Exxon Valdez Oil Spill
Restoration Project Annual Report

Pristane Monitoring in Mussels and Predators of Juvenile Pink Salmon and Herring

Restoration Project 97195
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been address-in this annual report.

Jeffrey W. Short
Patricia M. Harris

Auke Bay Laboratory
Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA
11305 Glacier Highway
Juneau, Alaska 99801-8626

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Pristane Monitoring in Mussels and Predators of Juvenile Pink Salmon and Herring

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Study History: This project was initiated in FY96. This is the second annual report for the project.

Abstract: Pristane concentrations in mussels were monitored at 30 stations during spring and summer to compare nearshore feeding conditions for juvenile pink salmon and herring. The dominant-biomass zooplankter of PWS (*Neocalanus plumchrus*) contains about 1% pristane, a refractory hydrocarbon. Fecal material produced consequent to predation on *Neocalanus* contains un-absorbed pristane that may be accumulated by mussels, so pristane concentrations in mussels indicate the intensity of local predation. Comparison of pristane in mussels collected in 1994 through 1997 suggests increasingly favorable feeding conditions for these near-shore forage fish in PWS as a whole. Pristane concentrations in mussels near hatcheries are weakly correlated with overall marine survival of hatchery-released pink salmon at low statistical power. This suggests that monitoring pristane in mussels near hatcheries may have some utility for predicting weak year classes of hatchery released salmon in years of low zooplankton densities.

A February sampling exercize with the Youth Area Watch program led to discovery of surprisingly high concentrations of pristane in mussels. The source and ecological pathway of pristane to mussels in late fall and early winter is not known, but is speculated to be acquired during the previous fall, perhaps from zooplankton grazing a late-fall phytoplankton bloom.

Key Words: *Exxon Valdez*, pristane, *Neocalanus spp.*, mussels, pink salmon, herring, Prince William Sound.

Project Data: (will be addressed in the final report)

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Figure 3. Pristane accumulation index (PAI) for 1997. The PAI at each station is calculated as a numerically-approximated integral of pristane concentration in mussels and time at the station. The total PAI is the sum of PAI's for selected stations. Different colors indicate PAI's that are usually significantly different ($P < 0.05$).

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Figure 5. Regression of overall marine survival of hatchery-released pink salmon in PWS with PAIs summed for stations within 25 km of each hatchery. Survivals are based on hatchery estimates for juvenile pink salmon release in spring 1994 through 1996.

Executive Summary

The purpose of this project is to assess marine feeding conditions during juvenile life stages of pink salmon and herring in Prince William Sound (PWS). In spring, the principal prey of these juveniles is the copepod *Neocalanus plumchrus*, and annual copepod abundances may vary considerably. Predators of these juvenile fish (such as adult pollock) may also prey on the copepods, and may possibly select copepods during years of high abundance. Variability of these feeding conditions may therefore modulate recruitment of these commercially exploited fishes, by *e.g.* alleviating predation pressure during years when conditions are favorable. This project indirectly assesses energy conversion from *Neocalanus* copepods to nearshore, juvenile fish during spring, by monitoring a surrogate measure of fish fecal production in mussels.

Copepods in the genera *Calanus* and *Neocalanus* are apparently unique in their ability to biosynthesize a hydrocarbon called pristane. Pristane is derived from chlorophyll ingested by the copepods, and concentrations of pristane approach 1% in these animals. As a terminally-branched alkane, pristane dissolves into lipids and resists catabolic degradation, making it a tracer molecule for the lipids produced by these copepods. When these copepods are ingested by fish, some of the pristane is excreted in fecal material as a result of incomplete lipid absorption in the intestine. The fecal material may disperse in the water column, and then be accumulated by mussels as they filter seawater for food. Thus, pristane accumulation by mussels may indirectly indicate the extent of predation on *Calanus* and *Neocalanus* by nearby juvenile fish, with high pristane concentrations in mussels during spring indicating simultaneously high abundances of copepods and fish.

Pristane concentrations in mussels have been shown to increase by orders of magnitude during spring in PWS. The sharpest increases occur in early May, about 2 weeks following the peak of the copepod bloom. This project evaluates whether systematic monitoring of these concentration changes in mussels at fixed stations throughout PWS may be related to early marine survival and subsequent recruitment of pink salmon and herring. Mussels were collected periodically from 32 stations and analyzed for pristane to document seasonal concentration changes. In the laboratory, pristane is extracted from mussels with pentane and then isolated and measured by flame ionization gas-chromatography. Seasonal incorporation of pristane by mussels at a station is summarized by a pristane accumulation index (PAI), calculated as the numerical approximation of the integral of pristane concentration in mussels and time. The PAI is used to compare results among stations geographically. The sum of these PAI's across stations sampled the same year permits comparison of fecal production among years.

The first sampling of the 1997 collection season occurred in mid-February, to verify depuration of pristane by mussels the previous year. As noted in the previous annual report, concentrations were consistently near detection limits (< 300 ng/g dry weight) in mussels collected in late March 1989, but were substantially higher (as high as 3,790 ng/g) in mussels collected in mid-March 1996. Surprisingly, concentrations of pristane as high as 14,700 ng/g (median 5,500 ng/g) were measured in mussels collected mid-February 1997. The highest concentrations appeared at stations proximal to the path followed by the Alaska Coastal Current through PWS (Figure 1A). The source of this pristane burden is not known, but depuration of pristane may be much slower during winter because of lower metabolic activity in response to lower water temperature and food abundance. It is thus possible that the mid-February body-burden of pristane was acquired during the previous fall, perhaps from zooplankton grazing a late-fall phytoplankton bloom. If so, this may indicate a significant energy source for forage fish during a critical season.

Pristane concentrations declined from mid-February through mid-April, then increased sharply at most stations by mid-May (Figures 2B - 2F). The lowest concentrations were generally observed during the April 10 - 14 sampling, and ranged from below detection limits to 2,630 ng/g (median 680 ng/g). By mid-May, concentrations ranged from 210 ng/g to 37,800 ng/g (median 4,760 ng/g). Most of this increase occurred during the first week of May, similar to 1996 and somewhat earlier than 1995. As in previous years, these increases tend to occur first at stations peripheral to the marine trench system of northwest PWS, and progressively later at stations closer to the Gulf of Alaska (Figures 2D - 2G). By June, concentrations decline through August (Figures 2H - 2J).

The sum of the PAI across comparable stations (Σ PAI) provides an indication of the extent of pristane accumulation by mussels within the whole of PWS for the season, and may be used as a comparative index across years. This Σ PAI index has increased continuously from 1994 through 1997 (Figure 4). Work reported in the previous annual report for this project (Short and Harris 1997) indicates that near-shore forage fish (particularly juvenile pink salmon) preying on *Neocalanus* copepods promotes pristane incorporation by mussels during spring in PWS. The increasing Σ PAI index during the last 4 years therefore suggests increasingly favorable feeding conditions for these near-shore forage fish in PWS as a whole.

The extent of pristane accumulation by mussels near hatcheries was examined to determine whether these measurements are related to marine survival of pink salmon released by the hatcheries. The marine survival of pink salmon released from hatcheries in 1994 through 1996 was regressed against the PAI summed across stations within 25 km of each hatchery. The 25 km radius was used because released juveniles would require at least 2 weeks to swim this distance from a hatchery, and probably reside within this radius substantially longer to feed. Hatcheries release juvenile pink salmon *en masse* near the peak of the zooplankton bloom in early May, so the PAI of nearby stations should reflect the intensity of feeding by these fish on *Neocalanus* copepods in the vicinity. As depicted in Figure 5, overall marine survival of hatchery released pink salmon is only weakly related ($r^2 = 0.11$) to this regional PAI index. The relationship is suggestive but not significant, however with only 9 observations the power is low, and mortality at later life stages in not addressed by this approach. Nonetheless, this approach may prove useful for partitioning overall marine survival into life-stage components. The ability of this regional PAI to reduce the variance of predicted marine survival for hatchery-released salmon will be evaluated more fully in subsequent years as more data become available.

This project enlisted the cooperation of the Prince William Sound Aquaculture Corporation (PWSAC) and the PWS Youth Area Watch (YAW) program (project 97210) to assist with collection of mussels. Staff at PWSAC collected mussels from 4 hatchery locations in PWS, and YAW students collected mussels from their hometowns. Hatchery collections substantially lower project costs, because sample collection is the most expensive component of this project. These collections also enable explicit incorporation of PWSAC hatcheries into geographic and inter-annual comparisons of project results, so that nearshore feeding conditions assessed near the hatcheries may be directly related to the rest of PWS.

Students in the YAW program participated in a joint mussel collection flight with this project. Staff from the Auke Bay Laboratory (ABL) demonstrated mussels collection methods and record keeping requirements to students on a YAW-sponsored flight in PWS in mid-

February, which led to the discovery that mussels had surprisingly high concentrations of pristane in February 1997. Students also traveled to the ABL to learn more about the project, including the chemical analysis principles involved, and then dissected mussels and prepared the tissue for chemical analysis.

Introduction

Determination of the causes of the dramatic declines in populations of pink salmon and herring following the *Exxon Valdez* oil spill requires an assessment of the natural factors that affect recruitment of these species, because any toxic effects of the spill may otherwise be confounded with these natural factors. In addition, these natural factors impose constraints on the recovery potential of these species. Pink salmon and herring are identified as species that have not recovered. If the recent population declines of these two species are the result of changes in the basic ecology of Prince William Sound due to natural phenomena (e.g. El Niño), then recovery of these populations to pre-spill levels may not be possible, and the criteria for recovery must recognize these changes.

The proposed project will provide evidence that may be used to evaluate why populations of pink salmon and herring are not recovering. One of the major natural factors hypothesized as a constraint on the recovery potential for these species is prey-switching by predators on the larval and juvenile stages. Under this hypothesis, predators are thought to concentrate on larval and juvenile pink salmon and herring predation in years of low copepod abundance, but switch their concentration to copepods in years of higher abundance. The proposed project addresses this hypothesis in two ways: first, by identifying unrecognized "pre-switching predators", and second, by indirectly monitoring survival through juvenile stages. Identification of prey-switching predators will permit subsequent evaluation of whether the identified species really do substantially determine recruitment success of pink salmon and herring.

Annual monitoring of pristane concentrations in mussels throughout Prince William Sound will permit an indirect evaluation of whether pink salmon and herring survival through the juvenile life stages primarily determines year class strength. In addition, the monitoring will identify important marine nursery areas for these species, the conservation of which may promote their recovery. Monitoring pristane in mussels will be necessary for at least 5 consecutive years to provide a minimal statistical basis for any observed relationship between variation of pristane concentrations in mussels and recruitment success of pink salmon and herring.

Pristane is a hydrocarbon biosynthesized from chlorophyll by herbivorous copepods in the genera *Calanus* and *Neocalanus*. These copepods are the only proven modern marine source of pristane (Avigan & Blumer 1968) (it also occurs in petroleum), and they typically contain concentrations that approach 1% dry weight (i.e. 10,000,000 ppb). As a branched alkane, pristane is highly lipophilic and resistant to metabolic degradation, which suggests that it may be a useful "tracer" molecule that would quantitatively label fats in predators of these copepods (Blumer *et al.*, 1964). The low detection limit (about 100 ppb) of the inexpensive analytical method further suggests the utility of pristane as a natural indicator of energy flow from these copepods to higher trophic level predators.

Calanus and *Neocalanus* copepods are marine zooplankters about 3 - 8 mm in length, and can be the dominant marine herbivores in Prince William Sound (PWS) during the spring phytoplankton bloom. They are consequently important prey during the reproductive period of many predator species. Important direct predators of *Calanus* and *Neocalanus* copepods identified in PWS include storm petrels, herring, and juvenile pink salmon. In addition, pristane concentrations that range to 50,000 ppb (dry weight) are evident in filter feeding organisms such as mussels and some clams during spring. Experiments conducted under this project at the Auke Bay Laboratory and in the field confirm that an important route of pristane accumulation in these filter feeders is through ingestion of fecal material derived from predators of *Calanus* and *Neocalanus*, e.g. juvenile pink salmon. Pristane concentrations in PWS mussels may therefore reflect the timing and simultaneous abundance of *Calanus* and *Neocalanus* and their predators in seawater adjacent to sampled mussels.

These results suggest that tissue analysis of pristane may be used to investigate the PWS marine ecosystem in at least 3 ways. First, such analyses may identify predators that have a direct dietary dependence on *Calanus* and *Neocalanus*, and these predators may include heretofore unrecognized "prey-switching" species that switch predation to larval herring and juvenile salmon in years of relatively low copepod abundance. Prey-switching has been hypothesized as major determinant of pink salmon and herring recruitment success in the SEA studies. Second, a regular monitoring program for pristane in mussels during spring could provide a quantitative basis for comparing inter-annual energy flow through *Calanus* and *Neocalanus* to commercially important predators such as herring and pink salmon. This may provide a relatively inexpensive indicator of survival through the early juvenile stages for these species. Finally, the monitoring program may identify locations where this flow is consistently high, i.e. critical marine habitats. These approaches may clarify some of the important natural factors that affect recruitment of e.g. juvenile salmon and herring, which is necessary for determining the restoration of these resources.

Objectives

This project has 2 objectives:

1. Measure pristane concentrations in mussels collected biweekly during spring from 30 stations in Prince William Sound to evaluate inter-annual variability of energy conversion from *Neocalanus* copepods to their nearshore predators.

2. Determine the existence and location of regions inside Prince William Sound where the energy conversion of objective 2 above is consistently above average, and synthesize these data over time and geographic location each succeeding project year.

Methods

Mussel Collection

The seasonal variability of pristane concentrations in mussels (*Mytilus trossulus*) is based on collections from 30 stations in Prince William Sound (fig. 1, table 1). Mussels are collected biweekly, beginning about mid-March through June 1, then July 1 and August 1 for a total of 9 collection periods and 270 mussel samples. The collection frequency is initially higher to more accurately establish the onset of the initial rise of pristane concentrations in the mussels, which is correlated with the zooplankton bloom and may vary from year to year. Collected mussels are stored frozen and analyzed for whole-body pristane concentration.

Of the 30 stations monitored, 26 are sampled by ABL staff by small float-plane based out of Cordova. Another 4 stations are located near Prince William Sound Aquaculture Corporation (PWSAC) hatcheries, and are sampled by volunteer PWSAC staff. Additional stations are sampled by volunteer primary and secondary school students in collaboration with the PWS Youth Area Watch program (project 97210). The Youth Area Watch (YAW) project also sponsored a sampling effort in mid-February at 24 of the stations routinely sampled by ABL staff later in the spring.

Mussels (10) are collected from selected mussel beds and placed into a plastic bag together with collection documentation (i.e. date, time, location, collector). Selected mussels are usually in the length range 20 - 45 mm. Mussels are collected along a transect parallel with the shoreline; 1 mussel is collected every consecutive meter. Previous results archived in the *Exxon Valdez* Oil Spill of 1989: State/Federal Trustee Council Hydrocarbon Database 1989 - 1995 (EVTHD) indicates that pristane concentrations in mussels collected in this way are representative of entire mussel beds.

Pristane Analysis

The chemical analysis of pristane involves pentane extraction of macerated tissues, lipid removal with silica gel, and separation and measurement of pristane by gas chromatography equipped with a flame ionization detector. Pristane concentrations are determined by the internal standard method, with deuterated hexadecane added to the pentane initially as the internal standard. Pristane identification is based on retention time relative to the internal standard. Quality control samples include method blanks, spiked method blanks, and reference sample analyzed with each batch of 20 samples to verify method accuracy, precision, and absence of laboratory introduced artifacts and interferences. Recovery of the internal standard will be determined by adding a second internal standard prior to instrumental analysis. Method detection limits will be assessed annually for the mussel tissue matrix, and these detection limits will be assumed for the other matrixes analyzed. Based on previous performance, we anticipate accuracy of ± 15% of National Institute of Science and Technology (NIST)-certified values for the spiked blank and reference samples, precision of 95% of reference samples within ± 15% of sample means, and laboratory artifacts below detection limits more than 99% of the time. This level of analytical performance will insure that variability due to sample analysis is negligible compared with variability among replicate mussel samples.

Percent moisture and percent lipid will also be determined in samples so that results may be analyzed on dry weight and lipid weight bases. Dry weights will be determined by heating samples at 60 C to constant final weight. Lipid proportions will be determined from weight loss due to dichloromethane extraction.

Data Analysis

Pristane concentrations in mussels are analyzed statistically using least-significant difference (LSD) criteria based on an extensive sampling of the error distribution for these measurements. An error distribution for log-transformed pristane concentrations in mussels is generated from 178 triplicate and 79 duplicate samples analyzed for the Exxon Valdez oil spill, which are contained in the EVTHD. These replicated samples were collected and analyzed by the same methods, and they all contained pristane concentrations above method detection limits. The variances of these replicates are homoscedastic after log transformation, so a distribution for differences of two random samples of the error distribution can be generated by Monte Carlo simulation. Based on this distribution of differences, the LSD at an $\alpha = 0.05$ type I error rate is about 1.015, which corresponds to a ratio of about 2.75 for un-transformed data. Thus, mussels from two different samples are judged significantly different if the ratio of the larger pristane concentration to the smaller is more than 2.75. The power of this test to detect an actual increase of 3 is about 58%, again derived from Monte Carlo simulation of the error distribution. Since pristane concentrations in mussels typically increase by factors of greater than 10 during the season, the power of the sampling design is more than adequate.

Propagation of errors for derived indexes indicates that 66% increases of the pristane accumulation index (PAI) are significant at the $\alpha = 0.05$ type I error rate. The PAI represents the productivity of near-shore *Neocalanus* consumers in one sampling season. The PAI is calculated as the product of pristane concentration and sampling interval, and is an approximation of the integral of concentration and time at each station. The power of these criteria to detect an actual doubling of the PAI is about 80%, estimated by Monte Carlo simulation. The power to detect differences among years for the sum of the PAI's across stations (Σ PAI) is even greater, due to the larger number of measurements involved: increases of 22% are significant, and the power to detect such increases when they occur is about 50%.

The basis for the Σ PAI calculation was changed to permit comparison with results for 1994 through 1996. The PAI calculation was possible for fewer stations sampled in 1994, so only stations that were comparably sampled during each of the years 1994 - 1997 were included in the calculation of Σ PAI for each year. The results for Σ PAI presented in this report for the years 1995 & 1996 are consequently somewhat lower than reported in previous annual reports, because fewer stations were included in the calculation for those years as presented in this report.

Results

Pristane Concentrations in Mussels

Substantial concentrations of pristane were detected in mussels collected in mid-February from PWS. The median concentration was 5,500 ng/g dry weight, and ranged as high as 14,700 ng/g (at Windy Bay, Figure 2A). Concentrations also exceeded 10,000 ng/g at Foxfarm and at Fairmont Island. Concentrations generally declined through mid-April (Figures 2A - 2D), and ranged from below detection limits to 2,630 ng/g (median 680 ng/g) by April 10 - 14. Most of the stations where pristane concentrations were higher in mid-April were near the Knight Island Passage area (Figure 2D).

Pristane concentrations increased sharply in early May (fig. 2F & 2G). Concentrations exceeding 10,000 ng/g occurred at 5 stations sampled May 1 - 20. Most of these stations were also associated with the marine trench system of the northwest sound, although concentration increases occurred at stations in the rest of the sound as well during this period. The highest concentration observed was 37,800 ng/g at Point Eleanor, and concentrations exceeding 17,000 ng/g occurred at Esther Island and Bligh Island.

As in previous years, these increases tend to occur first at stations peripheral to the marine trench system of northwest PWS, and progressively later at stations closer to the Gulf of Alaska (Figures 2D - 2G).

Pristane concentrations began to decline at most stations by the end of May (Figure 2G), and this decline continues through late-July/early-August (Figures 2H - 2J). The highest pristane concentrations observed during the last sampling period were 5,620 ng/g, 4,710 ng/g and 4,030 ng/g at Point Eleanor, Point Pakenham and Rocky Bay, and concentrations at all the remaining stations were less than 3,460 ng/g.

Pristane Accumulation Index (PAI)

The highest PAI were associated with stations adjacent to the marine trench system of the northwest sound (Figure 3). The highest PAI was 1,690,000 ng-d/g at Point Eleanor followed by 789,000 ng-d/g at Esther Island and 699,000 ng-d/g at Johnstone Point. The total PAI summed across stations (Σ PAI) was 10,600,000 ng-d/g.

The extent of pristane accumulation by mussels near hatcheries was examined to determine whether these measurements are related to marine survival of pink salmon released by the hatcheries. The marine survival of pink salmon released from hatcheries in 1994 through 1996 was regressed against the PAI summed across stations within 25 km of each hatchery. The 25 km radius was used because released juveniles would require at least 2 weeks to swim this distance from a hatchery, and probably reside within this radius substantially longer to feed. Hatcheries release juvenile pink salmon *en masse* near the peak of the zooplankton bloom in early May, so the PAI of nearby stations should reflect the intensity of feeding by these fish on *Neocalanus* copepods in the vicinity. As depicted in Figure 5, overall marine survival of hatchery released pink salmon is only weakly related ($r^2 = 0.11$) to this regional PAI index. The relationship is suggestive but not significant, however with only 9 observations the power is low, and mortality at later life stages in not addressed by this approach. Nonetheless, this approach may prove useful for partitioning overall marine survival into life-stage components. The ability of this regional PAI to reduce the variance of predicted marine survival for hatchery-released salmon will be evaluated more fully in subsequent years as more data become available.

Youth Area Watch (YAW)

Ten students from YAW joined staff from this project for 3 joint-sponsored training flights in Prince William Sound in mid-February. We demonstrated sample collection and record keeping at several pristane collection sites and introduced the basic principals of the project to the students.

Two groups of YAW students, a total of 12, visited the ABL in mid-February and early March to learn about the project and participate in the sample analysis process. Staff at ABL presented a detailed explanation of the project, including the chemical analysis principles involved, followed by student participation in the mussel dissection, tissue processing, and chemical analysis procedures. Participation and sponsorship by YAW in the early sampling enabled this project to detect unexpectedly high concentrations of pristane in mussels at this time.

Discussion

1. Source of Pristane in Winter

The cause of the relatively high pristane concentrations detected in mussels of PWS in February 1997 is not clear. Surprisingly high pristane concentrations were reported in mussels collected from the Foxfarm stations in early February 1996 in the previous annual report for this project (Short and Harris 1997). Also, comparison with results for late March in 1995 through 1997 suggests that the winter pristane source has been available during each of those years. The decreasing concentrations observed from February through mid-April 1997 suggests slow depuration during this period. This would be consistent with lower metabolic activity in response to lower water temperature and food abundance. Conceivably, the winter pristane burden accumulated in mussels during late Fall 1996, perhaps by a mechanism involving predation on pristane-bearing zooplankters grazing a late-Fall phytoplankton bloom, similar to what occurs during spring. Alternatively, pollock have invaded PWS since 1989 and may filter-feed on *Neocalanus spp.*, so perhaps the March accumulations of pristane are due to fecal production by pollock feeding on *Neocalanus spp.* Investigation of this winter pristane source should be pursued, as it may lead to discovery of a significant energy source for forage fish during a critical season, or to an important source of predation affecting the population dynamics of *Neocalanus spp.* in PWS.

2. Timing comparison of 1995, 1996 & 1997

The sharp increase of pristane concentrations in mussels during early May, 1997 is consistent with results for 1995 and 1996 to within about a week. Timing differences of 1 week are at the limit of resolution of the sampling frequency. The generally consistent appearance and high Spring abundances of *Neocalanus spp.* in each of the years 1994 through 1997 in PWS suggests that a match/mis-match mechanism probably does not affect the early marine survival of predators dependent on this forage base. Consequently, discrimination of timing differences in the appearance of pristane in mussels during Spring is probably not worth the increased sampling effort.

3. Interannual PAI Comparison

The steadily increasing Σ PAI index from 1994 through 1997 (Figure 4) suggests that utilization of *Neocalanus spp.* by their predators has increased during this period for PWS as a whole. This implies that early marine forage conditions for juvenile salmonids, herring, and other forage fishes have been favorable, and increasingly so, during the last 4 years. Estimates of overall marine survival for hatchery-released juvenile pink salmon have also been quite high during this period. The high Σ PAI index for 1997 suggests that these high survivals may continue, so that high returns of adult salmon in Fall 1998 may be expected in PWS on this basis, absent unusually high predation losses during later marine life stages. In addition, the consistent patterns of geographic distribution during these years suggests continued higher productivity of northwest PWS.

4. PAI and Survival of Hatchery Pink Salmon

Survival during the early marine life stages is widely believed to determine recruitment in salmonids, but partitioning overall mortality among marine life stages is a daunting challenge. In recent years, overall marine survival of hatchery-released salmonids has been quite high, which may be due in part to continued high abundances of *Neocalanus spp.* prey during initial marine residence. When such prey are consistently abundant, recruitment is more likely to be determined by predation on these salmonids. As long as these conditions persist, relatively small interannual fluctuations of *Neocalanus spp.* abundances may have little effect on salmonid recruitment. Thus, the utility of the PAI as a predictive variable for salmonid recruitment may not become apparent until a sharp reduction in zooplankton abundance occurs.

Conclusions

1. The high concentrations of pristane measured during February might indicate the existence of a zooplankton prey resource available to forage fish near the onset of winter. This unknown pristane source should be investigated further.

2. As in previous years, increases of pristane in mussels during spring begins a stations adjacent to the marine trench system of northwest PWS and then radiates outward toward the Gulf of Alaska. The timing of the Spring increase of pristane in mussels was consistent (within about 1 week) during 1995-1997.

3. Feeding conditions for nearshore zooplanktivores, as reflected by the Σ PAI index, have been very favorable (and increasingly so) during the period 1994 - 1997. On this basis, abundant pink salmon returns to PWS in Fall 1998 may be anticipated.

4. Regression of hatchery estimates of marine survival against PAIs of adjacent pristane sampling stations may provide a means of evaluating the utility of the PAI to partition overall marine survival into early and later life stage components. However, an adequate evaluation of this issue will require several more years of results (in part because survival estimates succeed pristane measurements by a year), which include years of relatively poor survival (which have not occurred in recent years).

Literature Cited

Avigan, J., and M. Blumer. 1968. On the origin of pristane in marine organisms. Journal of Lipid Research **9**:350-352.

Blumer, M., M. M. Mullin, and D. W. Thomas. 1964. Pristane in the marine environment. Helgoländer Wissenschaftliche Meeresuntersuchungen **10**:187-201.

Exxon Valdez oilspill of 1989: State/Federal trustee council hydrocarbon database, 1989-1995. Available from Bonita Nelson, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, Alaska 99801-8626.

Short, J. and P. Harris. 1997. Pristane monitoring in mussels and predators of juvenile pink salmon & herring, *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project 97195), Auke Bay Laboratory, Juneau, Alaska.

Table 1. Locations and abbreviations of mussel collection stations sampled for this project. The abbreviations are also used in figure 1.

Station Abbreviation	Station Name	Latitude Deg N	Latitude Min	Latitude Sec	Longitude Deg W	Longitude Min	Longitude Sec
AFKHA	AFK Hatchery	60	3	8	148	3	30
APPLI	Applegate Island	60	37	30	148	8	10
BLIGI	Bligh Island	60	52	2	146	44	59
CANNC	Cannery Creek Hatchery	60	59	39	147	32	19
CHENB	Chenega Bay	60	3	47	148	1	10
CHENI	Chenega Island	60	23	11	148	0	4
CONSH	Constantine Harbor	60	21	16	146	40	25
CPUGE	Cape Puget	59	57	35	148	28	48
DAYVI	Dayville	61	5	13	146	16	40
DECIP	Decision Point	60	48	21	148	28	35
DIVIP	Division Point	60	28	55	148	17	13
EKNII	East Knight Island	60	20	49	147	38	32
ESTHI	Esther Island (WN Hatchery)	60	47	7	148	3	30
FAIRI	Fairmont Island	60	52	51	147	26	17
FLEMI	Fleming Island	60	10	29	148	2	3
FOXFA1	Fox Farm 1	59	58	15	148	8	22
FOXFA2	Fox Farm 2	59	58	7	148	6	36
FOXFA3	Fox Farm 3	59	58	10	148	10	22
GREEI	Green Island	60	16	55	147	24	57
HANNB	Hanning Bay	59	57	12	147	42	56
HERRP	Herring Point	60	28	28	147	47	27
JOHNP	Johnstone Point	60	29	1	146	34	15
KENNC	Kenny Cove	60	25	24	146	7	23
MAINB	Main Bay	60	32	0	148	3	30
NAKEI	Naked Island	60	39	3	147	26	24
OLSEN	Olsen Bay	60	44	30	146	11	58
PATTB	Patton Bay	59	52	40	147	26	15
PELEA	Point Eleanor	60	34	33	147	33	49
PERRI	Perry Island	60	40	40	147	54	50
PPAKE	Point Pakenham	60	0	23	148	5	7
ROCKB	Rocky Bay	60	20	14	147	7	32
SNUGC	Snug Corner Cove	60	44	8	146	37	32
STORI	Storey Island	60	43	41	147	27	2
TATIT	Tatitlek	60	51	48	146	41	6
WHITT	Whittier	60	46	42	148	40	0
WINDB	Windy Bay	60	34	22	148	57	29

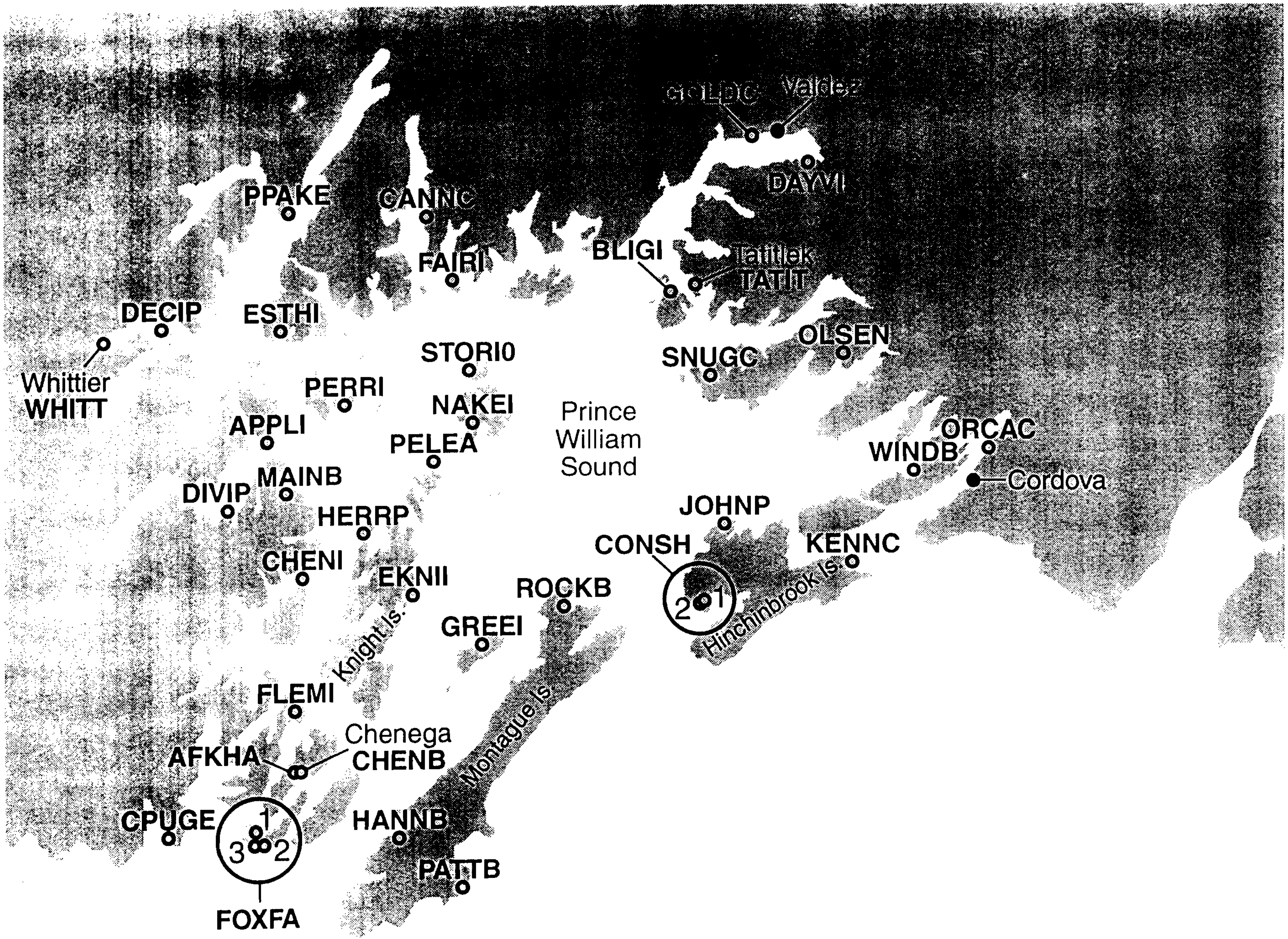

GOLDC
Valdez
DAYVI
PPAKE
CANNC
FAIRI
BLIGI
Tatitlek
TATIT
DECIP
ESTHI
Whittier
WHITT
STORI0
SNUGC
OLSEN
PERRI
NAKEI
Prince William Sound
APPLI
PELEA
ORCAC
WINDB
Cordova
MAINB
DIVIP
HERRP
JOHNP
CONSH
KENNC
CHENI
EKNII
ROCKB
2
1
Hinchinbrook Is.
GREEI
Knight Is.
FLEMI
Montague Is.
Chenega
AFKHA
CHENB
CPUGE
1
3
2
HANNB
PATTB
FOXFA

Figure 1

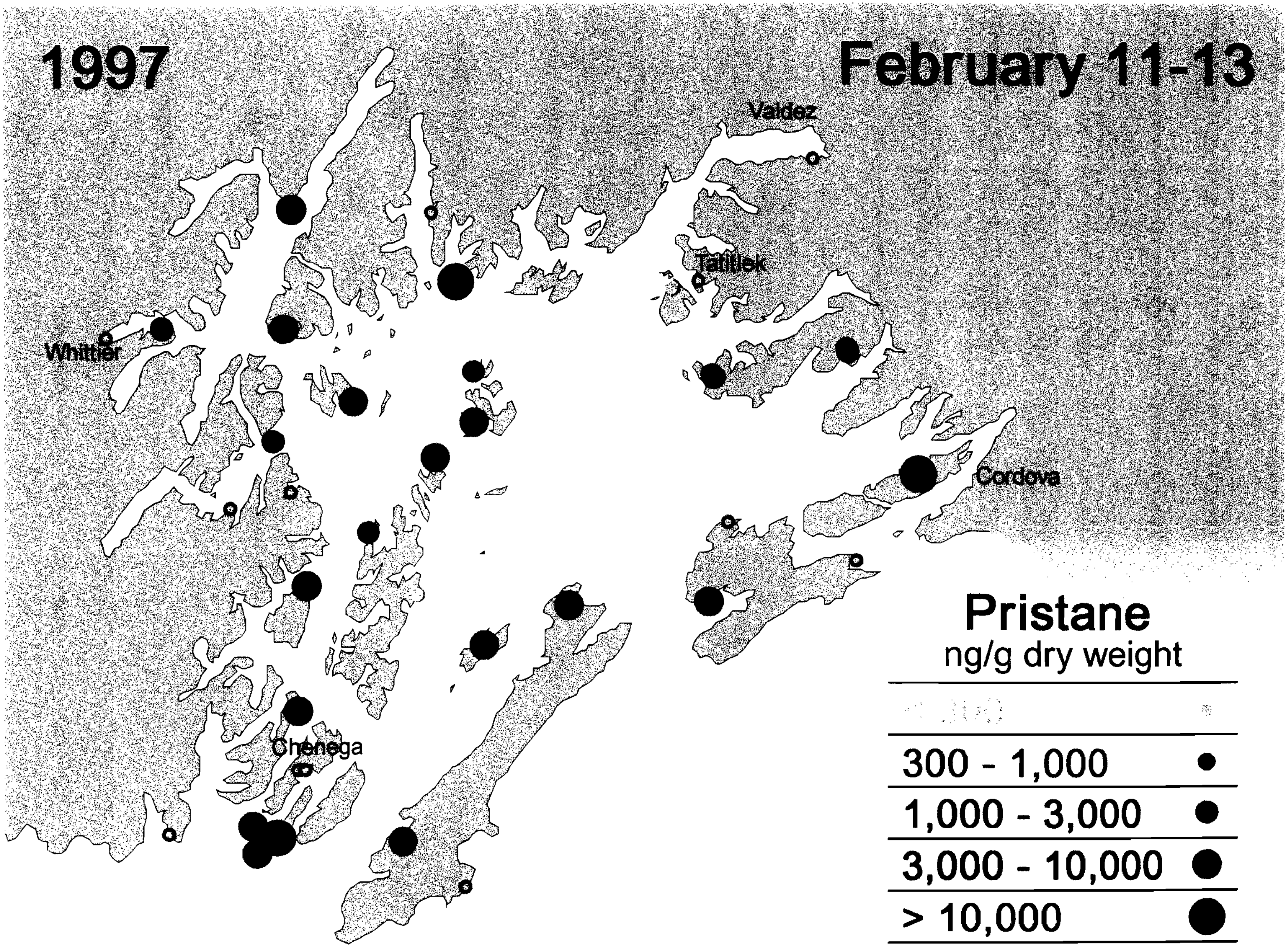

1997
February 11-13
Valdez
Tatitlek
Whittier
Cordova
Chenega
Pristane
ng/g dry weight
300 - 1,000
1,000 - 3,000
3,000 - 10,000
> 10,000

Figure 2A

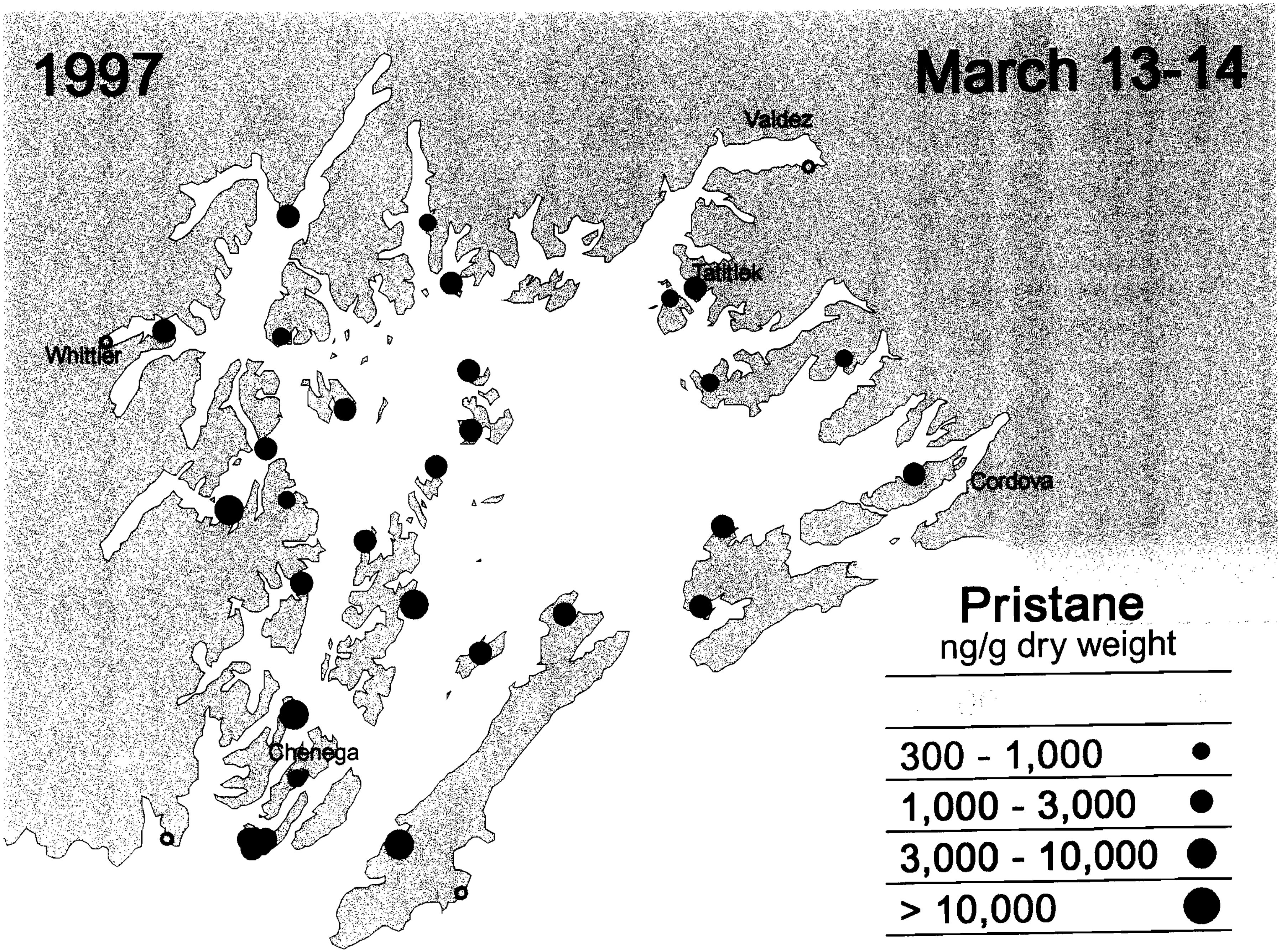

1997
March 13-14
Valdez
Tatitlek
Whittier
Cordova
Chenega
Pristane
ng/g dry weight
300 - 1,000 ●
1,000 - 3,000 ●
3,000 - 10,000 ●
> 10,000 ●

Figure 2B

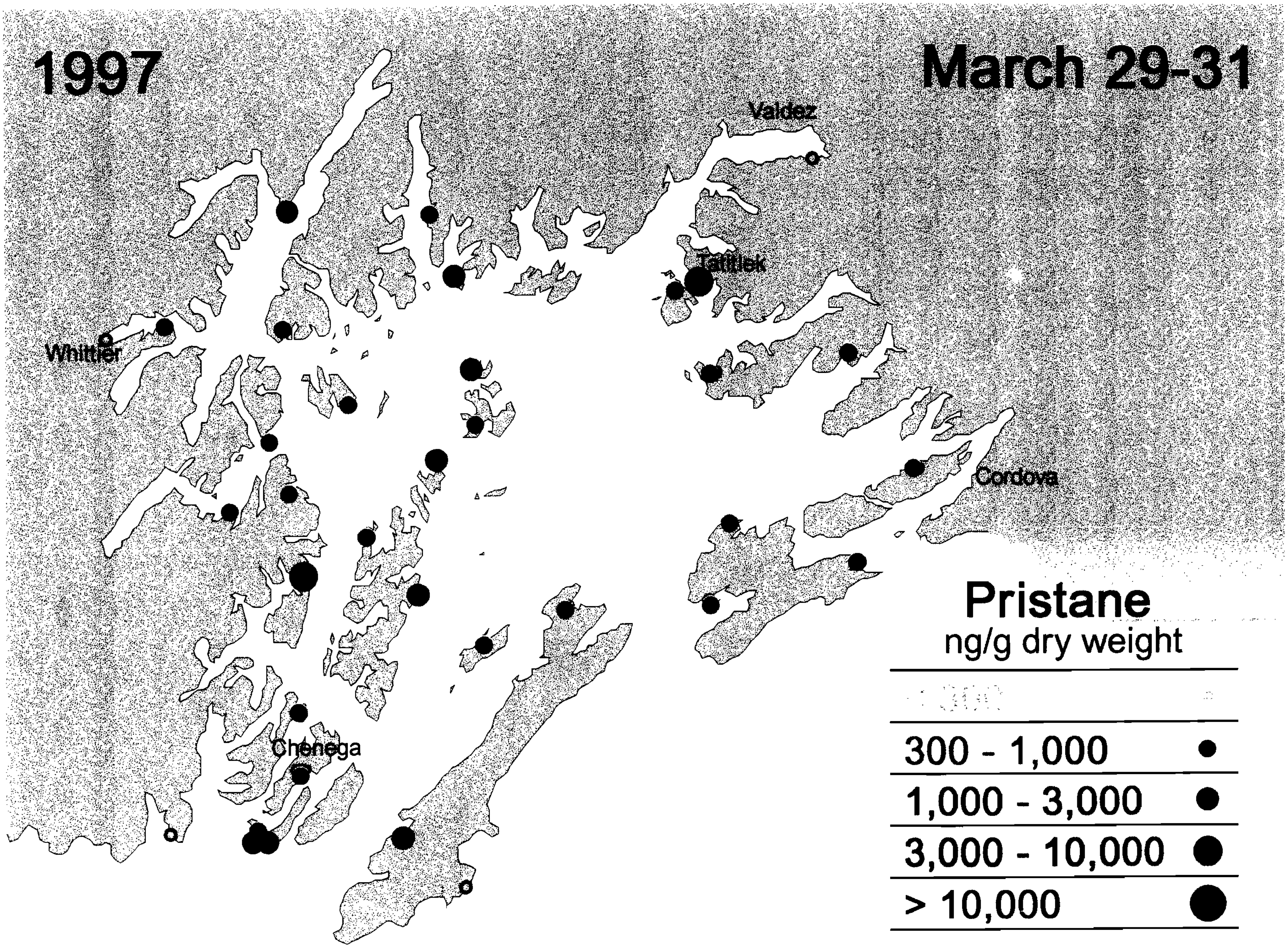

1997
March 29-31
Valdez
Tatitlek
Whittier
Cordova
Chenega
Pristane
ng/g dry weight
< 300 ○
300 - 1,000 ●
1,000 - 3,000 ●
3,000 - 10,000 ●
> 10,000 ●

Figure 2C

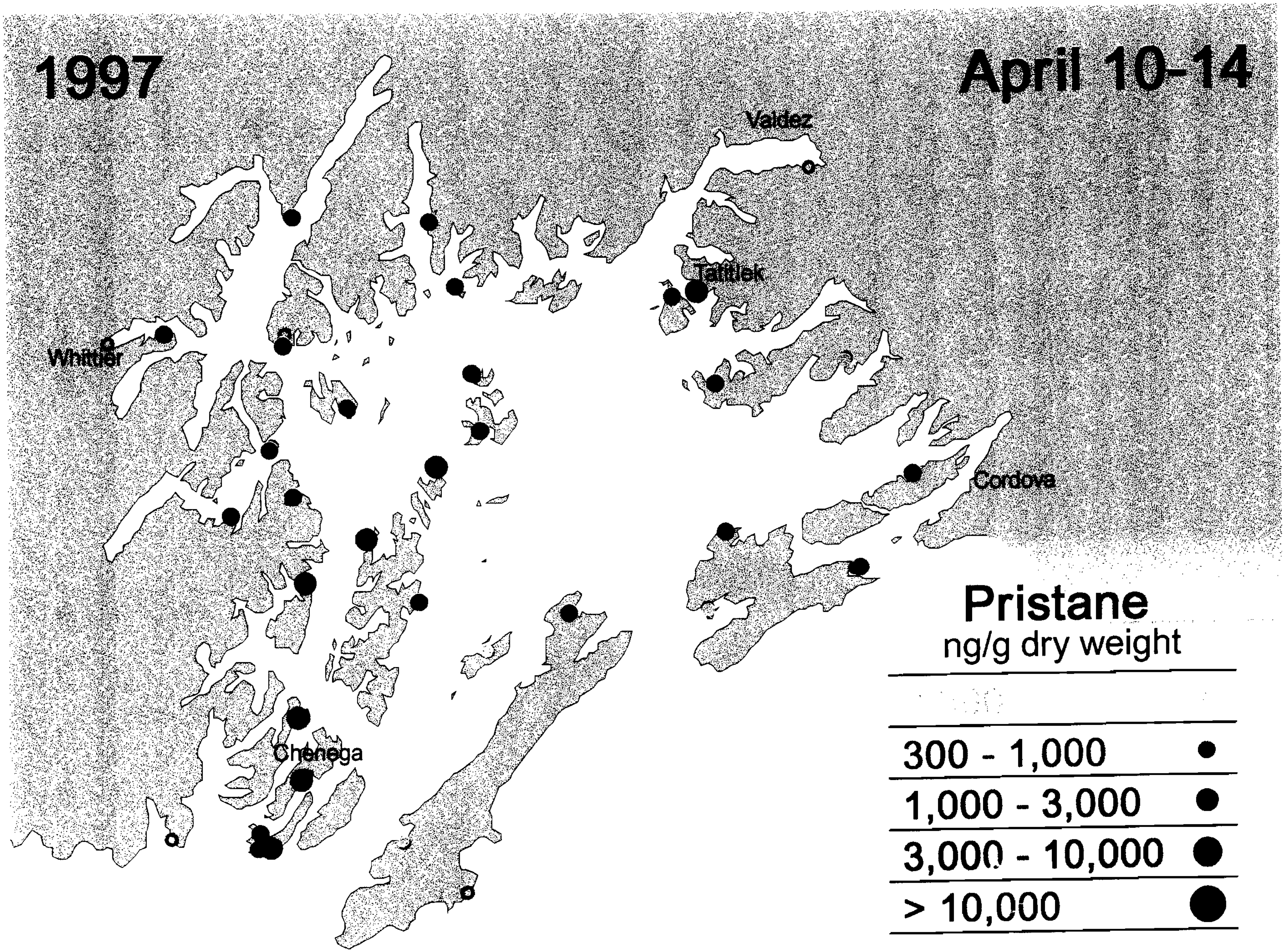

1997
April 10-14
Valdez
Tatitlek
Whittier
Cordova
Chenega
Pristane
ng/g dry weight
300 - 1,000 ●
1,000 - 3,000 ●
3,000 - 10,000 ●
> 10,000 ●

Figure 2D

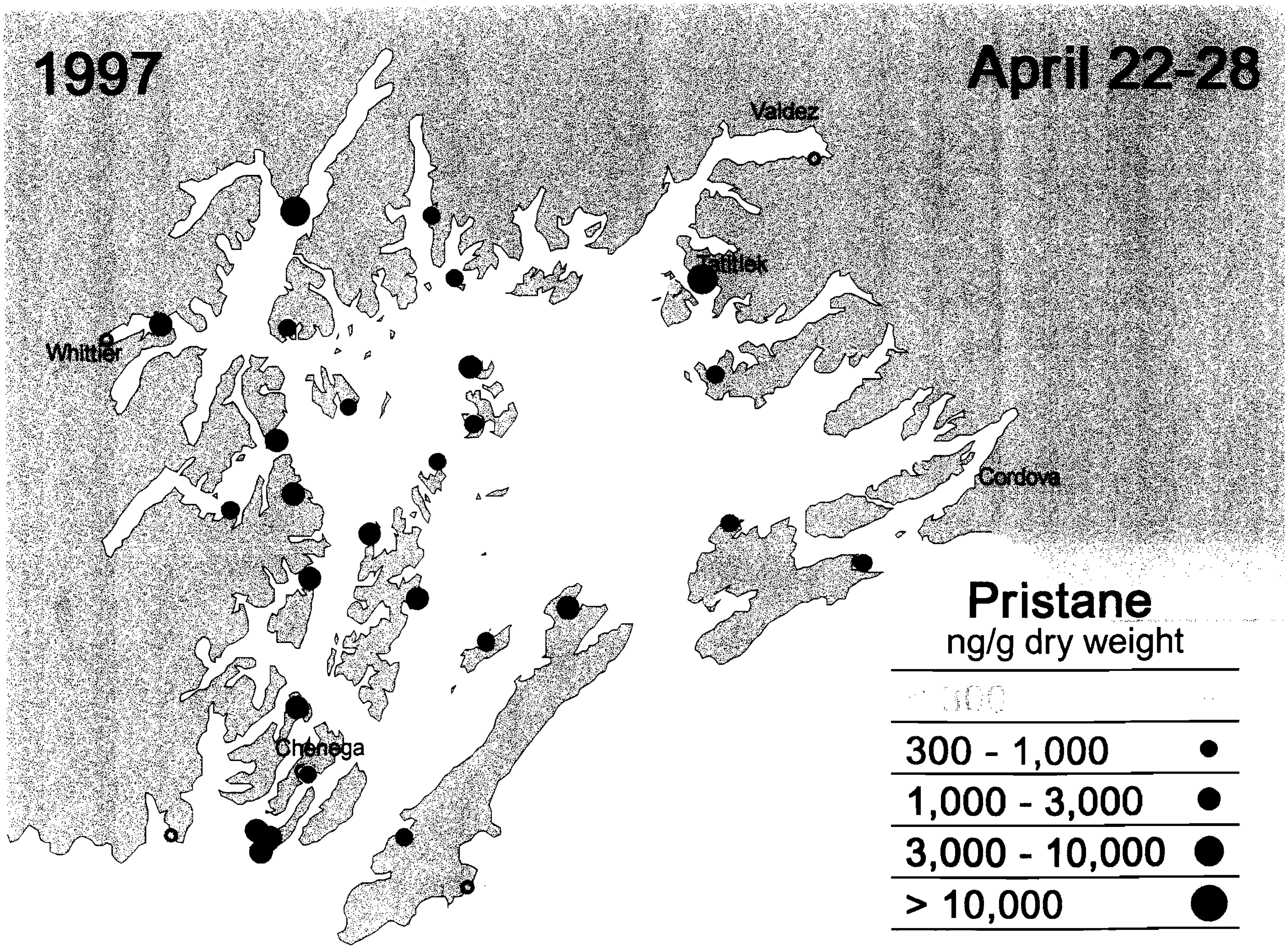

1997
April 22-28
Valdez
Tatitlek
Whittier
Cordova
Chenega
Pristane
ng/g dry weight
< 300
300 - 1,000 ●
1,000 - 3,000 ●
3,000 - 10,000 ●
> 10,000 ●

Figure 2E

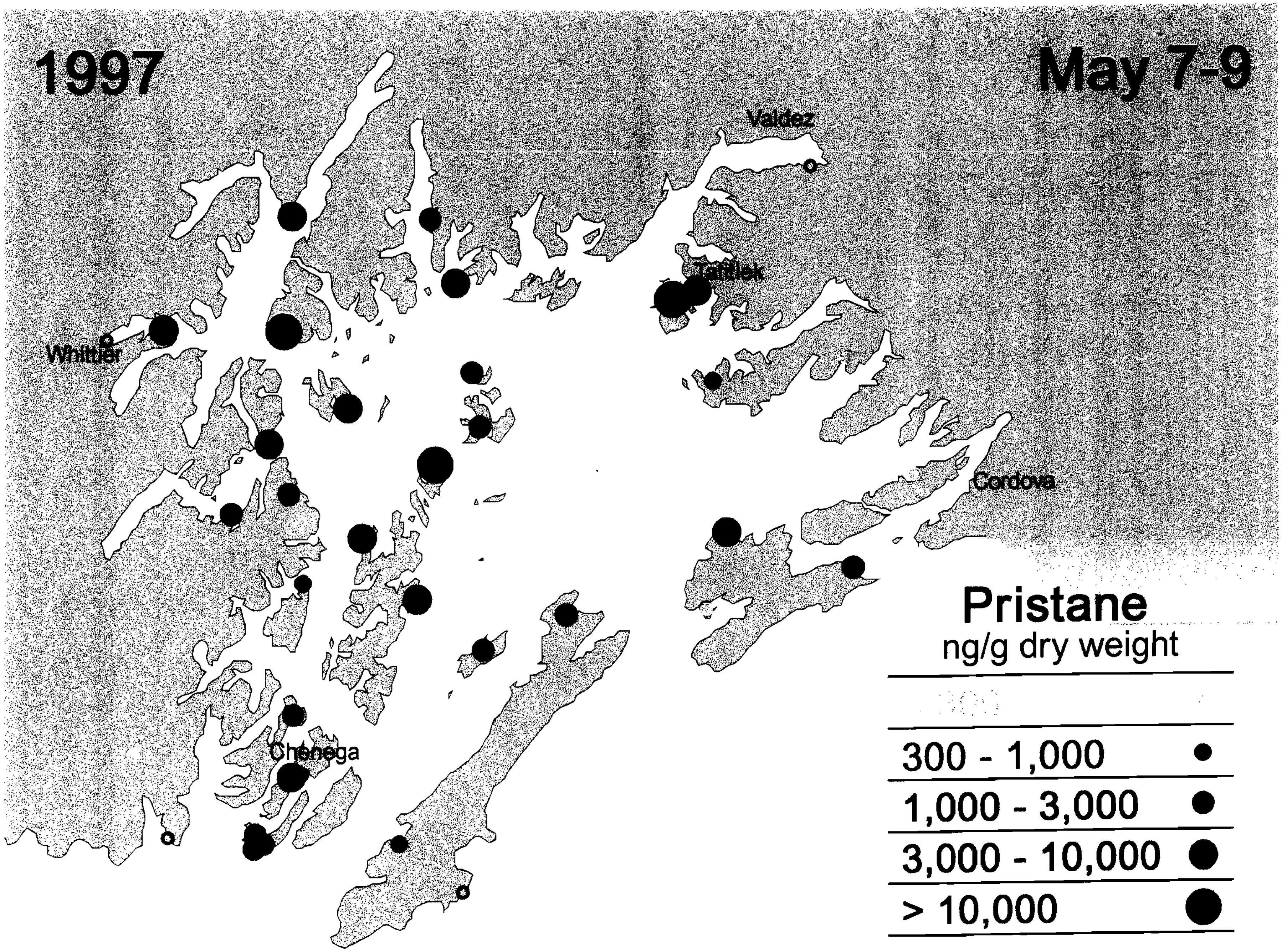

1997
May 7-9
Valdez
Tatitlek
Whittier
Cordova
Chenega
Pristane
ng/g dry weight
300 - 1,000 ●
1,000 - 3,000 ●
3,000 - 10,000 ●
> 10,000 ●

Figure 2F

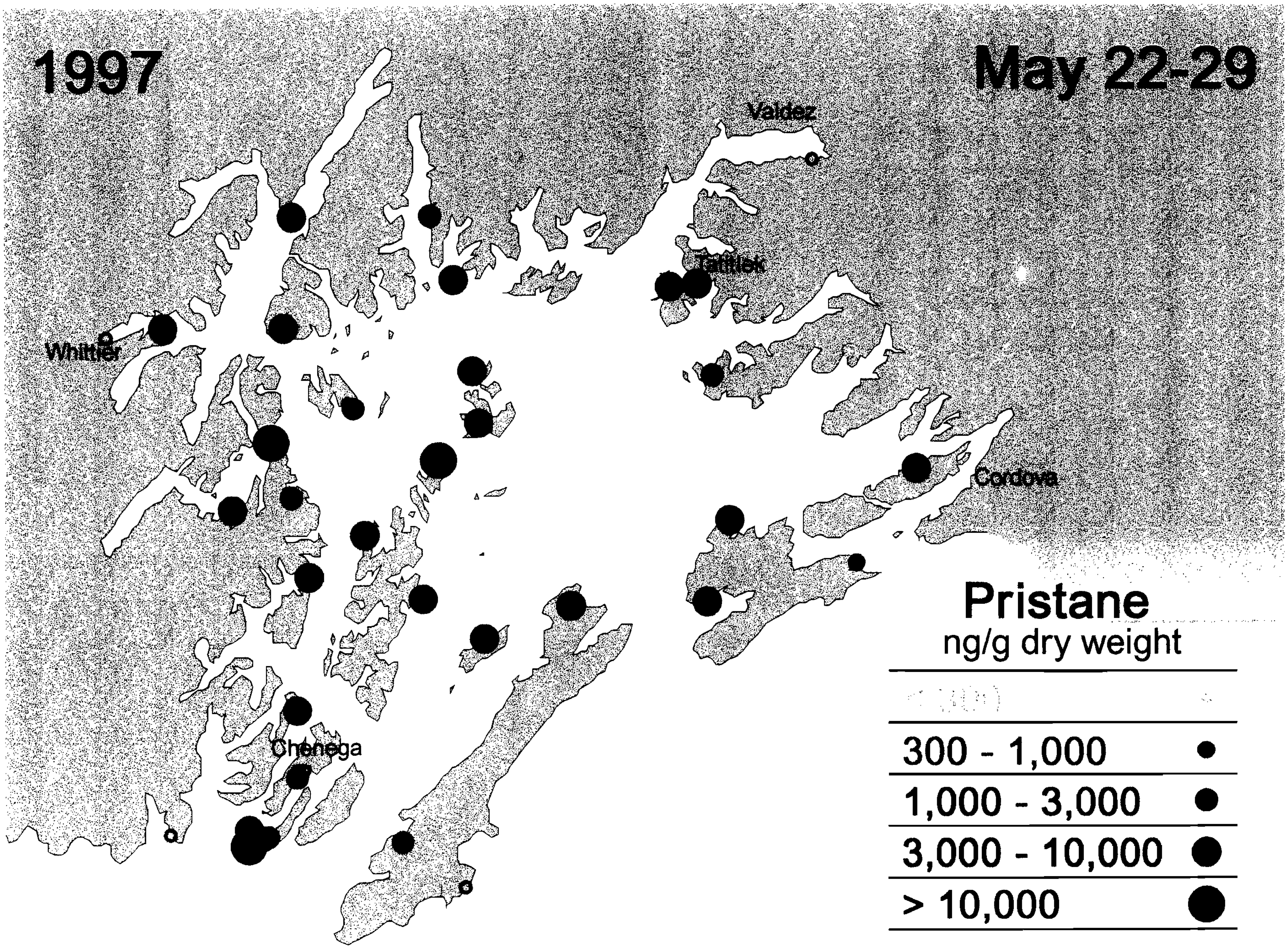

1997
May 22-29
Valdez
Tatitlek
Whittier
Cordova
Chenega
Pristane
ng/g dry weight
< 300
300 - 1,000 ●
1,000 - 3,000 ●
3,000 - 10,000 ●
> 10,000 ●

Figure 2G

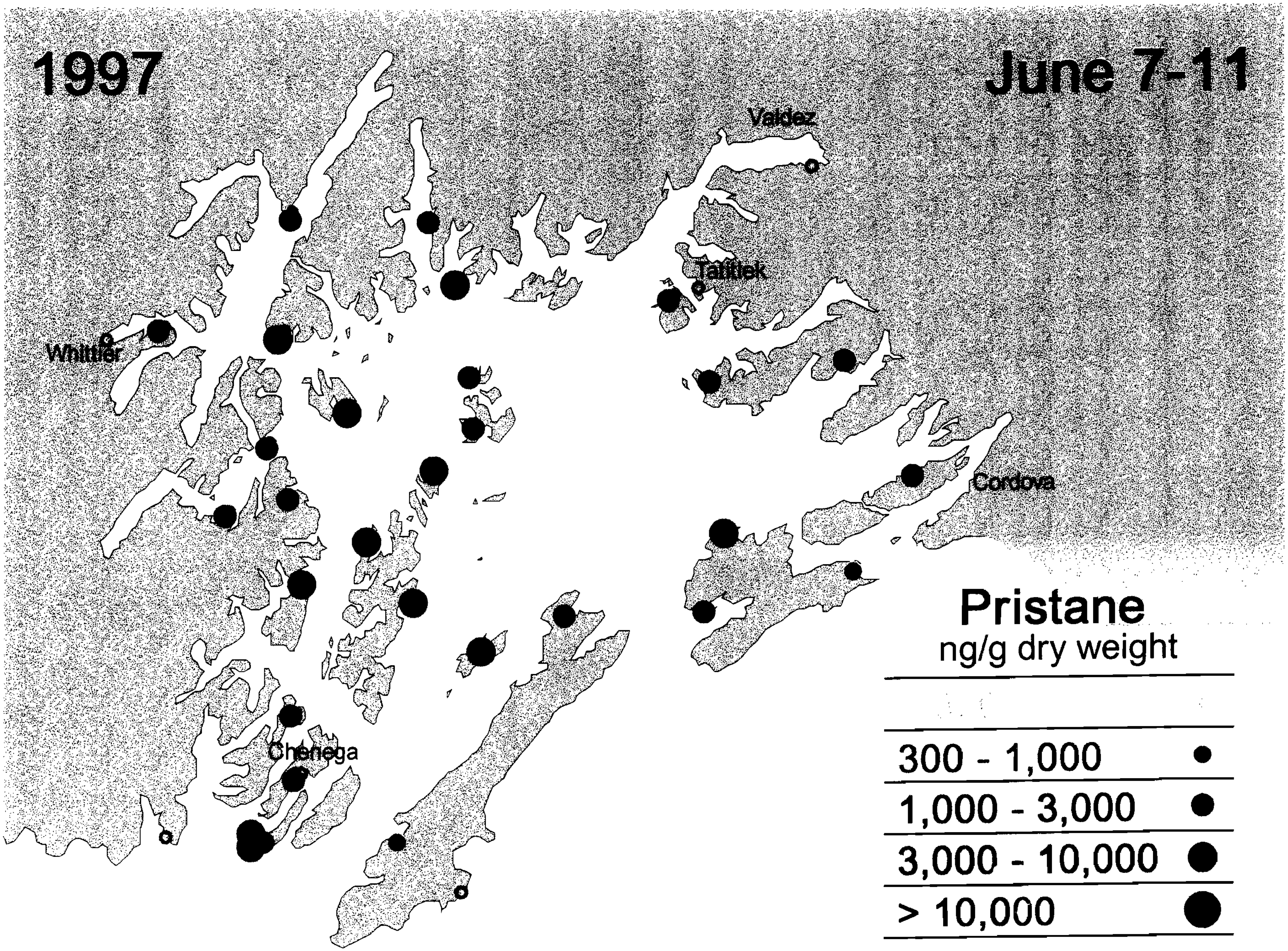

1997
June 7-11
Valdez
Tatitlek
Whittier
Cordova
Chenega
Pristane
ng/g dry weight
300 - 1,000 ●
1,000 - 3,000 ●
3,000 - 10,000 ●
> 10,000 ●

Figure 2H

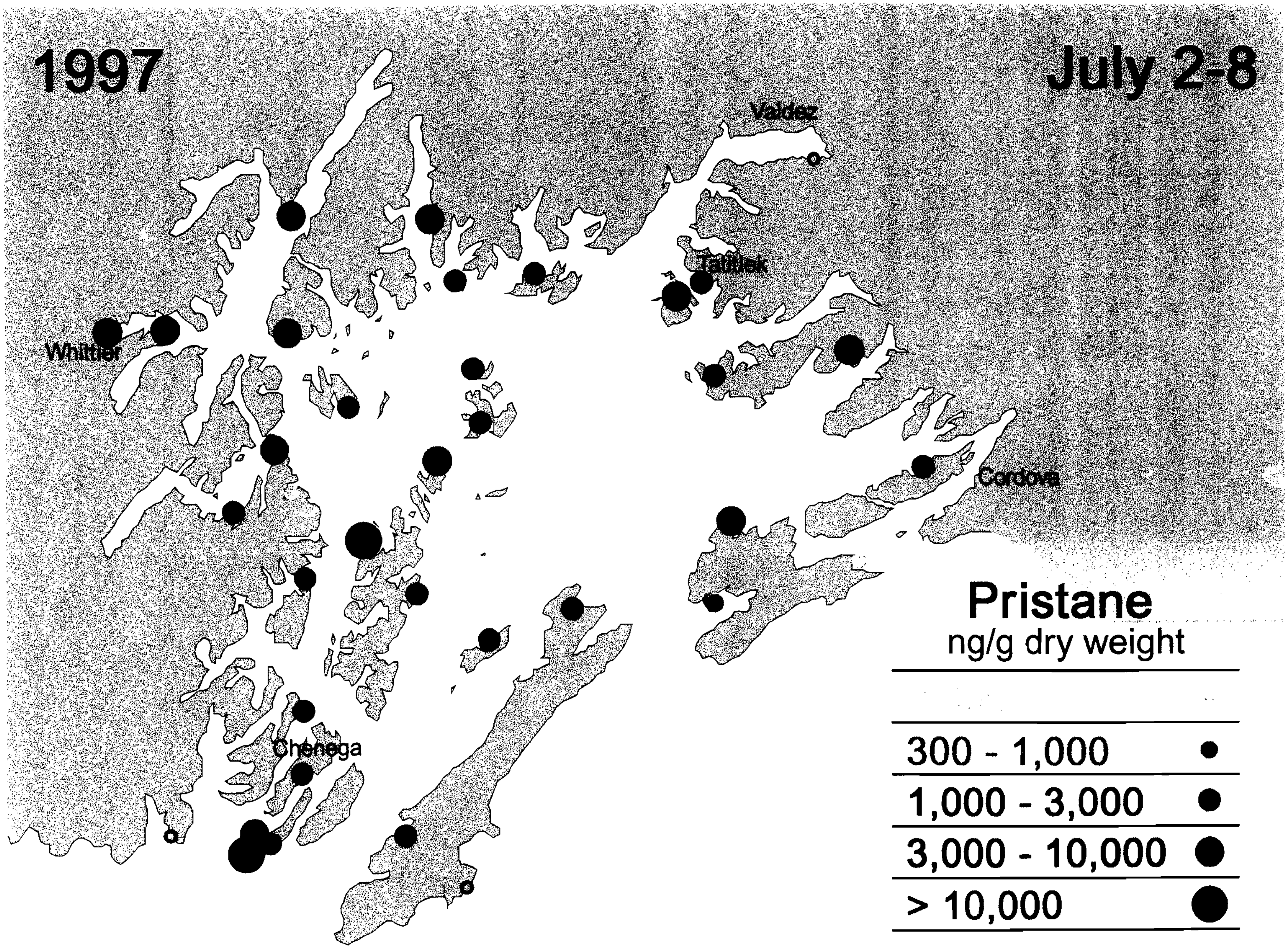

1997
July 2-8
Valdez
Tatitlek
Whittier
Cordova
Chenega
Pristane
ng/g dry weight
300 - 1,000 ●
1,000 - 3,000 ●
3,000 - 10,000 ●
> 10,000 ●

Figure 2I

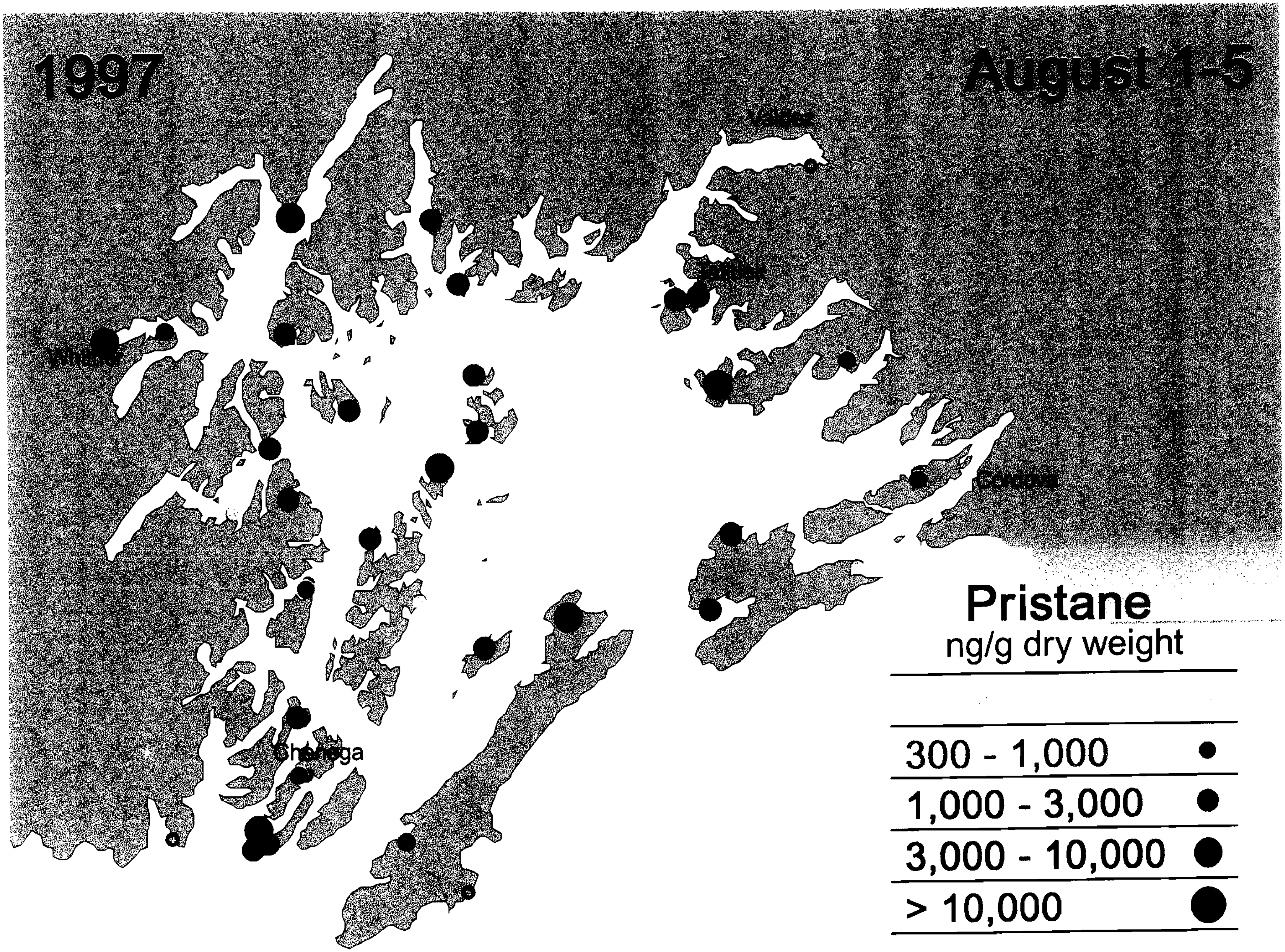

1997
August 1-5
Valdez
Tatitlek
Whittier
Cordova
Chenega
Pristane
ng/g dry weight
300 - 1,000 ●
1,000 - 3,000 ●
3,000 - 10,000 ●
> 10,000 ●

Figure 2J

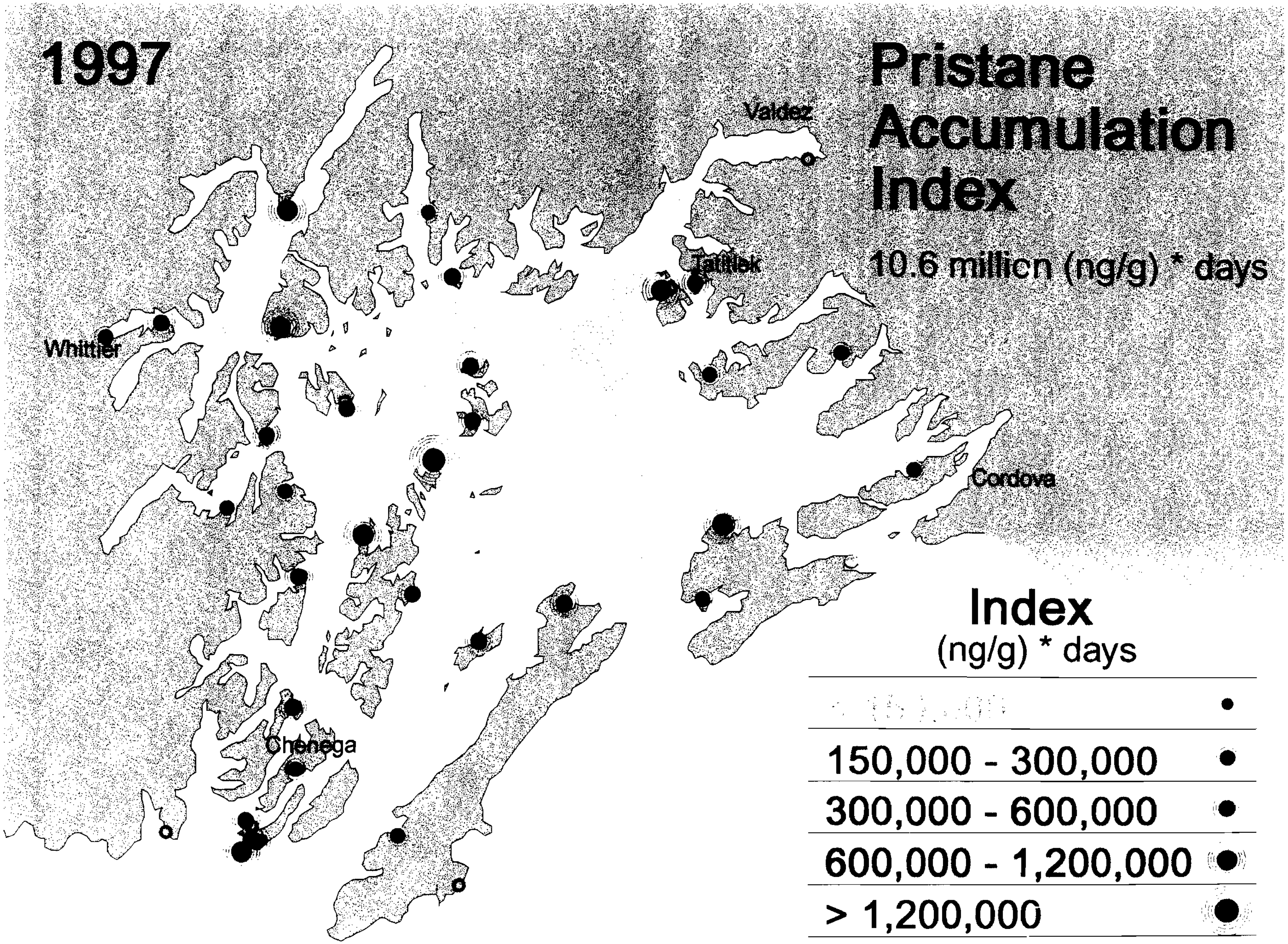

1997
Pristane Accumulation Index
10.6 million (ng/g) * days
Valdez
Tatitlek
Whittier
Cordova
Chenega
Index
(ng/g) * days
< 150,000 ●
150,000 - 300,000 ●
300,000 - 600,000 ●
600,000 - 1,200,000 ●
> 1,200,000 ●

Figure 3

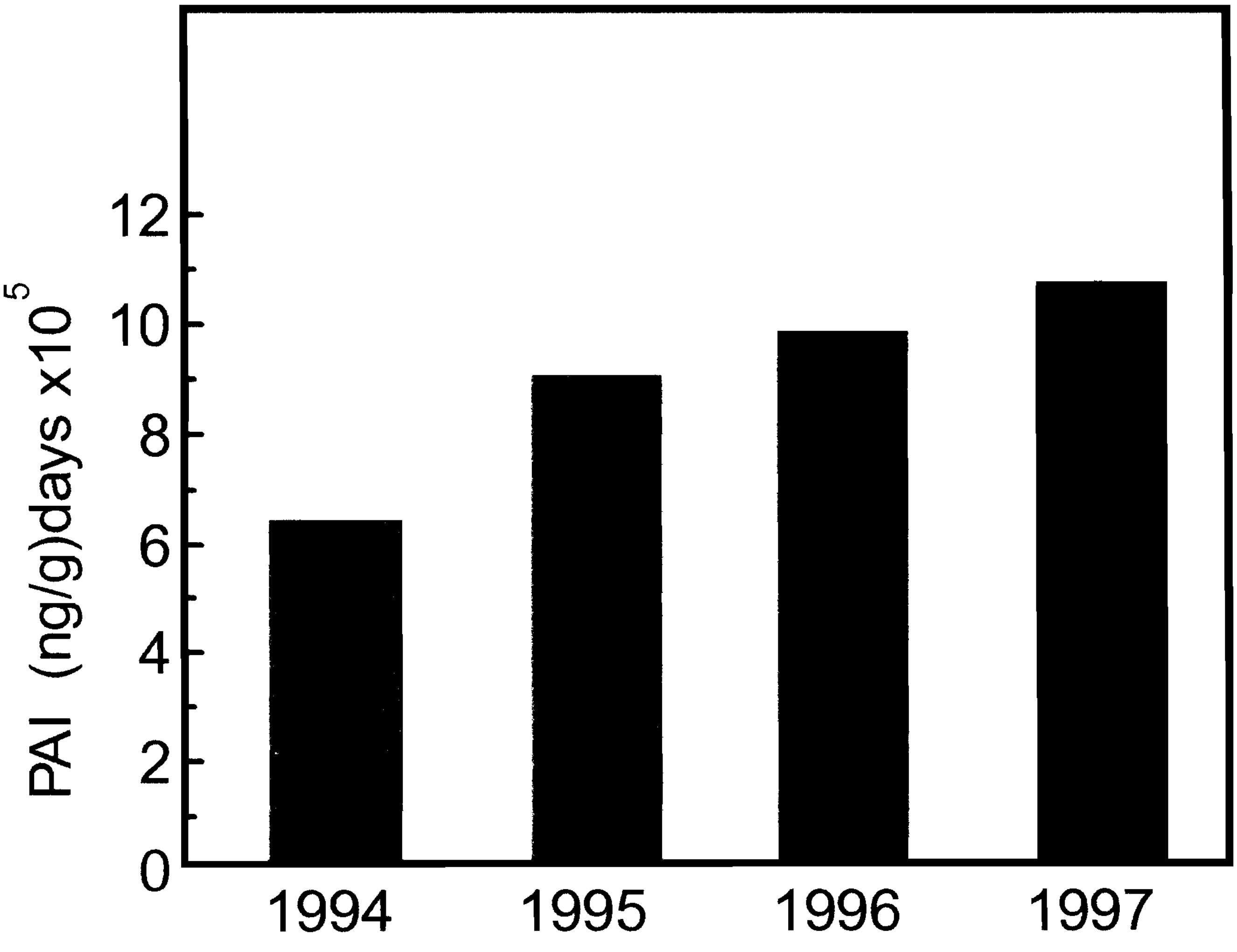
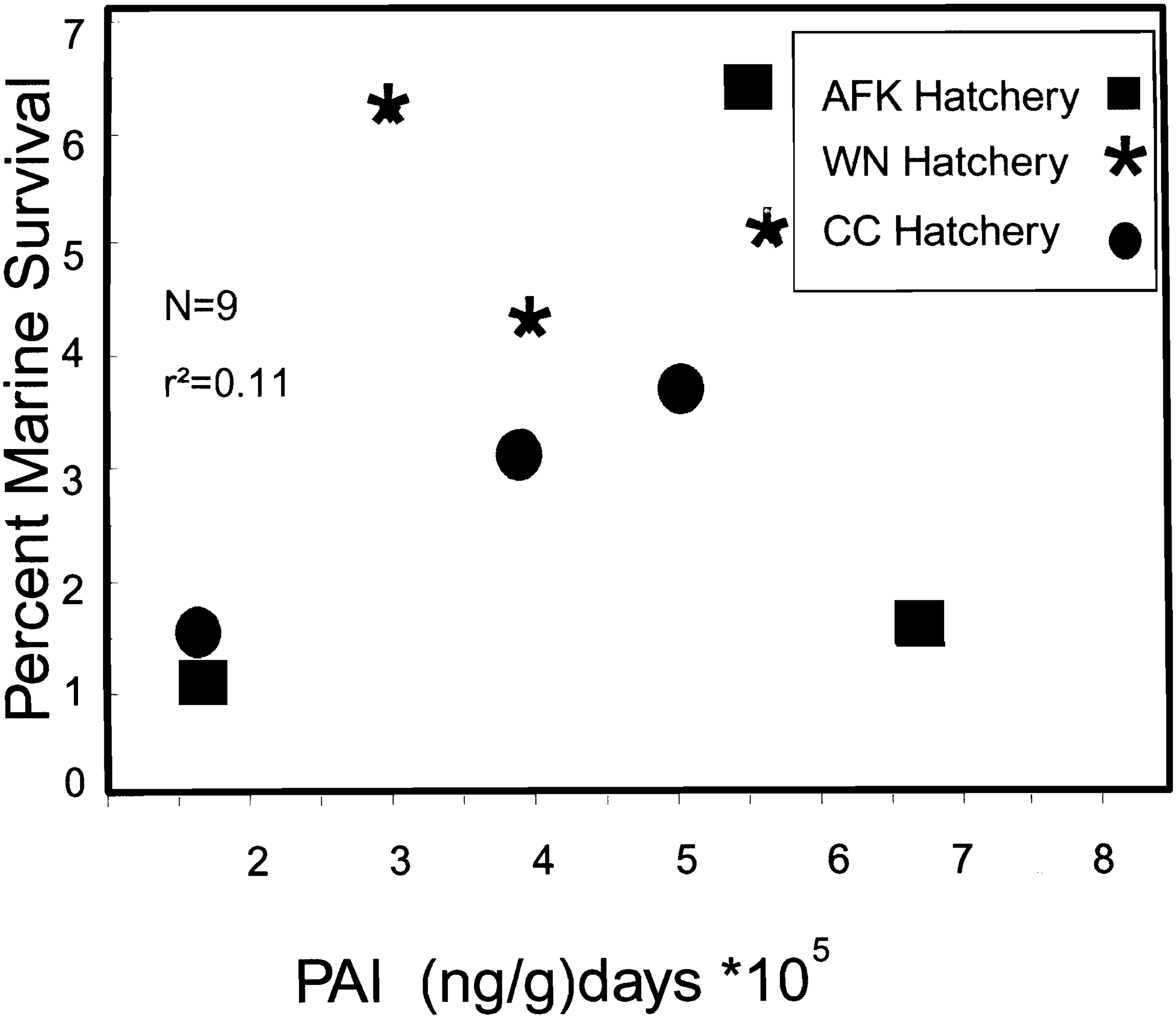


Figure 4



Percent Marine Survival
0
1
2
3
4
5
6
7
2
3
4
5
6
7
8
PAI (ng/g)days *10^5
N=9
r²=0.11
AFK Hatchery ■
WN Hatchery *
CC Hatchery ●

Figure 5