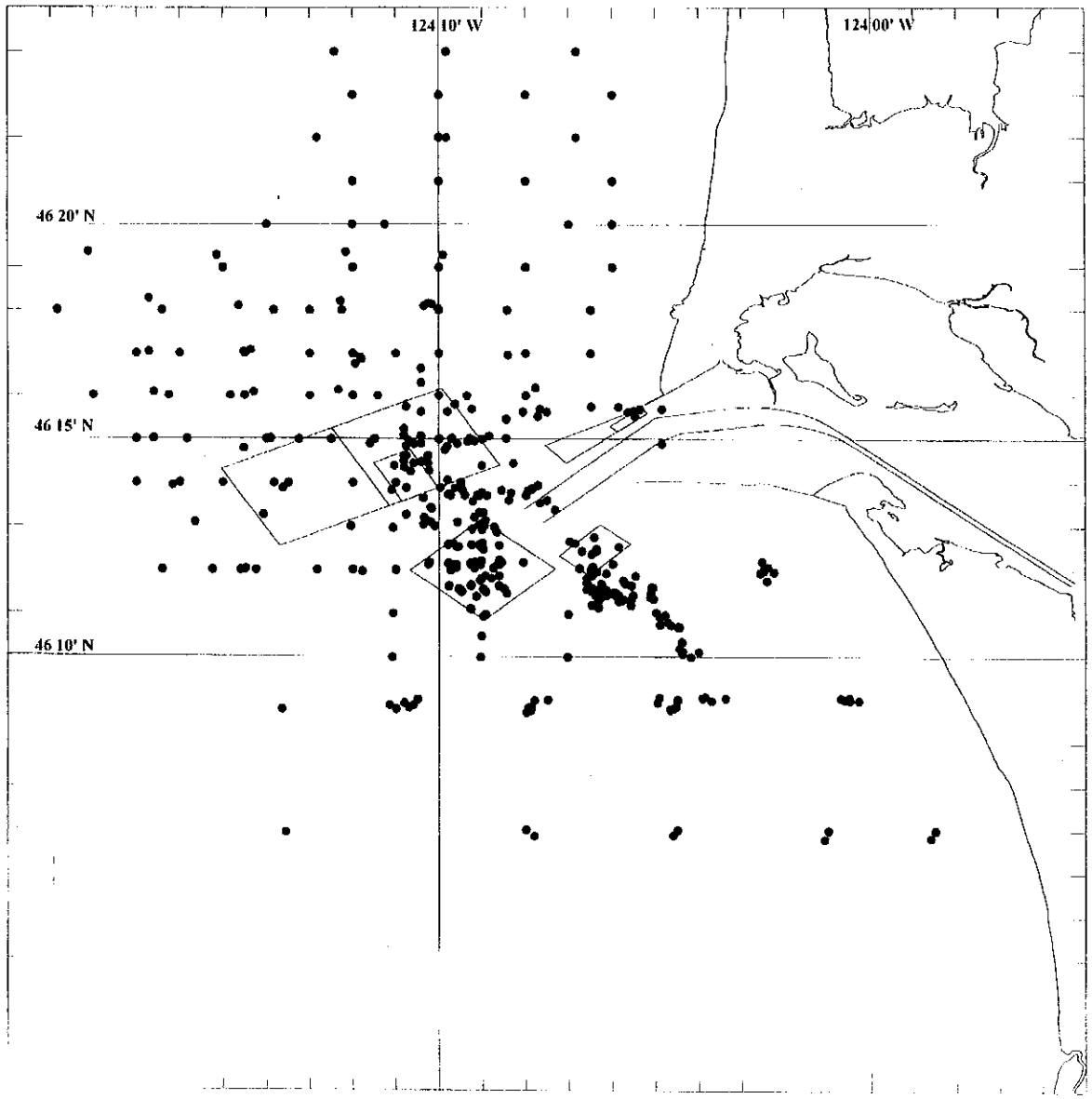
- McCabe et al. 83-1986
- McCabe et al. 84-1986
- McCabe et al. 85-1986
- Durkin. et al 74-1977
- Durkin et al. 75-1977
- Durkin et al. 76-1977
- Richardson et al. 1977
- Siipolo 89-1993
- Siipolo 90-1993
- Siipolo 91-1993
- Siipolo 92-1993
- Hinton & Emmett 92-1994
- Emmett & Hinton 93-1995
- Hinton & Emmett 94-1996
- 95-96-unpublished
- Columbia River mouth basemap

C27347

Benthic Invertebrate Sample Locations

(excluding crab and fish/shellfish data)

Figure 2



- Richardson et al. 1977
- Siipolo 89-1993
- Siipolo 90-1993
  Siipolo 91-1993
- Siipolo 92-1993
- Hinton & Emmett 92-1994
- Emmett & Hinton 93-1995
- Hinton & Emmett 94-1996
- 95-96-unpublished

Columbia River mouth basemap

8 0 8 16 Miles

N

C27348

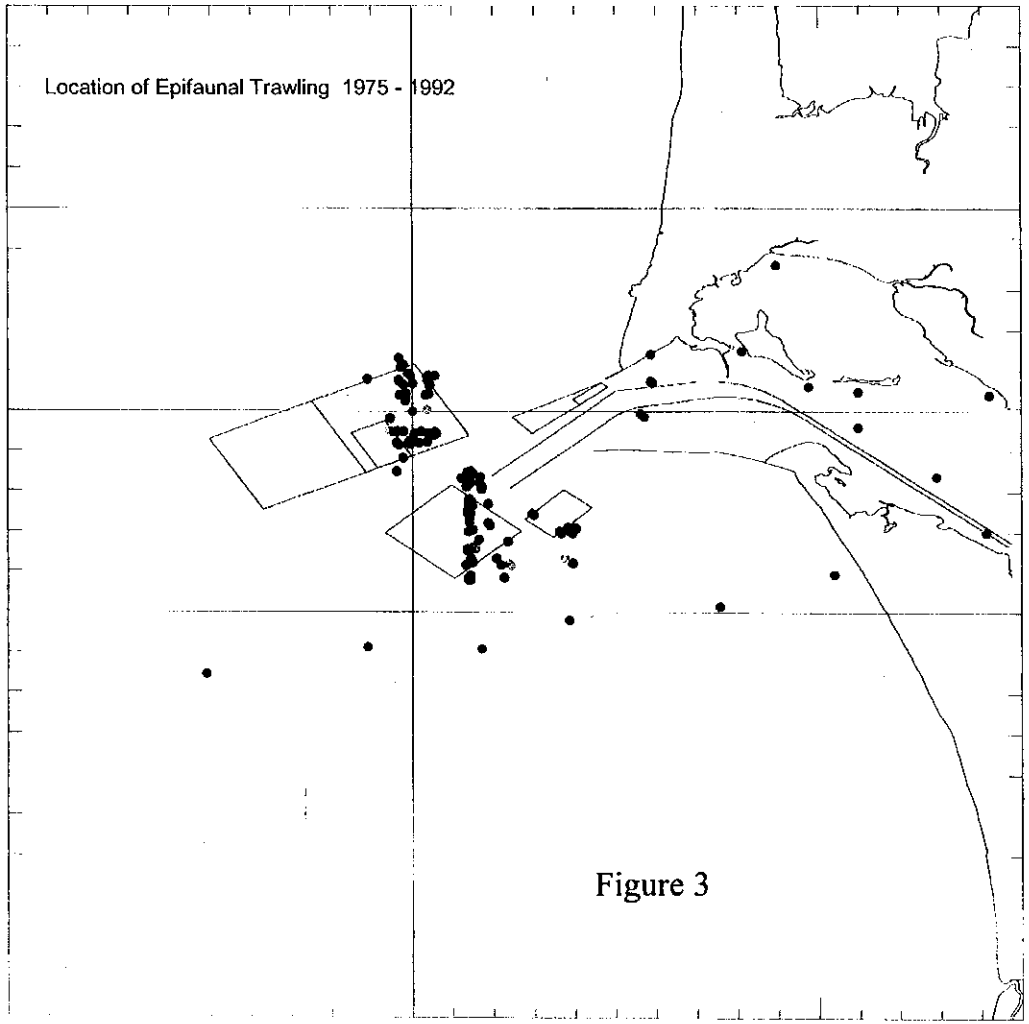
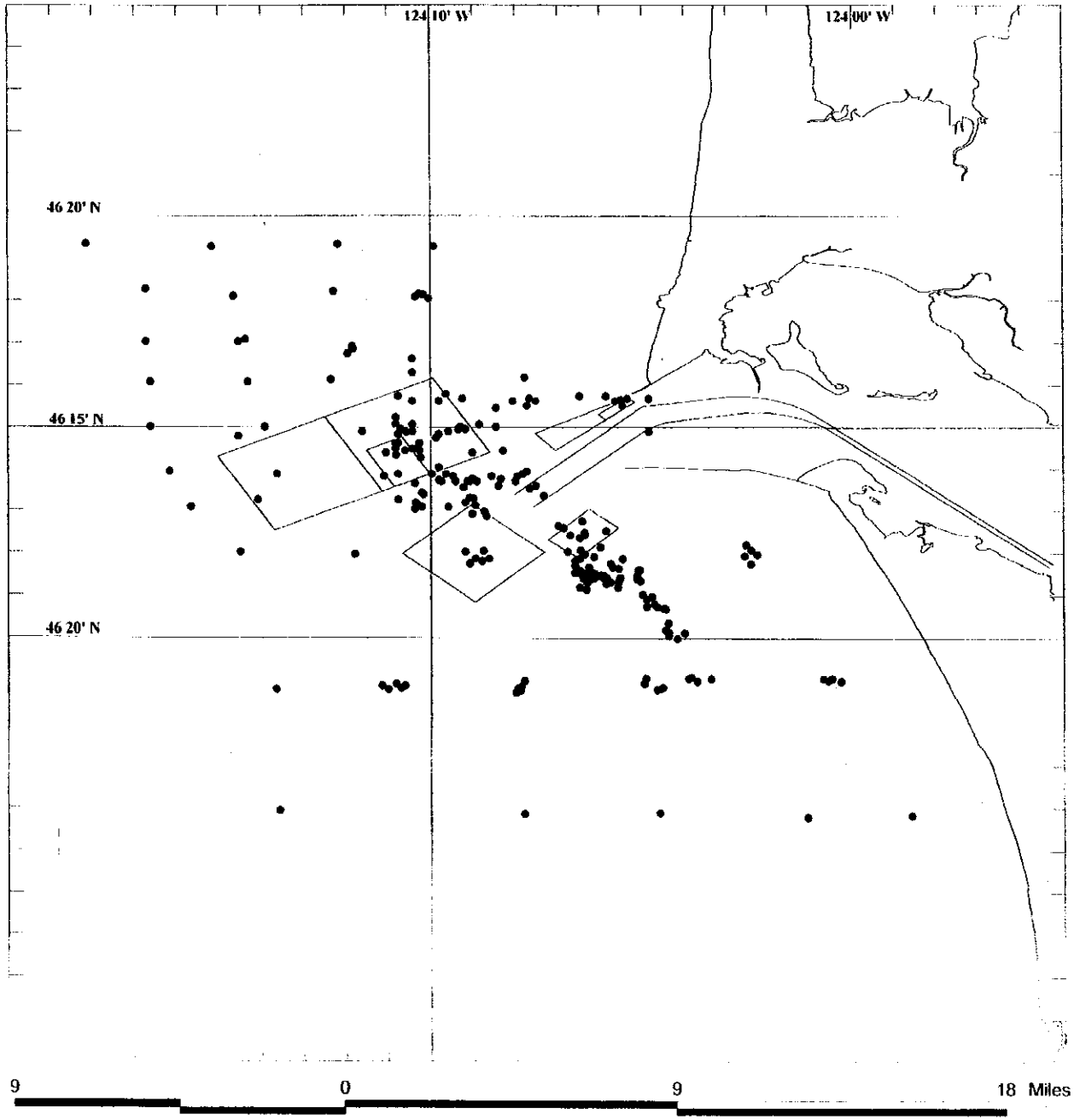


Figure 3

1977 Benthic Infauna Sample Locations

Figure 4

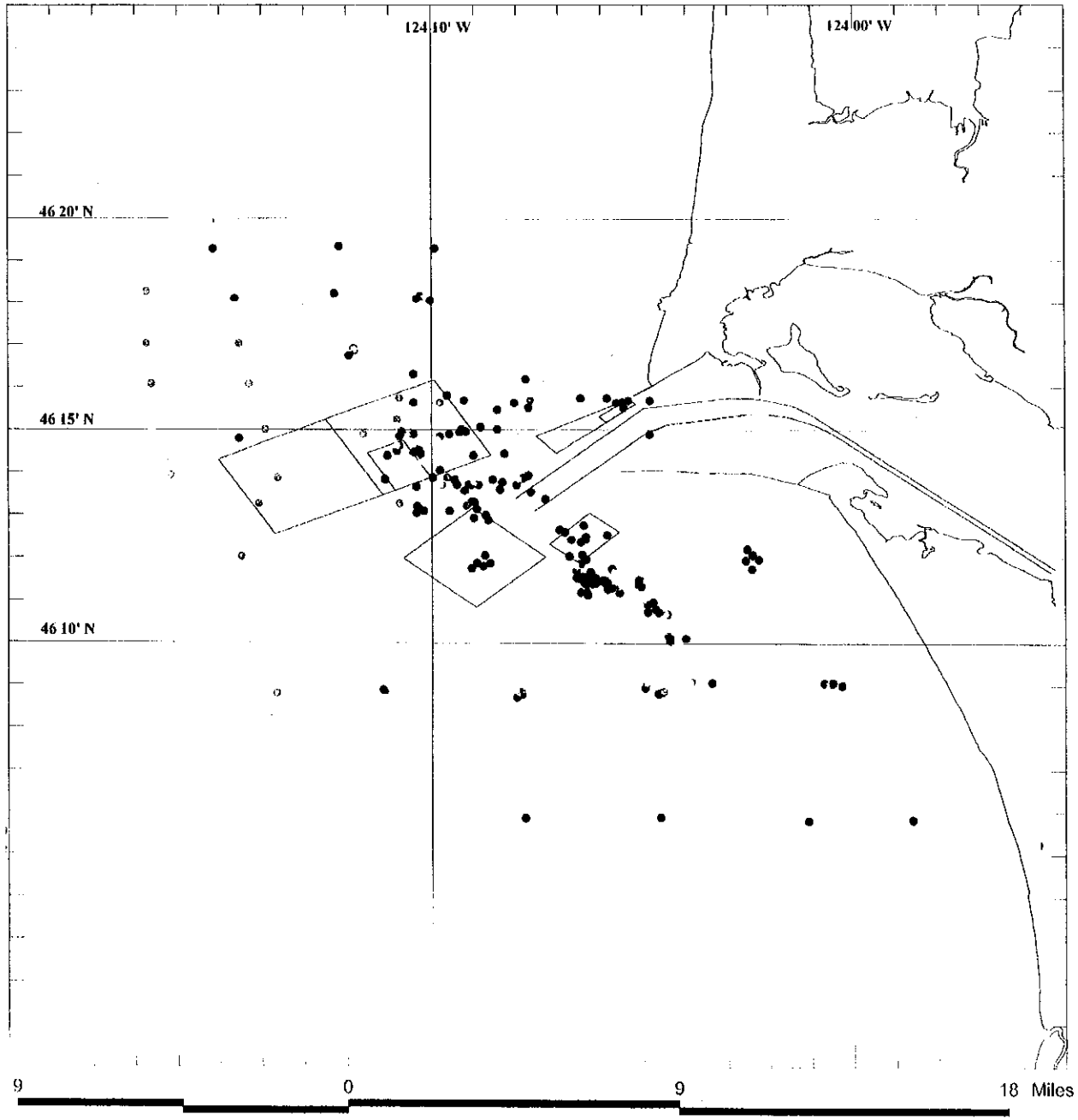


• Richardson et al. 1977
Columbia River mouth basemap

C27350

1977 Invertebrate Density

Figure 5



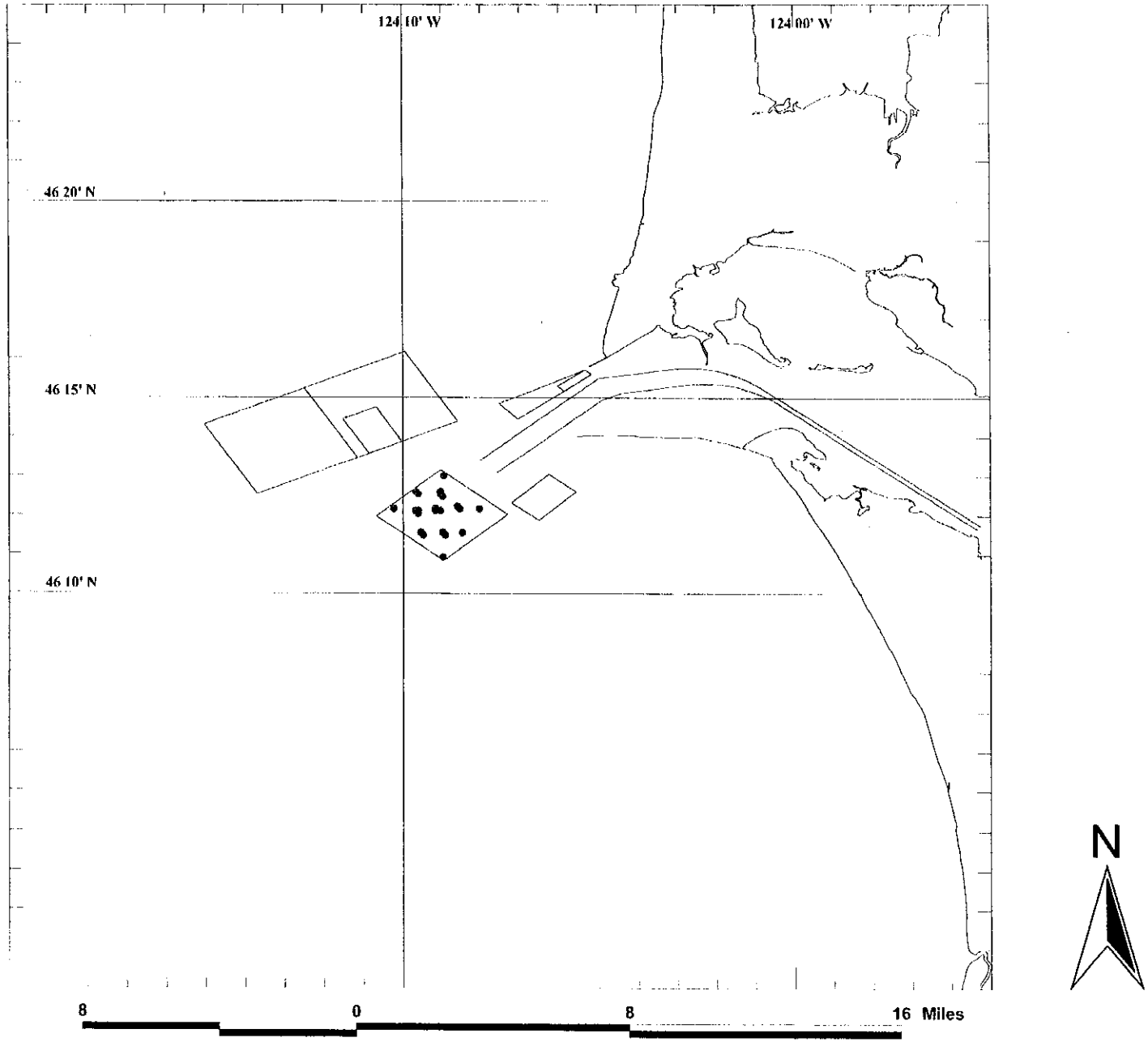
Richardson et al. 1977 (#/m2)
- 1 - 1848
- 1849 - 4890
- 4891 - 9454
- 9455 - 20488
- 20489 - 43802
- Columbia River mouth basemap

N

C27351

1989 Benthic Infauna Sample Locations
(disposal site F)

Figure 6a

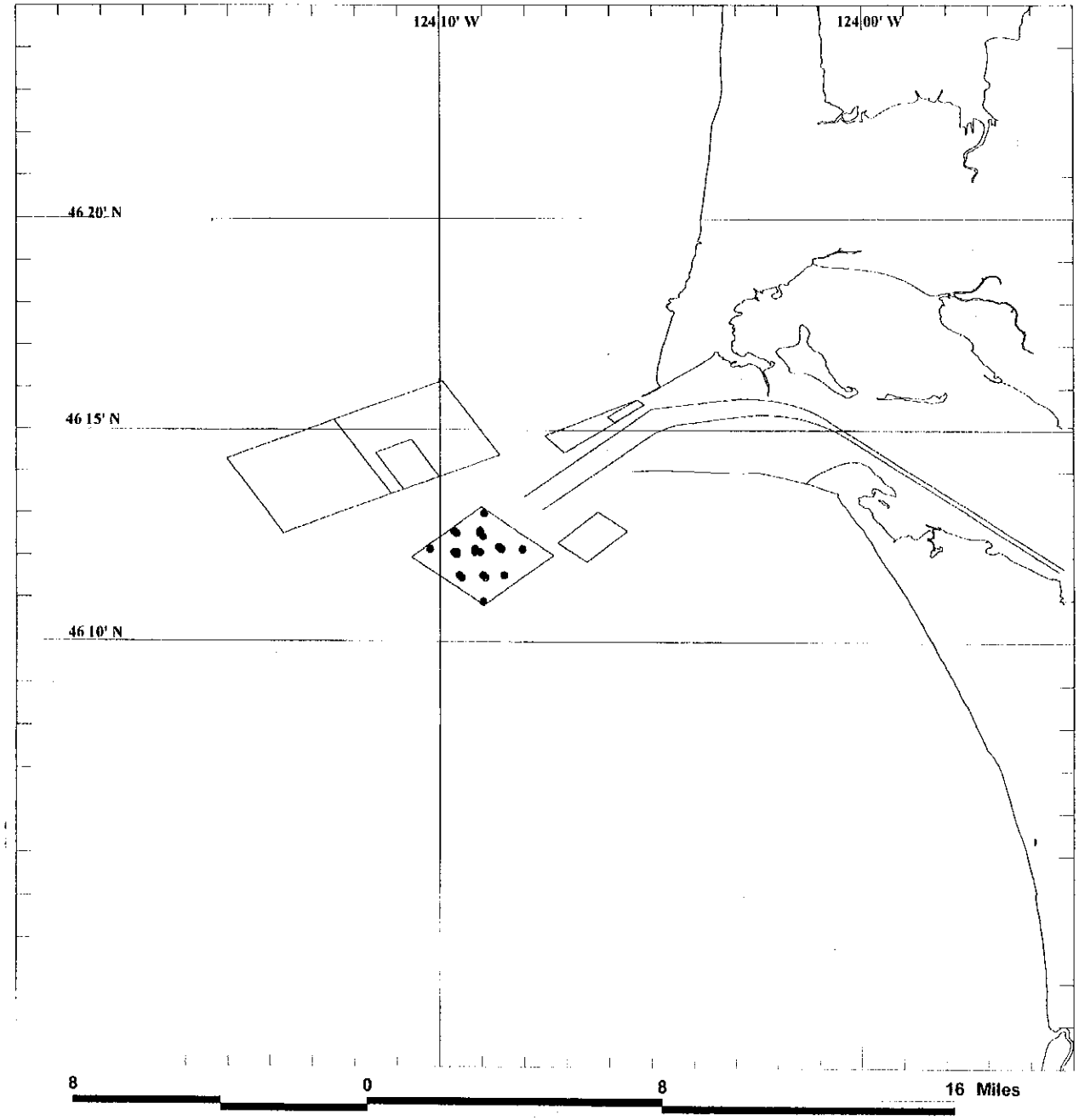


• Siipolo 89-1993
Columbia River mouth basemap

C27352

1990 Benthic Infauna Sample Locations (disposal site F)

Figure 6b

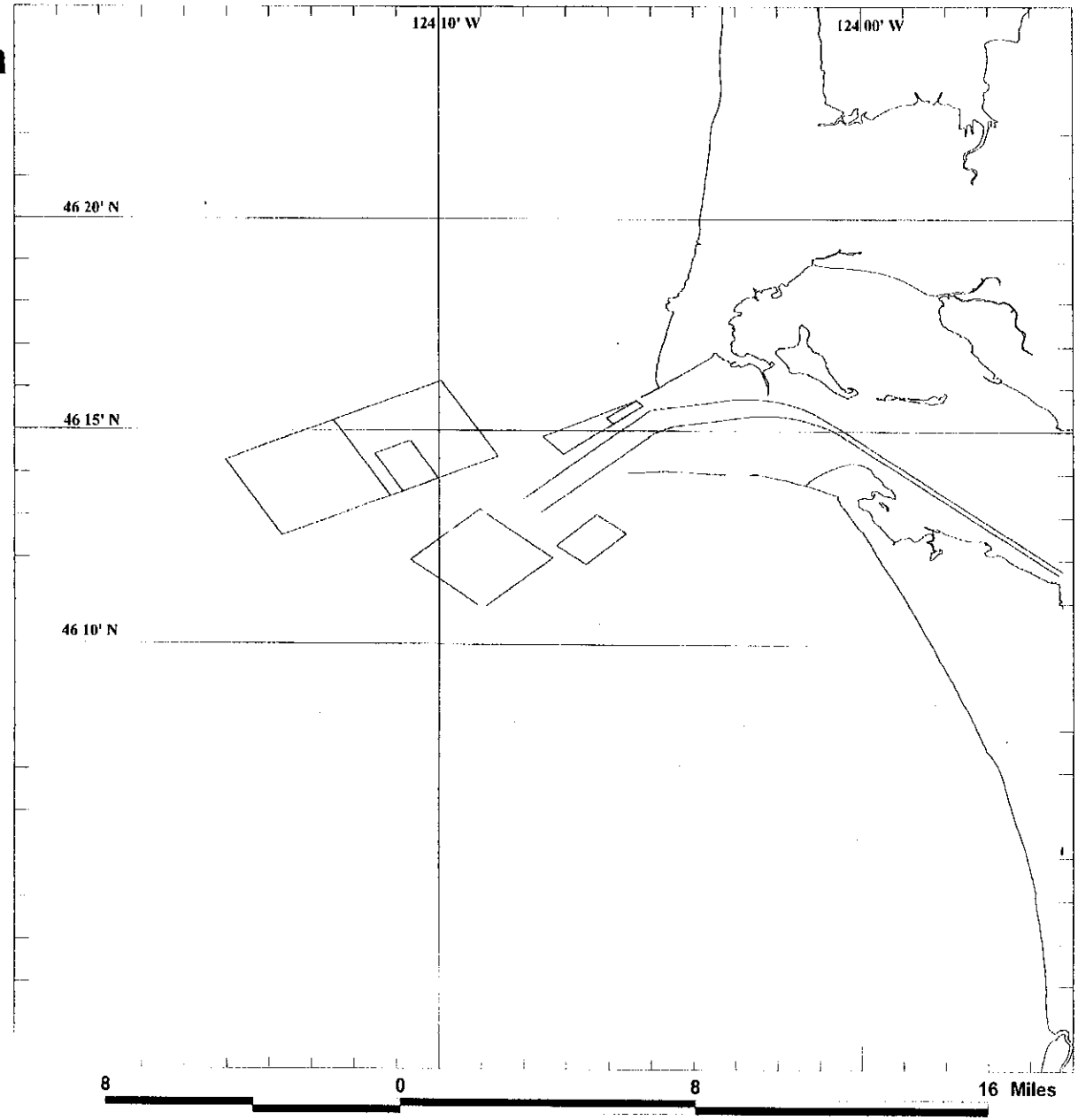


• Siipolo 90-1993
Columbia River mouth basemap

C27353

1991 Benthic Infauna Sample Locations (disposal site F)

Figure 6c



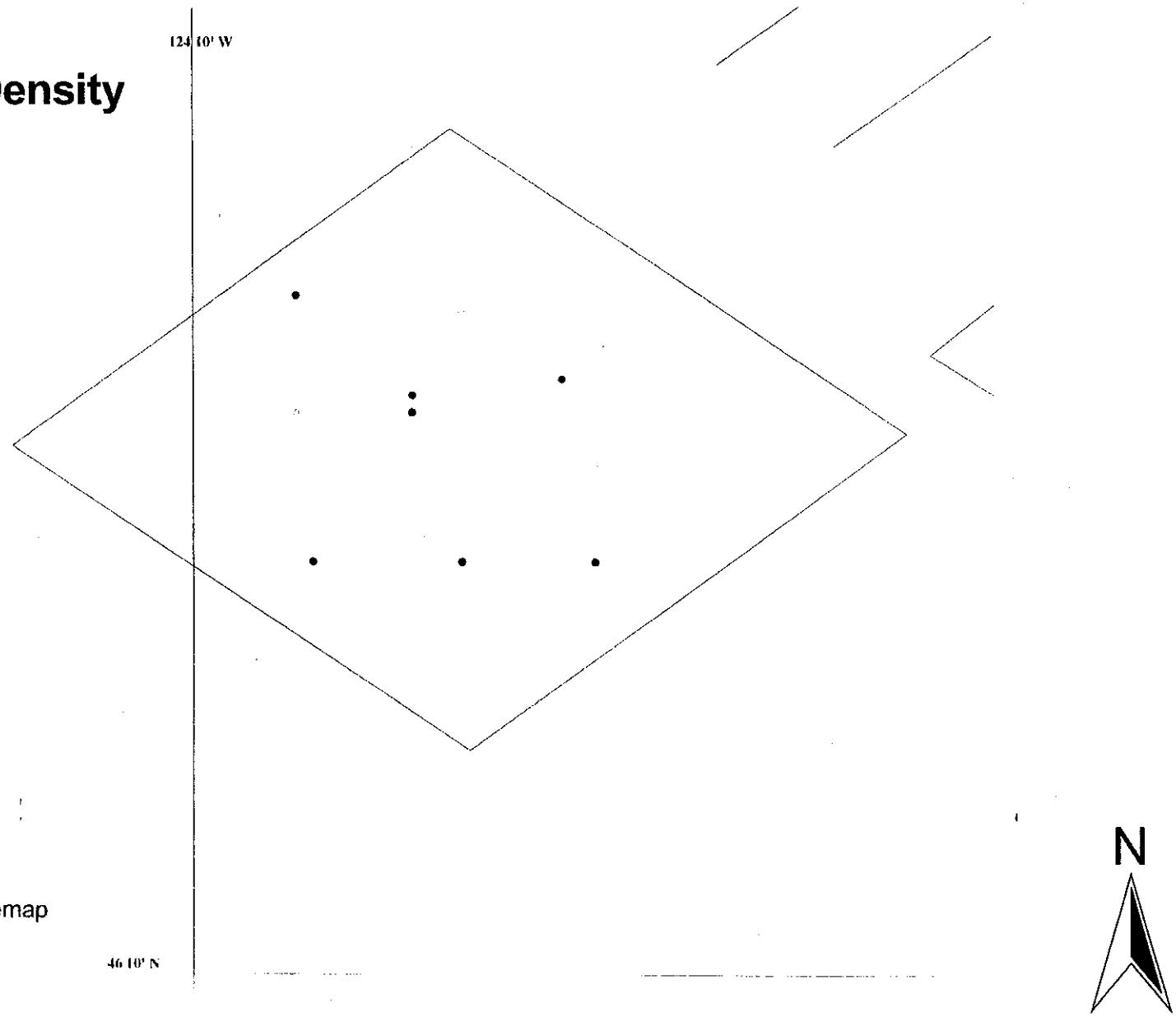
Siipolo 91-1993
Columbia River mouth basemap

N

C27354

1989 Invertebrate Density
(disposal site F)

Figure 7a



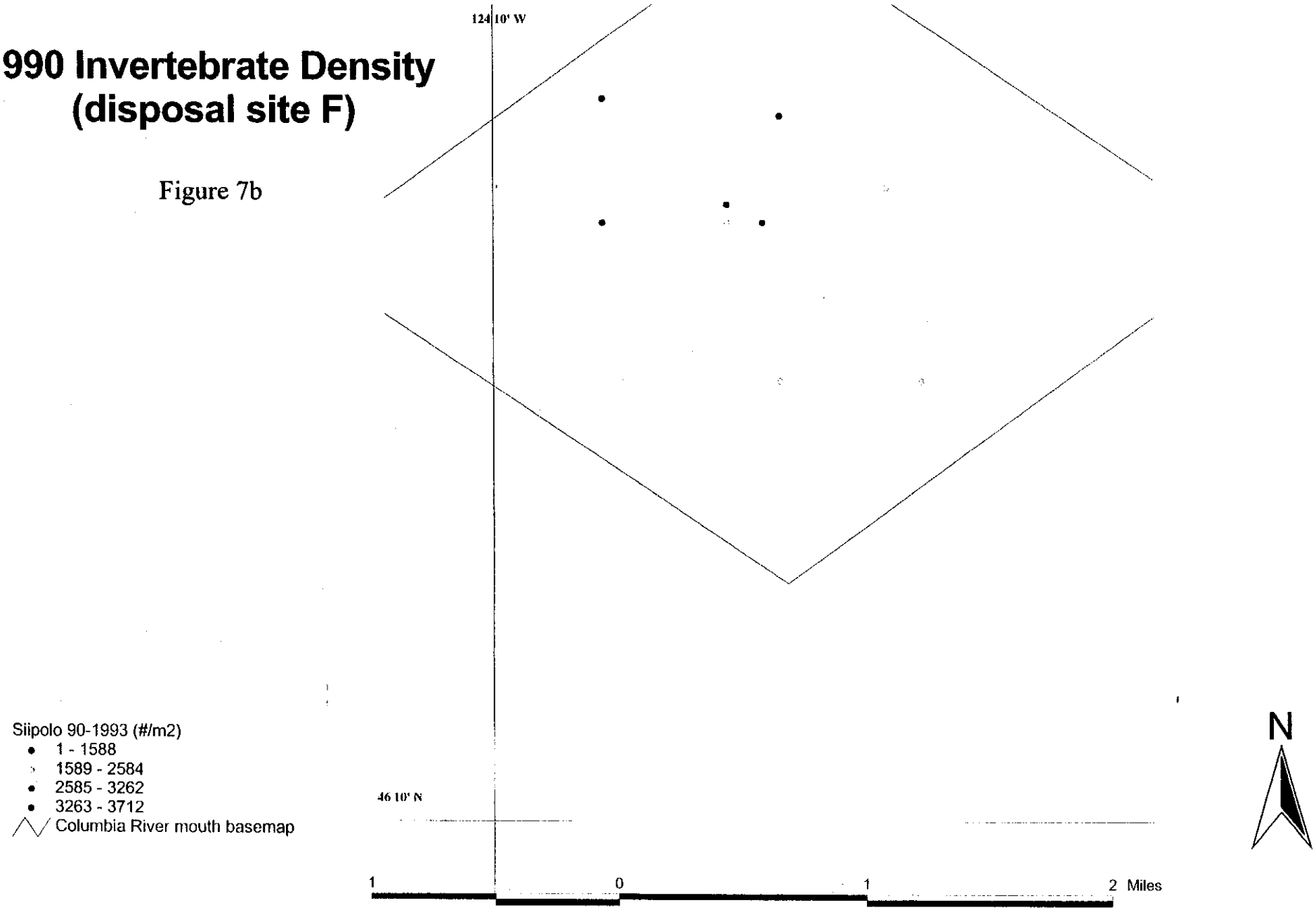
Siipolo 89-1993 (#/m2)
- 1 - 882
- 883 - 1046
- 1047 - 1294
- 1295 - 1517

Columbia River mouth basemap

C27355

1990 Invertebrate Density (disposal site F)

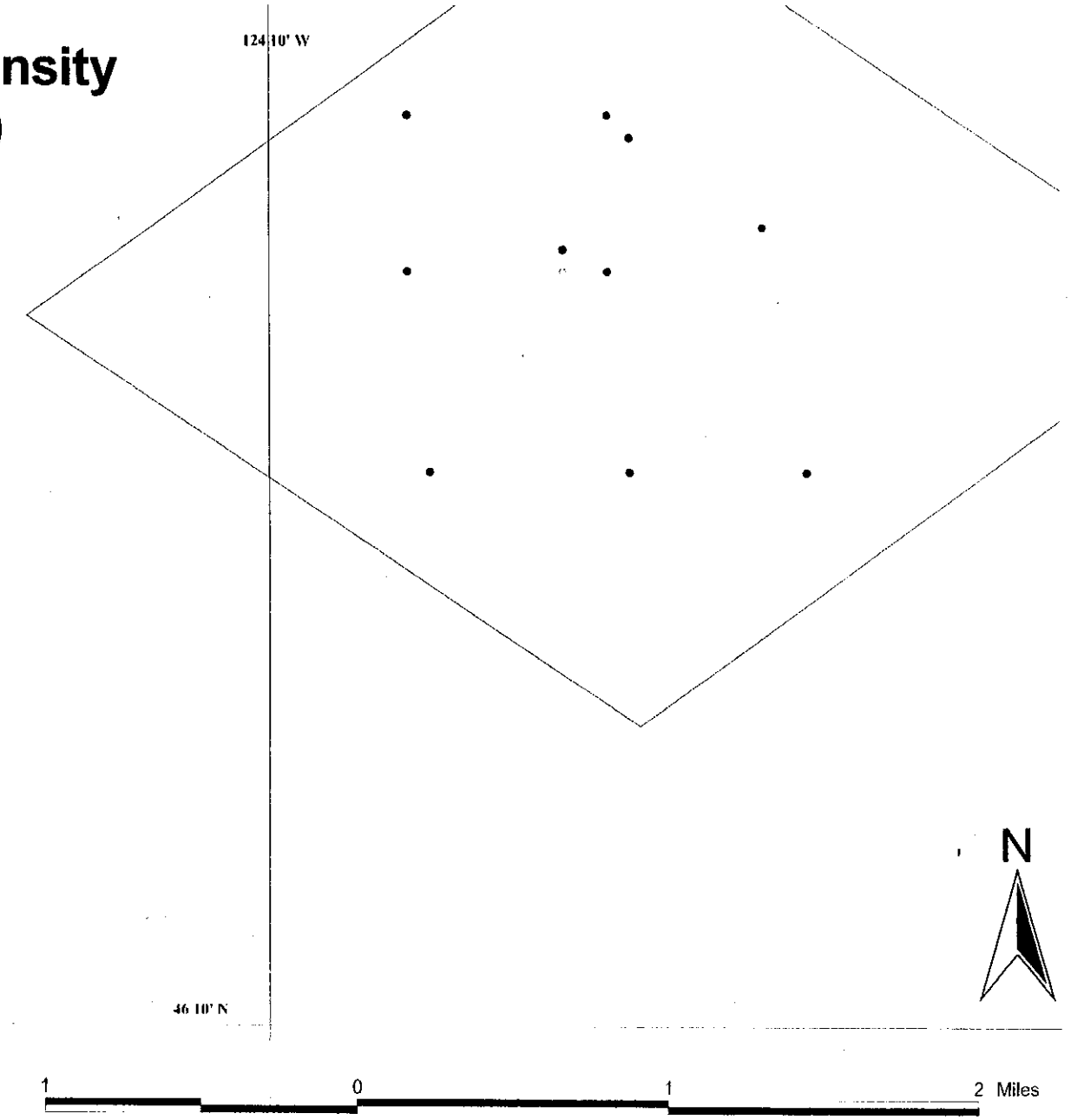
Figure 7b



C27356

1991 Invertebrate Density (disposal site F)

Figure 7c



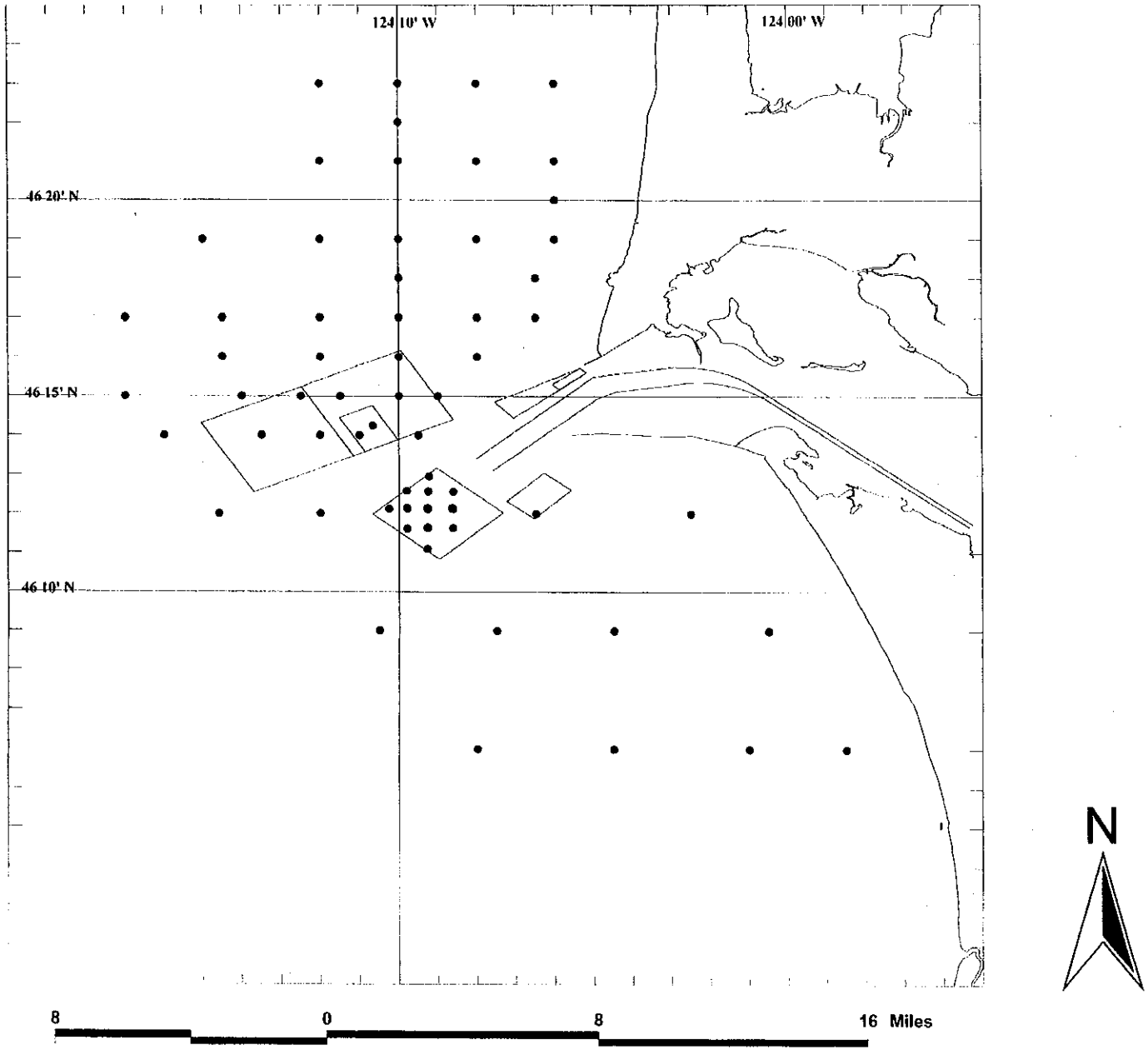
Siipolo 91-1993 (#/m2)
- 1 - 4001
- 4002 - 4379
- 4380 - 4987
- 4988 - 6823

Columbia River mouth basemap

C27357

1992 Benthic Infauna Sample Locations

Figure 8

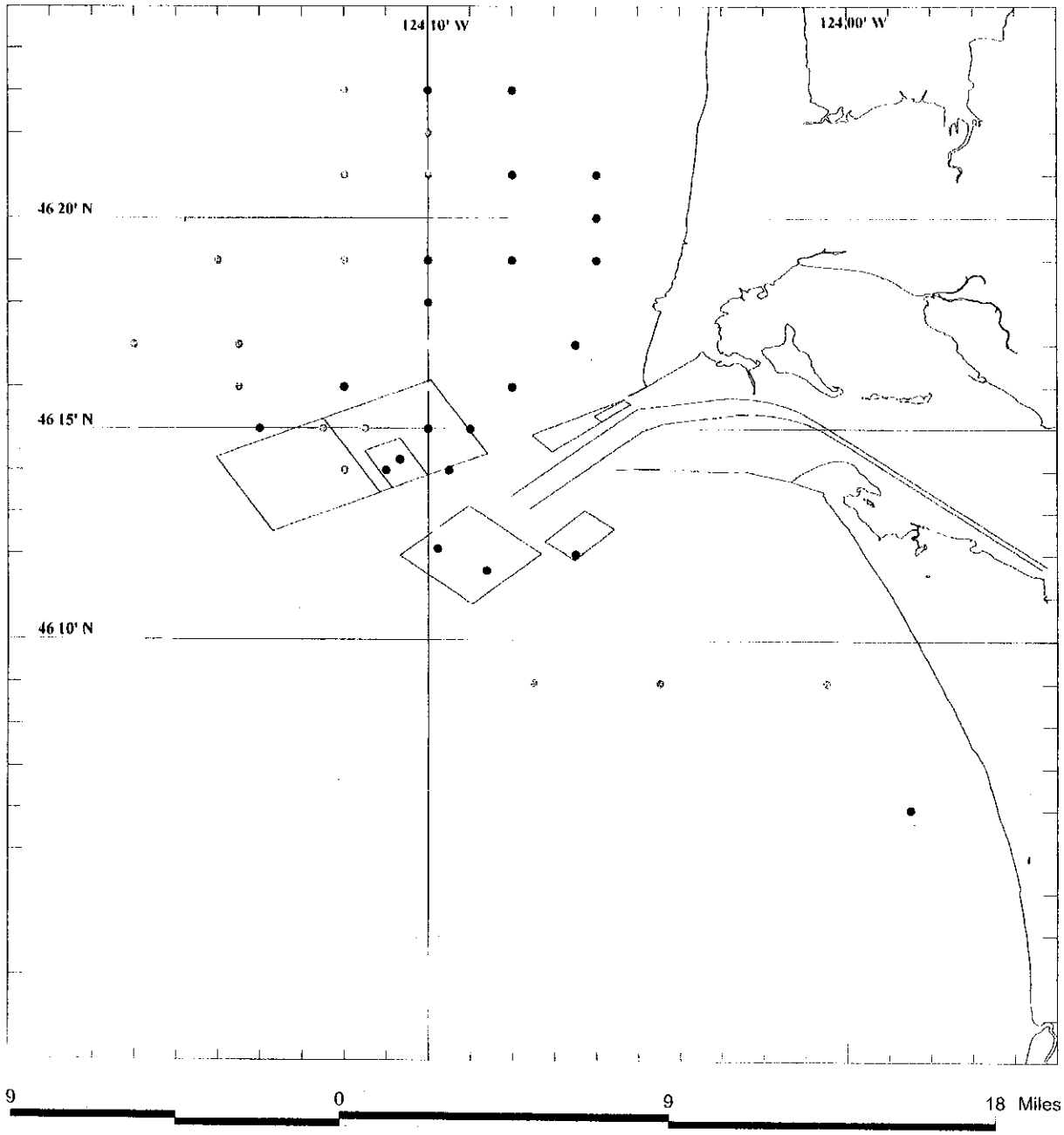


• Hinton & Emmett 92-1994
Columbia River mouth basemap

C27358

1992 Invertebrate Density

Figure 9



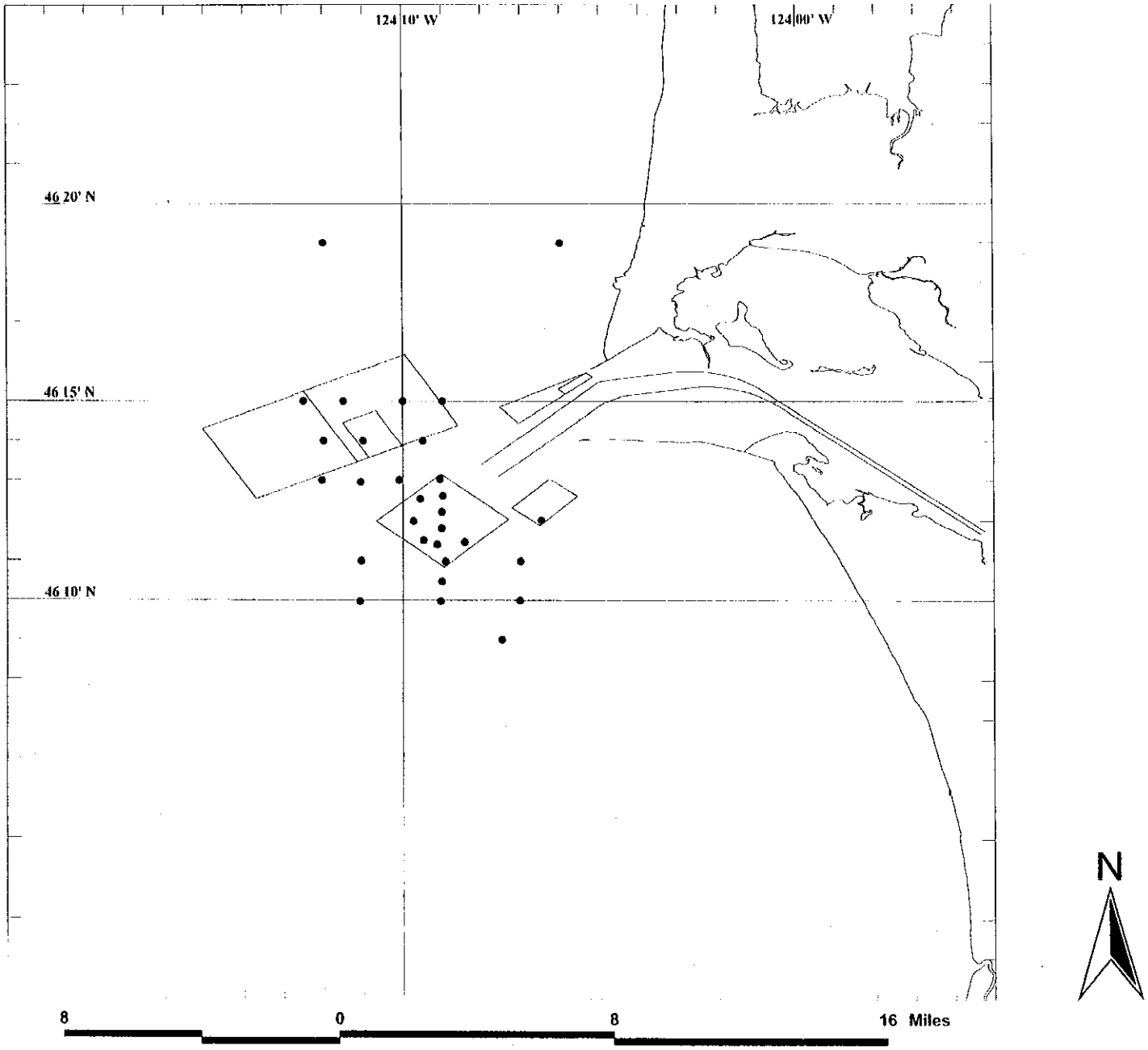
Hinton & Emmett 92-1994 (#/m2)
- 1 - 6646
- 6647 - 18360
- 18361 - 46661
- 46662 - 165105
- 165106 - 369462
- Columbia River mouth basemap

N

C27359

1993 Benthic Infauna Sample Locations

Figure 10

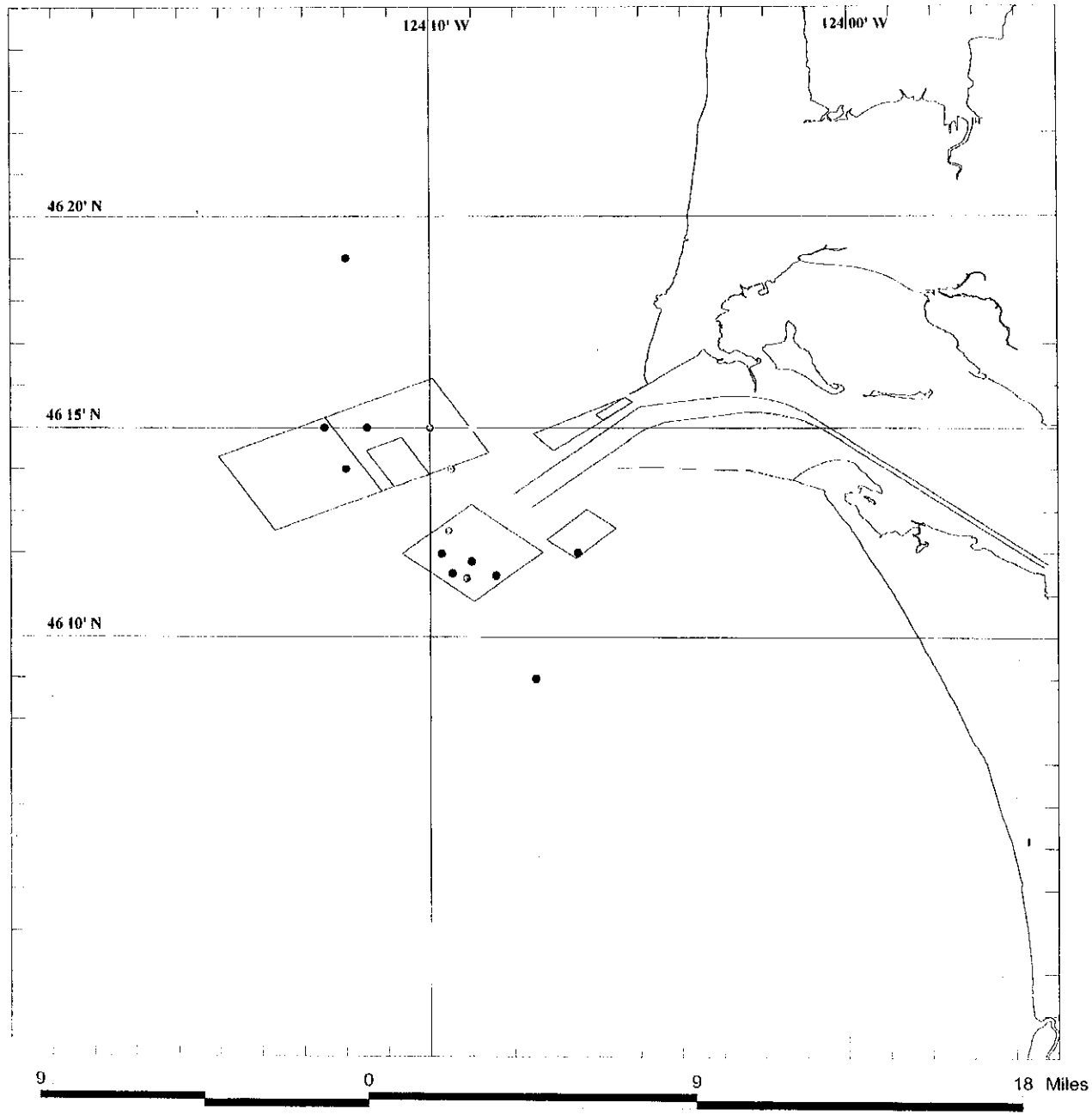


- Emmett & Hinton 93-1995
- Columbia River mouth basemap

C27360

1993 Invertebrate Density

Figure 11

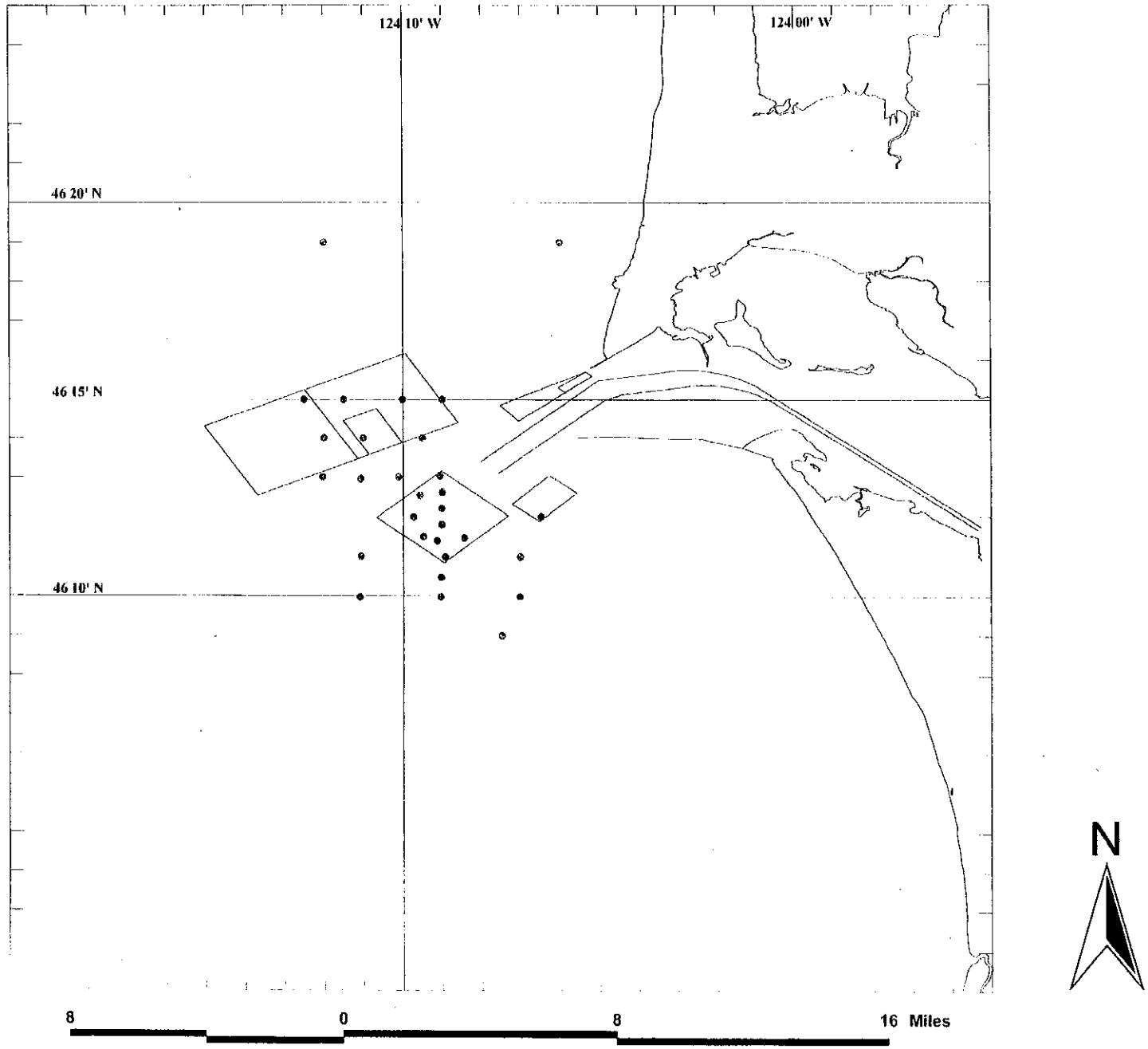


Emmett & Hinton 93-1995 (#/m2)
- 1 - 1542
- 1543 - 5156
- 5157 - 7613
- 7614 - 9802
- 9803 - 13375
- Columbia River mouth basemap

C27361

1994 Benthic Infauna Sample Locations

Figure 12

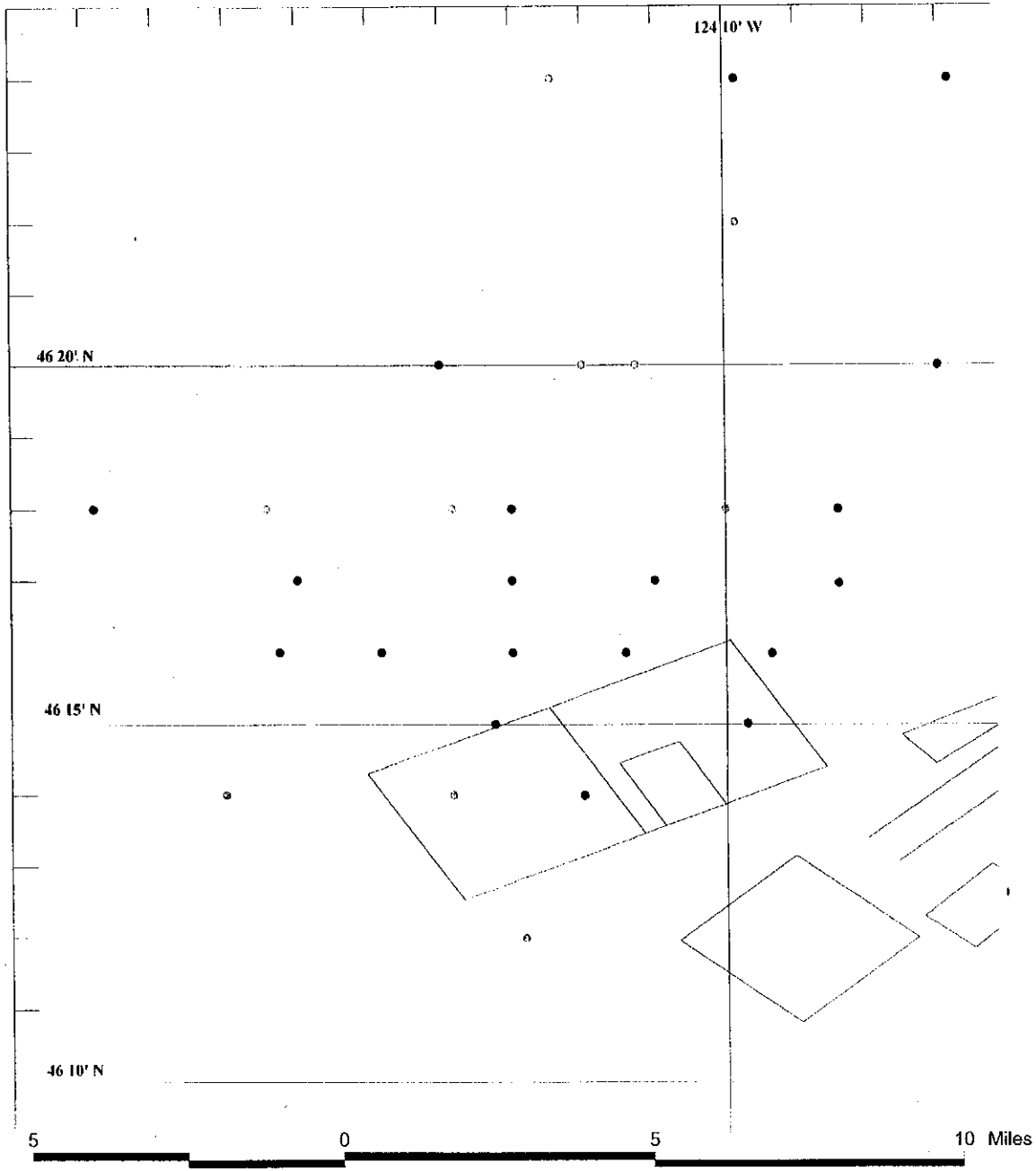


- Hinton & Emmett 94-1996
  Columbia River mouth basemap

C27362

1996 Invertebrate Density

Figure 13



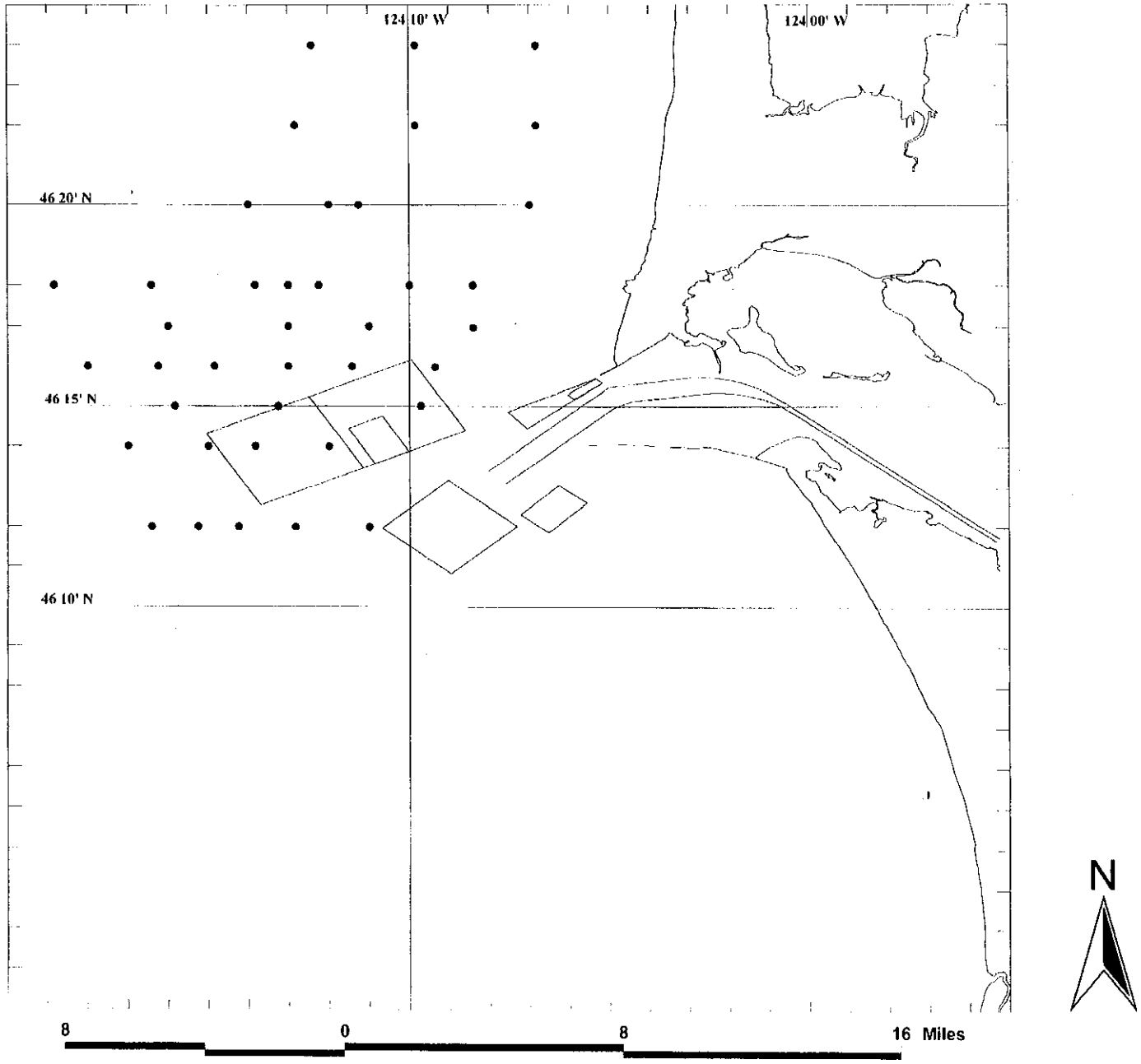
95-96-unpublished (#/m2)
- 0 - 4689
- 4690 - 9899
- 9900 - 13702
- 13703 - 19652
- 19653 - 35240

Columbia River mouth basemap

C27363

1996 Benthic Infauna Sample Locations

Figure 14

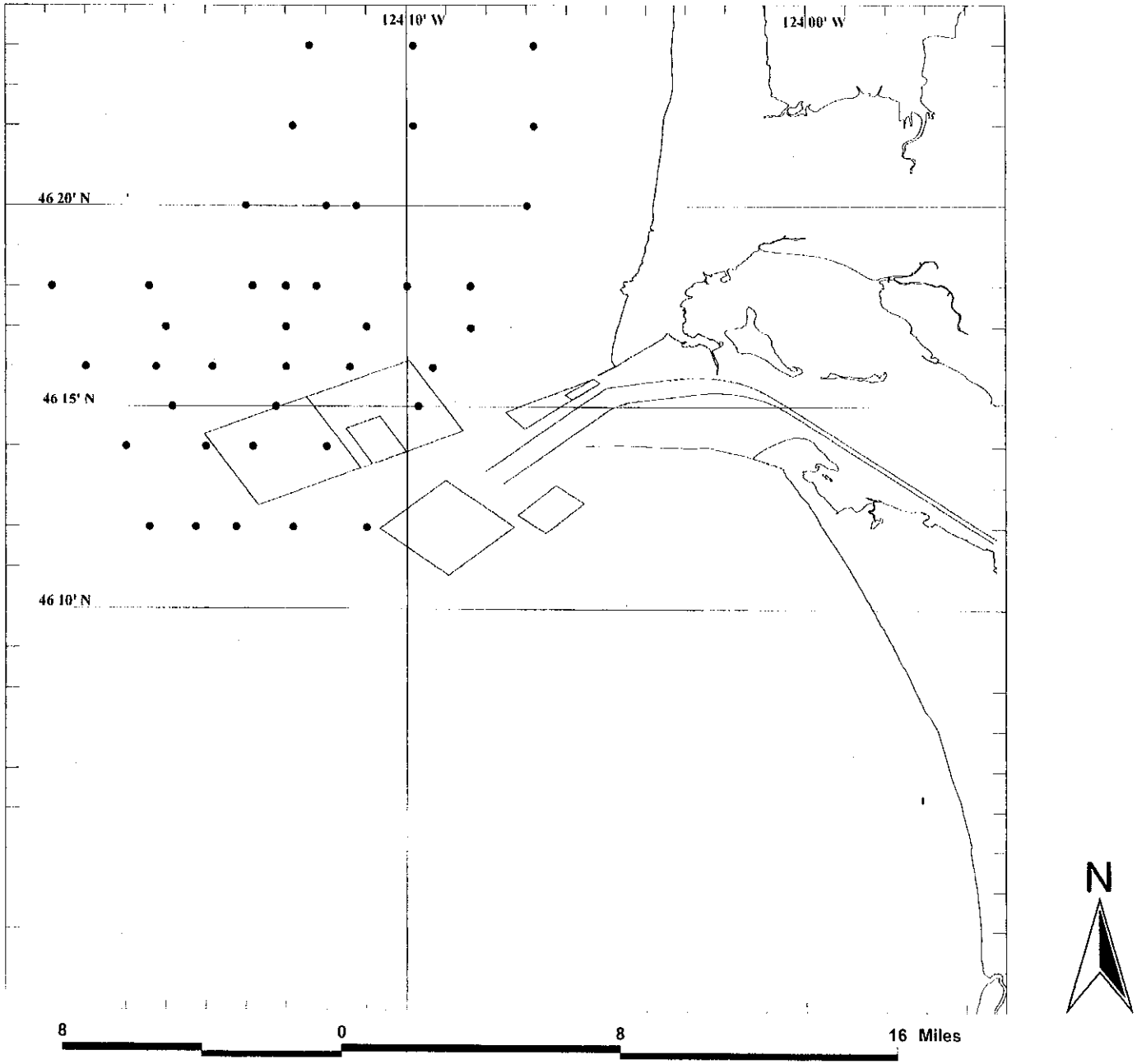


• 95-96-unpublished
Columbia River mouth basemap

C27364

1996 Benthic Infauna Sample Locations

Figure 14

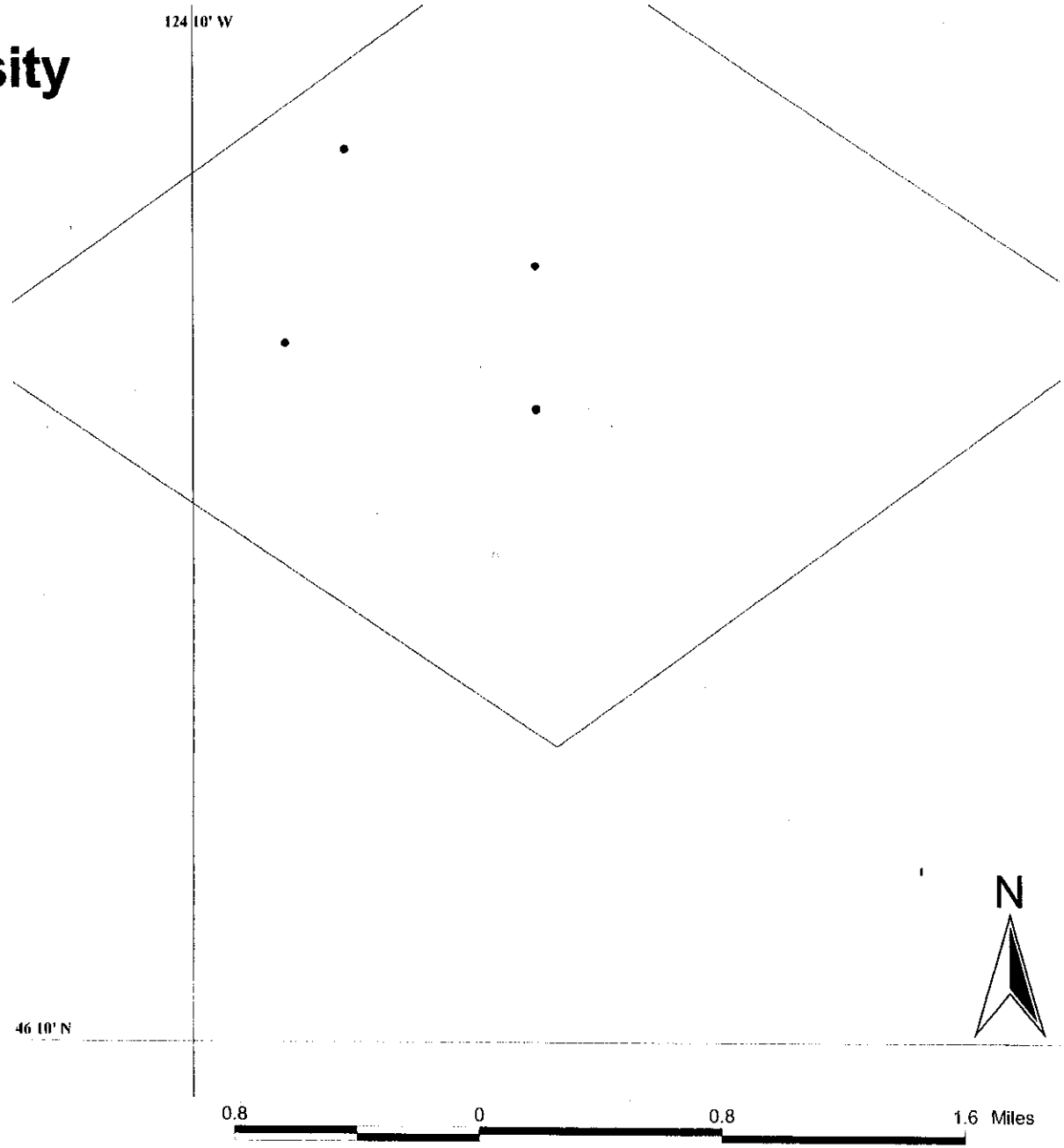


• 95-96-unpublished Columbia River mouth basemap

C27365

1994 Invertebrate Density

Figure 15

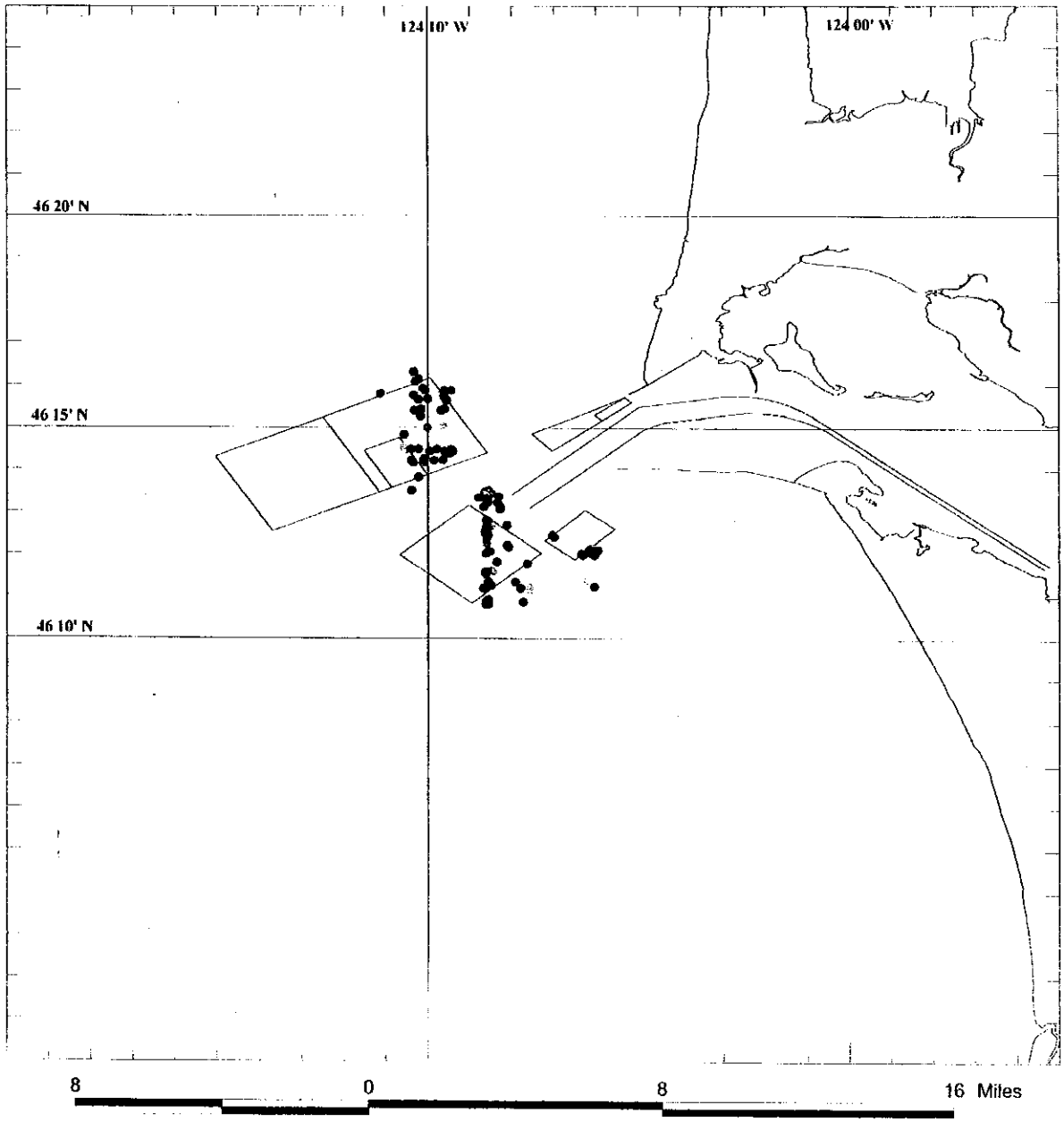


Hinton & Emmett 94-1996 (#/m2)
- 1 - 3205
- 3206 - 6752
- 6753 - 13798
- 13799 - 17439
- Columbia River mouth basemap

C27366

Fish and Shellfish Sample Locations
(1974, 1975, 1976)

Figure 16



- Durkin, et al. 74-1977
- Durkin et al. 75-1977

Durkin et al. 76-1977
Columbia River mouth basemap

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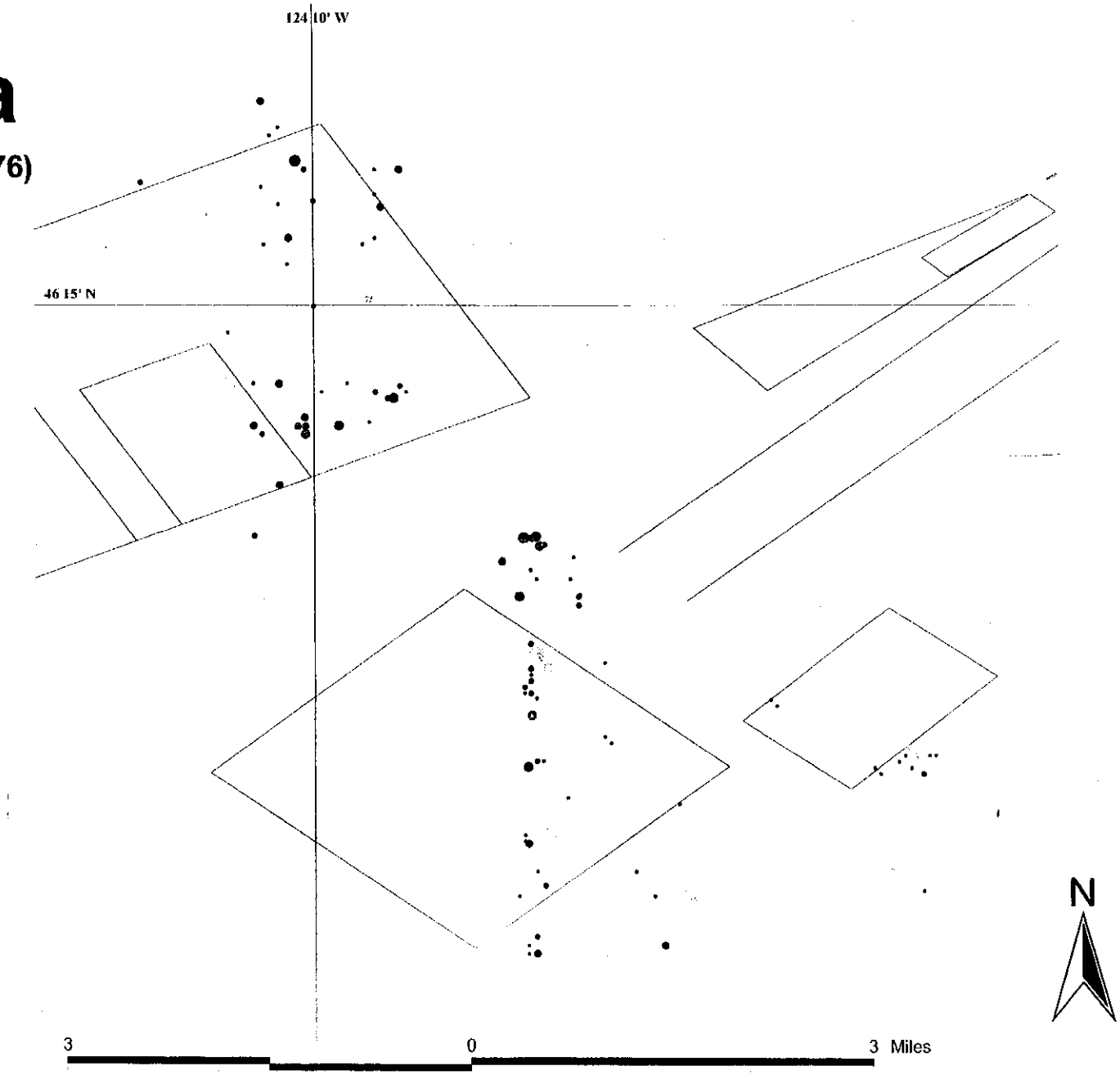
Fish Data

(total fish for 1974, 1975, 1976)

Figure 17



Durkin et al. 74-1977 (total fish)
- 186 - 266
- 267 - 406
- 407 - 587
- 588 - 875
- 876 - 951

Durkin et al. 75-1977 (total fish)
- 1 - 349
- 350 - 929
- 930 - 2281
- 2282 - 5325
- 5326 - 8144

Durkin et al. 76-1977 (total fish)
- 90 - 151
- 152 - 232
- 233 - 361
- 362 - 605
- 606 - 1046

Columbia River mouth basemap

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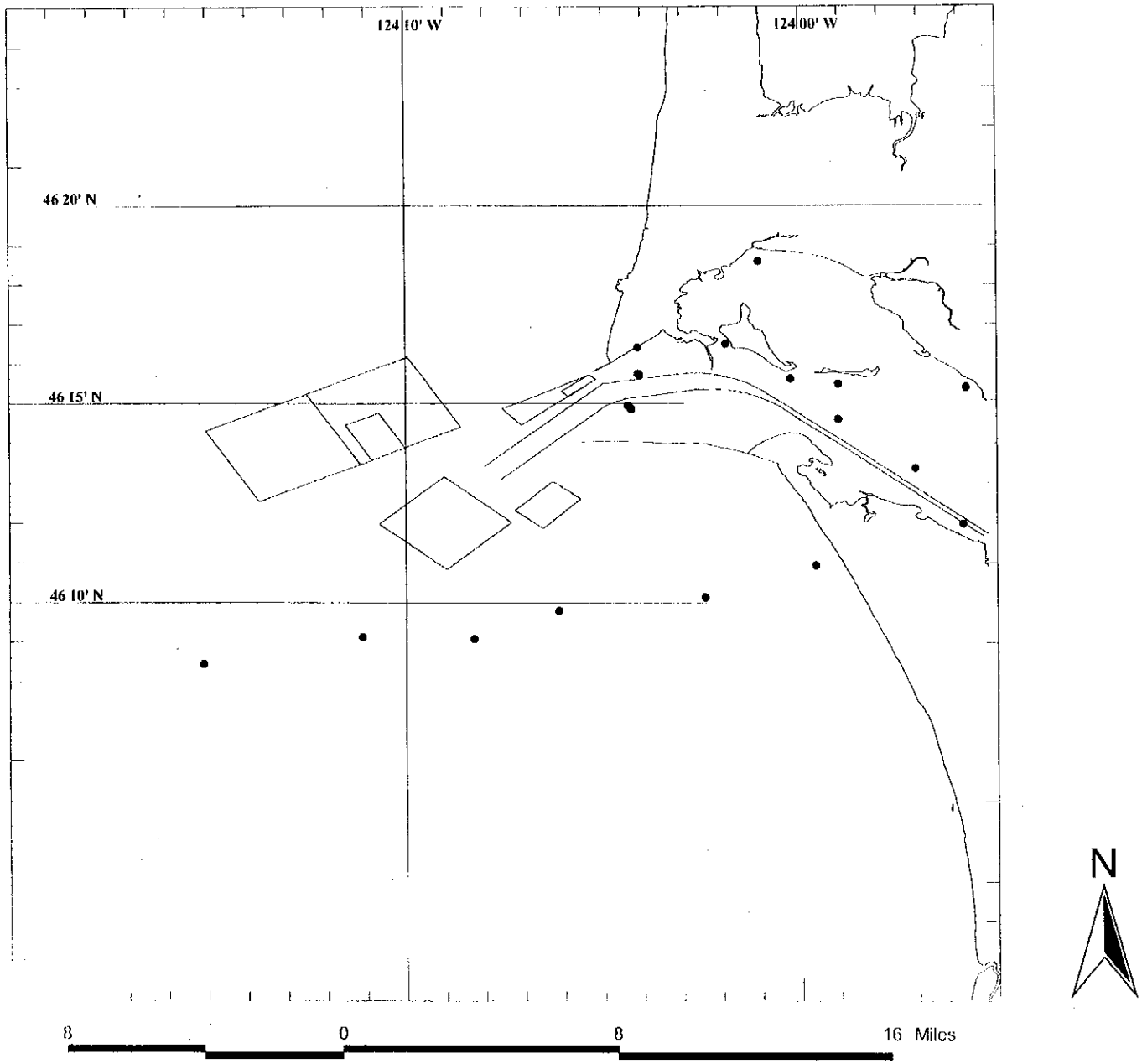
Dungeness Crab Sample Locations (1983, 1984, 1985)

Figure 19



- McCabe et al. 1986
  Columbia River mouth basemap

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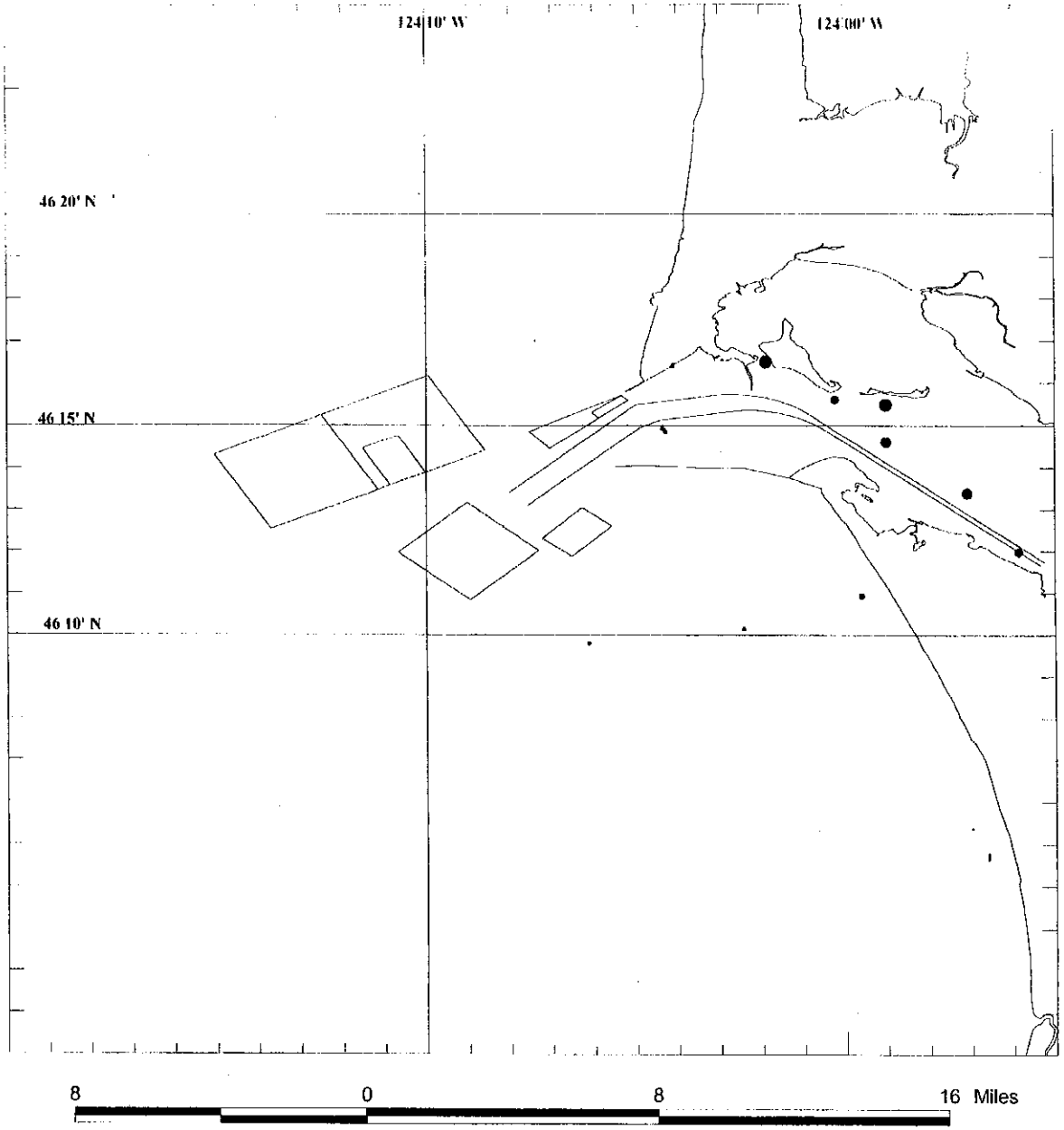
1983 Distribution of Dungeness Crabs

Figure 20



McCabe et al. 83-1986
- 1 - 4
- 5 - 9
- 10 - 38
- 39 - 85
- 86 - 1118
- Columbia River mouth basemap

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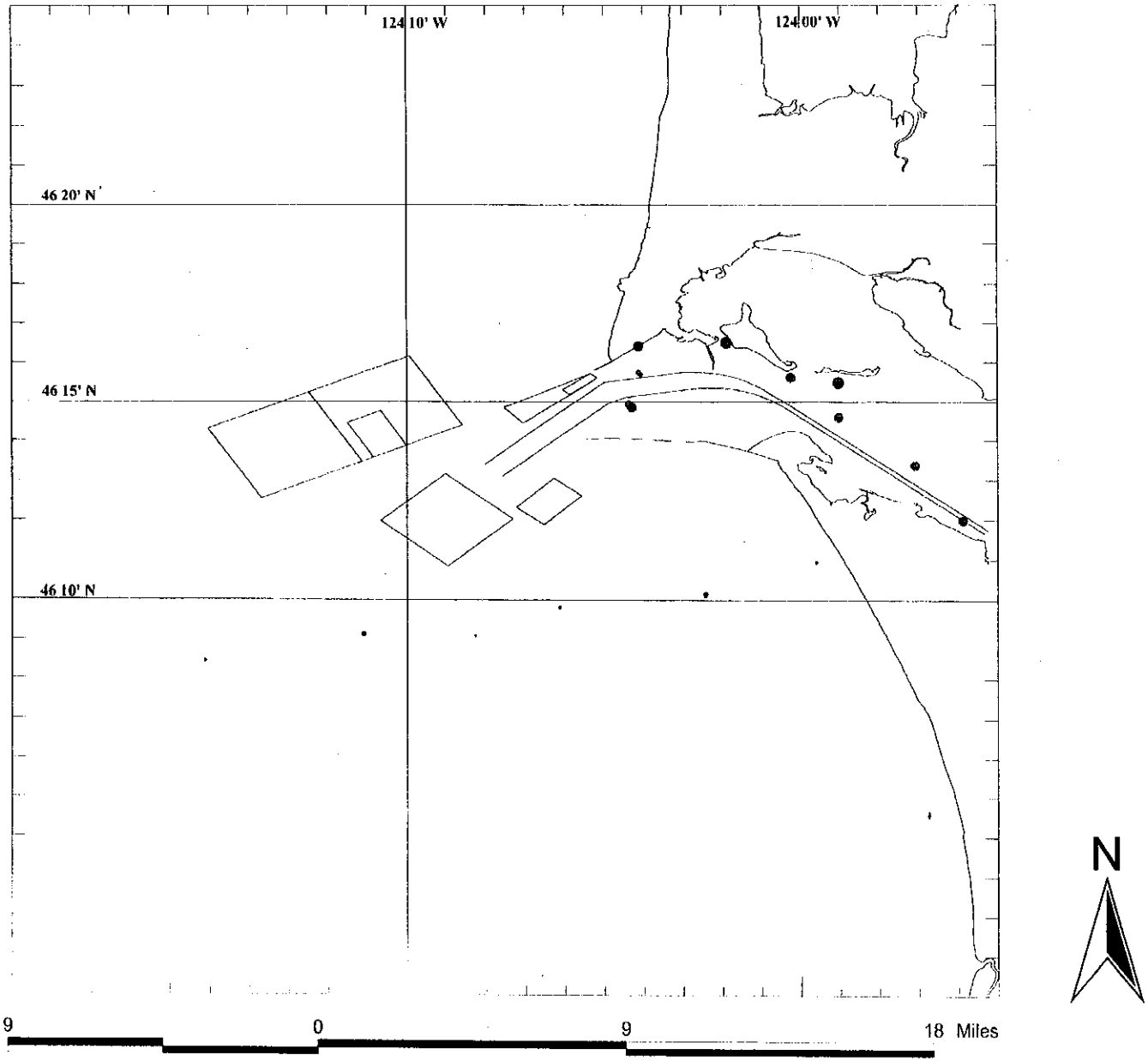
1984 Distribution of Dungeness Crabs

Figure 21



McCabe et al. 84-1986
- 1 - 16
- 17 - 41
- 42 - 72
- 73 - 265
- 266 - 729
- Columbia River mouth basemap

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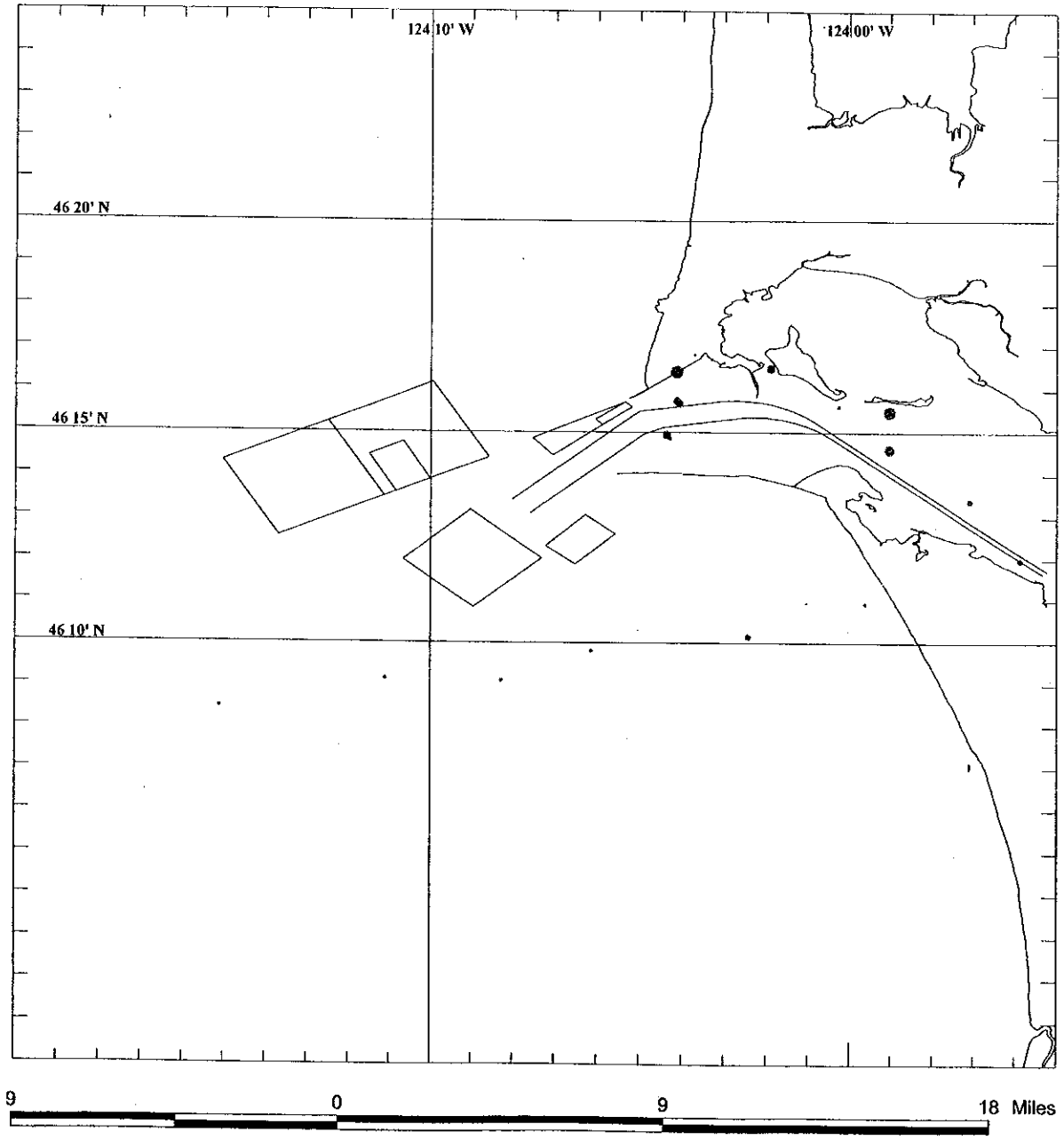
1985 Distribution of Dungeness Crabs

Figure 22



McCabe et al. 85-1986
- 1 - 97
- 98 - 300
- 301 - 896
- 897 - 1806
- 1807 - 3370

Columbia River mouth basemap

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