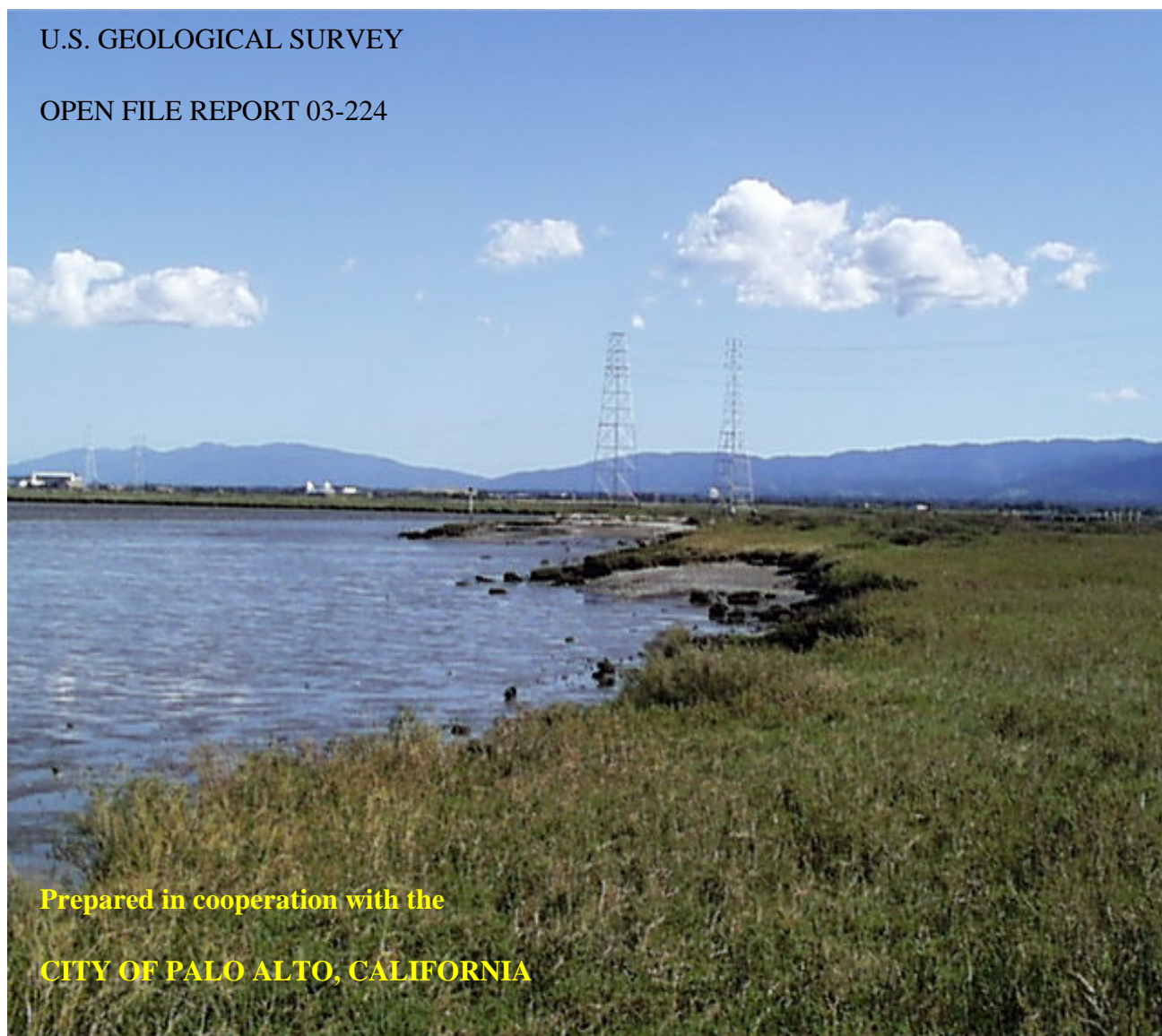




NEAR-FIELD RECEIVING WATER MONITORING OF A BENTHIC COMMUNITY NEAR THE PALO ALTO WATER QUALITY CONTROL PLANT IN SOUTH SAN FRANCISCO BAY: FEBRUARY 1974 THROUGH DECEMBER 2002

U.S. GEOLOGICAL SURVEY

OPEN FILE REPORT 03-224



Prepared in cooperation with the

CITY OF PALO ALTO, CALIFORNIA

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 2003	2. REPORT TYPE N/A	3. DATES COVERED -	
4. TITLE AND SUBTITLE Near-Field Receiving Water Monitoring of A Benthic Community Near the Palo Alto Water Quality Control Plant in South San Francisco Bay: February 1974 Through December 2002		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of the Interior U.S. Geological Survey 1849 C. Street, NW Washington, DC 20240		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited			
13. SUPPLEMENTARY NOTES The original document contains color images.			
14. ABSTRACT			
15. SUBJECT TERMS			
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified	
			18. NUMBER OF PAGES 38
			19a. NAME OF RESPONSIBLE PERSON

NEAR-FIELD RECEIVING WATER MONITORING OF A BENTHIC COMMUNITY NEAR THE PALO ALTO WATER QUALITY CONTROL PLANT IN SOUTH SAN FRANCISCO BAY: FEBRUARY 1974 THROUGH DECEMBER 2002

Michelle K. Shouse, Francis Parchaso, and Janet K. Thompson

U.S. GEOLOGICAL SURVEY

OPEN FILE REPORT 03-224

Prepared in cooperation with the
CITY OF PALO ALTO, CALIFORNIA

Menlo Park, California

U.S. DEPARTMENT OF THE INTERIOR
GAIL NORTON, Secretary

U.S. GEOLOGICAL SURVEY
CHARLES GROUT, Director

For additional information
Write to:

Janet K. Thompson, MS496
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

Copies of this report may be
obtained from the authors or

U.S. Geological Survey
Information Center
Box 25286, MS 517
Denver Federal Center
Denver, CO 80225

CONTENTS

	Page
ABSTRACT.....	5
INTRODUCTION	6
Previous monitoring of the benthic community in the near field receiving waters	6
Approach.....	7
Objectives	8
Study Site.....	8
Methods	8
Laboratory Analysis.....	8
Results and Discussion	9
Benthic Community	9
Reproduction of <i>Macoma balthica</i>	10
Value of Long Term Monitoring.....	11
Bibliography	12
Appendix 1: Palo Alto Benthic Community	A
Appendix 2: Palo Alto <i>Macoma balthica</i> Reproduction	B

FIGURES

	Page
Figure 1. Map of sampling station at Palo Alto in South San Francisco Bay with location of Palo Alto Regional Water Quality Control Plant (PARWQCP) effluent noted.	14
Figure 2. Number of species present in each sample period (1974-2002)	15
Figure 3. Total average number of individuals present in each sample period (1974-2002)	16
Figure 4. Average abundance and standard deviation of <i>Macoma balthica</i> in each sampling period (1974-2002)....	17
Figure 5. Average abundance and standard deviation of <i>Mya arenaria</i> in each sampling period (1974-2002).....	18
Figure 6. Average abundance and standard deviation of <i>Gemma gemma</i> in each sampling period (1974-2002).....	19
Figure 7. Average abundance and standard deviation of <i>Ampelisca abdita</i> in each sampling period (1974-2002)....	20
Figure 8. Average abundance and standard deviation of <i>Streblospio benedicti</i> in each sampling period (1974-2002)	21
Figure 9. Average abundance and standard deviation of <i>Grandiderella japonica</i> in each sampling period (1974-2002).....	22
Figure 10. Average abundance and standard deviation of <i>Heteromastus filiformis</i> in each sampling period (1974-2002).....	23
Figure 11. Time series of <i>Heteromastus filiformis</i> abundance with silver and copper tissue concentrations in <i>Macoma balthica</i>	24
Figure 12. <i>Heteromastus filiformis</i> annual abundance with silver concentrations in <i>Macoma balthica</i> tissue and in sediment.....	25
Figure 13. <i>Heteromastus filiformis</i> annual abundance with copper concentrations in <i>Macoma balthica</i> tissue and in sediment.....	26
Figure 14. Time series of <i>Ampelisca abdita</i> abundance with silver and copper tissue concentrations in <i>Macoma balthica</i>	27
Figure 15. <i>Ampelisca abdita</i> annual abundance with silver concentrations in <i>Macoma balthica</i> tissue and in sediment	28
Figure 16. <i>Ampelisca abdita</i> annual abundance with copper concentrations in <i>Macoma balthica</i> tissue and in sediment.....	29
Figure 17. Time series of <i>Streblospio benedicti</i> abundance with silver and copper tissue concentrations in <i>Macoma balthica</i>	30
Figure 18. <i>Streblospio benedicti</i> annual abundance with silver concentrations in <i>Macoma balthica</i> tissue and in sediment.....	31
Figure 19. <i>Streblospio benedicti</i> annual abundance with copper concentrations in <i>Macoma balthica</i> tissue and in sediment.....	32
Figure 20. Time series of <i>Gemma gemma</i> abundance with silver and copper tissue concentrations in <i>Macoma balthica</i>	33
Figure 21. <i>Gemma gemma</i> annual abundance with silver concentrations in <i>Macoma balthica</i> tissue and in sediment	34
Figure 22. <i>Gemma gemma</i> annual abundance with copper concentrations in <i>Macoma balthica</i> tissue and in sediment	35
Figure 23. Reproductive activity of <i>Macoma balthica</i> (1974-2002).....	36

APPENDICES

	Page
<u>Appendix 1: Palo Alto Benthic Community (* data from larger core that have been standardized to the area of the smaller core)</u>	A
<u>Appendix 2: Palo Alto <i>Macoma balthica</i> Reproduction</u>	B

NEAR-FIELD RECEIVING WATER MONITORING OF A BENTHIC COMMUNITY NEAR THE PALO ALTO WATER QUALITY CONTROL PLANT IN SOUTH SAN FRANCISCO BAY: FEBRUARY 1974 THROUGH DECEMBER 2002

Michelle K. Shouse, Francis Parchaso, and Janet K. Thompson

ABSTRACT

Analyses of the benthic community structure over a 28-year period show that changes in the community have occurred concurrent with reduced concentrations of metals in the sediment and in the tissues of the biosentinal clam *Macoma balthica* from the same area. The community has shifted from being dominated by several opportunistic species to a community where the species are more similar in abundance, a pattern that could be indicative of a more stable community that is subjected to less stress. In addition, two of the opportunistic species (*Ampelisca abdita* and *Streblospio benedicti*) that brood their young and live on the surface of the sediment in tubes have shown a continual decline in dominance coincident with the decline in metals. *Heteromastus filiformis*, a subsurface polychaete worm that lives in the sediment, consumes sediment and organic particles residing in the sediment, and reproduces by laying their eggs on or in the sediment has shown a concurrent increase in dominance. These changes in species dominance reflect a change in the community from one dominated by surface dwelling, brooding species to one with species with varying life history characteristics. Analysis of the reproductive activity of *Macoma balthica* shows increases in reproductive activity concurrent with the decline in metal concentrations in the tissue of this organism. Reproductive activity is presently stable with almost all animals reproducing during the two reproductive seasons (spring and fall) of most years. These findings are consistent with findings previously reported for the 1974 through 2000 period.

INTRODUCTION

A common method of monitoring the effects of contaminants in aquatic systems is to examine the community structure of sediment dwelling benthic organisms (Simon 2002). Because these organisms are sedentary and are relatively long-lived, linkages between contaminant exposures and changes at the population or community level can be used to collect a time-integrated picture of ecosystem response to contaminant loading. Biomonitoring also allows us to evaluate the chronic effects of relatively low levels of contaminants as well as examine the combined effects of contaminant exposure and natural stresses in a system. Lastly, unlike many laboratory assessments of contaminant effects on organisms, field studies integrate environmental routes of exposure, including contaminants that are partitioned into the sediment, water, and diet (see Wang and Fisher 1999 for a summary of the potential transport of trace elements through food) at all life stages.

Contaminants can adversely impact benthic organisms at several organizational levels. For example, responses of a pollutant at the cellular or physiological level of an individual can result in changes at the population level, such as reductions in growth, survival and reproductive success. Community level responses to population level impairment can include changes in predator/prey interactions, changes in competition for available resources, and overall shifts in species abundance. Changes in the benthic community can ultimately result in changes at the ecosystem level due to the importance of carbon cycling in aquatic environments (see Alpine and Cloern 1992 for a local example).

Presented here is an evaluation of the benthic community changes over a 28-year period during which time the point-source metal loading from the nearby Regional Water Quality Control Plant significantly declined. Coincident with declines in metal loadings, concentrations of metals in the sediment and in a bio-sentinel clam (*Macoma balthica*) also declined as described by the work of the S.N. Luoma project staff (U.S.G.S.; hereafter referred to as Luoma) (Hornberger et al. 2000). Concurrent, and prior to the initiation of the Luoma study, the USGS has been collecting benthic community data at three nearby intertidal sites. Luoma's results (see Hornberger et al. 1999, 2000) have shown that sediments and local populations of clams at this location are sensitive indicators of the response of receiving waters to changes in metal output from a point-source discharger. These studies have illustrated that the reduction of metal discharge in South Bay is reflected, within a year, by reduced near-field contamination in both the sediment and benthic organisms of San Francisco Bay. We show here that, while the benthic community response to reduced metal output is likely to take longer, we see a response at the organismal level (i.e. reproductive activity, a manifestation of a cellular or physiological change) within a year or two and a response at the population and community levels soon thereafter. Due to the natural intra-annual variability of benthic community dynamics, it is likely to take 5-10 years for a stable change in the benthic community to be expressed. Thus, this study highlights the importance of long time series data that incorporates seasonal and inter-annual variability in studies of contaminant effects.

Previous monitoring of the benthic community in the near field receiving waters

Since 1974, USGS personnel have monitored and studied the benthic community and reproductive activity of *Macoma balthica* in the vicinity of the discharge of the Palo Alto Regional Water Quality Control Plant (PARWQCP). Our findings from the first 10 years of this study were published in Nichols and Thompson (1985a and 1985b). We found that this community was composed of non-indigenous, opportunistic species that dominated the community due to their ability to survive the many physical disturbances on the mudflat. The disturbances discussed included sediment erosion and deposition, and exposure at extreme low

tides. The possible effects of metal exposure as a disturbance factor were not considered in these analyses as the decline in metal concentrations in *Macoma balthica* and sediment had just begun.

The time series of benthic data in the present study is of particular interest because it encompasses the period when exceptionally high concentrations of copper and silver were found in the benthic animals (1970's) and the period when concentrations of the most enriched pollutants, copper and silver, declined (after 1981). The time series presented here updates our previous findings (Thompson et al. 2002) with additional data from January 2001 through December 2002, to create a dataset spanning 28 years.

Approach

We collect samples at a frequency of no more than once per month. We learned in our analyses of the early data (1974 through 1983) (Nichols and Thompson 1985a, 1985b) that benthic samples need to be collected at a maximum time step of every other month in order to distinguish seasonal differences from inter-annual differences if the differences are small. In dynamic systems such as San Francisco Bay, distinguishing between the effects of natural seasonal changes and anthropogenic environmental stressors is more probable when samples are collected at an increased temporal intensity. The approach described here has been shown to be effective in relating changes in near field contamination to changes in benthic community structure (Kennish, 1998) and in reproductive activity of a clam (Hornberger et al. 2000), despite the complexities inherent in monitoring natural systems. By using historical data as a basis of this study, we will provide a context within which cause and effect can be assessed for change in the future.

We will look at the biological response of the benthic community to pollutant changes in the environment at three levels of organization: the physiological/cellular, the population, and the community. First, for the physiological/cellular level, tissue concentrations of metals in *Macoma balthica* during this period are examined to determine if metal concentration changes correspond to physiological changes to the clams (i.e. reproduction). Analysis of the trace element concentration in the tissues of *Macoma balthica*, as done by Luoma, provides a measure of exposure to bioavailable pollutants and an estimate of dietary exposures to pollutants. This does not, however, examine the physiological effects of metal exposure on *Macoma balthica*. One of the more common animal responses to an environmental stressor is a change in reproductive activity. Earlier studies (Hornberger et al 2000) have shown that reproductive activity of *Macoma balthica* has increased with declining metal concentrations in animals from this location. Therefore, reproductive activity of *Macoma balthica* appears to be a useful indicator of physiological stress by pollutants at this location and is examined coincident with the continuing studies by Luoma on *Macoma balthica*.

Next, the population trends of the dominant species in the benthic community are examined to see if some species have been differentially affected by the pollutant concentrations. Finally, benthic community structure is examined to see if any population changes are reflected in changes to the benthic community. Prior studies have shown that more opportunistic species are likely to persist in highly disturbed environments (as was shown by Nichols and Thompson (1985a) at this location in 1974 through 1983) and thus we might expect to see a shift in community composition if metal contamination has been a major disturbance factor. We might also expect to see shifts in the benthic community with changes in the concentrations of specific metals. For example, it has been shown that some crustacean and polychaete species are particularly sensitive to elevated copper (Morrisey et al. 1996, Rygg 1985) and that most taxonomic groups have species that are sensitive to elevated silver (Luoma et al. 1995). Previous analysis of this community has shown no correlation between changes in the community and measured environmental parameters (Shouse 2002) therefore, the community data will only be compared to trace metal data in this report.

OBJECTIVES

The purpose of this study is to characterize long term trends in benthic community structure and reproductive activity of *Macoma balthica* near the discharge of the PARWQCP. These data will be used in conjunction with data collected by Luoma to achieve the following objectives:

- Provide data (1978-1990, 1998-2002) to assess seasonal and annual trends in benthic community structure at a location near the discharge (specifically at the site designated in the Regional Water Quality Control Board's (RWQCB) Self-Monitoring Program for PARWQCP).
- Assess seasonal and annual trends in benthic community structure (1974-2002) at a location near the discharge (specifically at the site designated in the RWQCB's Self-Monitoring Program for PARWQCP).
- Present the data within the context of historical changes inshore in South Bay and within the context of on-going monitoring of effluents.
- Provide data to assess seasonal and annual trends in reproductive activity of clams near the discharge; specifically at the site designated in the RWQCB's Self-Monitoring Program for PARWQCP.

STUDY SITE

Samples were collected at a station located south of Sand Point (Figure 1): the station is 12 m from the edge of the marsh and 110 cm above MLLW. The location of this station, on a mudflat on the shore of the bay (not a slough) one kilometer south of the Palo Alto discharge, is influenced by the discharge of PARWQCP, but is not immediately adjacent to that discharge. Thus, this location reflects a response of receiving waters to the effluent, beyond just a measure of the effluent itself. Earlier studies (Thomson et al. 1984) have shown that dyes, natural organic materials in San Francisquito Creek, and waters in the PAWQCP discharge move predominantly south toward Sand Point and thereby influence the mudflats in the vicinity of Sand Point. Earlier work by Thomson et al. (1984) showed that San Francisquito Creek and the Yacht Harbor were minor sources of most trace elements compared to the PARWQCP.

METHODS

Samples for benthic community analysis and reproductive activity were collected in an 8.5 cm diameter x 20 cm deep core. Three replicate samples were arbitrarily taken, within a one m² area, during each sampling date.

Samples for analysis of reproductive activity were collected through December 2002 concurrently with the clam and sediment collection of the Luoma study (see Appendix 2 for January 2001 through December 2002 dates). A minimum of 10 individual *Macoma balthica* of varying sizes (minimum of 5mm) was used in the analyses.

Laboratory Analysis

Benthic community samples were washed on a 0.5mm screen and preserved. All animals in all samples were sorted to species level where possible (some groups are still not well defined in the bay, such as the oligochaetes) and individuals for each species were enumerated by a private contractor familiar with the taxonomy of San Francisco Bay invertebrates (Susan

McCormick, Colfax, CA). S. McCormick also compared and verified her identifications with previously identified samples.

A minimum of 10 clams were processed for reproductive activity each month. Clams were immediately preserved in 10% formalin at the time of collection. The visceral mass of each clam was removed in the laboratory, stored in 70% ethyl alcohol, and then prepared using standard histological techniques: tissues were dehydrated in a graded series of alcohol, cleared in toluene (twice for one hour each), and infiltrated in a saturated solution of toluene and Paraplast® for one hour, and two changes of melted Tissuemat® for one hour each. Samples were embedded in Paraplast® in a vacuum chamber and then thin sectioned (10 micrometer) using a microtome. Sections were stained with Harris' hematoxylin and eosin and examined with a light microscope. Each individual was characterized by size (length in mm), sex, developmental stage, and condition of gonads, thus allowing each specimen to be placed in one of five qualitative classes of gonadal development (previously described by Parchaso 1993).

RESULTS AND DISCUSSION

Benthic Community

The simplest metrics that are used in assessing environmental stress on biological communities are estimates of species diversity and total animal abundance. Species diversity as estimated by a time series of number of species for each month showed no significant trend in this study (Figure 2) nor did total animal abundance (Figure 3). The difficulty with these types of metrics is that they do not consider the possibility that one species can take the place of another, and thus not alter the number of species or number of individuals. However, depending on the characteristics of the new species, the community structure and function may change as a result of this exchange of species. In addition, the details of changes in species composition are important as these changes may reflect the relative ability of species to accommodate environmental stress. As will be shown, examining these details was very important in attaining our objectives.

Time series plots of the abundance of several species are shown in the following set of figures. Three common bivalves did not show any consistent trend over the 28-year period (Figures 4, 5, and 6). In all cases, there is significant seasonal and inter-annual variability in species abundances. The next four plots are of three species that did show trends in their abundance throughout the study. The first species, *Ampelisca abdita*, is a small crustacean that lives above the surface of the mudflat in a tube that they build from selected sediment particles. There was a general decline in this species over the period of the study, in both the annual average abundances and annual maximum abundances (seasonal peaks in abundance) as seen in Figure 7. The second species to show a significant trend was the small polychaete worm *Streblospio benedicti* (Figure 8), which also builds a tube above the surface of the mudflat. As with *A. abdita*, this worm has shown a decline in seasonal maximum abundances as well as annual average abundances. The small burrowing crustacean *Grandiderella japonica* shows a declining trend initially followed by increasing seasonal maximum abundances in recent years (Figure 9). The only species to show an increase in abundance through the time series was the polychaete worm *Heteromastus filiformis* (Figure 10), a deposit feeding, burrowing species that lives deep in the sediment (usually 5-20 cm below the surface of the mudflat).

As stated earlier, multivariate analyses of population data of the dominant species with the environmental parameters did not reveal any relationships except with the concentration of silver and copper in the sediment and in the tissue of *Macoma balthica* (using Luoma data as most recently reported by David et al. 2002). Therefore, only silver and copper trends will be considered in this update. This comparison can be made by plotting the metals and individual species together over the period of the study. The worm *H. filiformis* has increased in abundance

with the decrease in silver and copper through time (Figure 11). The natural spatial variability (i.e. the large standard deviations around the monthly means) and seasonal variability in invertebrate abundance and metal concentration can be quite large as seen in these plots. Thus, the annual average abundances for *H. filiformis* and annual average metal concentrations are shown in Figures 12 and 13. To interpret these plots, we must first examine the life history characteristics of this species and determine if there is some mechanism by which this organism could be responding to a decrease in silver or copper in the environment. *H. filiformis* has continual tissue contact with the sediment both at the exterior of its body as well as within its body due to its life style of burrowing through the sediment and consuming a diet of mud and organic particles. In addition, this is one of the few species in the present community that reproduces exclusively by laying its eggs in the sediment. The larvae hatch from the eggs after two to three days and then spend two to three days in the plankton before settling back to the mud as juvenile worms (Rasmussen 1956). Thus one hypothesis for *H. filiformis*' increase in abundance may be that either the adult worms or the eggs are less stressed in the present environment. Because of its mode of reproduction and short planktonic larval period, this species is not likely to move into an area quickly after the environment becomes acceptable. Therefore, it is not possible to identify either the identity of the metal and or the threshold concentration of the metal to which the animal is responding without laboratory tests. However, other investigators have shown that silver can adversely affect reproduction in invertebrates and that adult *H. filiformis* can tolerate high levels of copper (Ahn et al. 1995). The gradual increase in *H. filiformis* abundance through 1984 may be a response to the gradual reduction of metals in the environment or may indicate that it took several years for the population to build up in the area. The large abundance increase in 1985 and 1986, followed by a decline and leveling out of abundance, may be an example of the "boom and bust" principle whereby a species rises to levels too high for the habitat to support, and then declines in abundance until it levels out to what becomes their normal, habitat-supportable, abundance. It is unclear, based on only five years of data since the early 1990's, if this species has established a stable abundance.

The two species that have declined in abundance coincident with the decline in metals, the crustacean *A. abdita* (Figures 14, 15 and 16) and the worm *S. benedicti* (Figures 17, 18 and 19), have very similar life history characteristics. Both live on the surface of the sediment in tubes that are built from sediment particles, are known as opportunistic species and are thus capable of rapid increase in population size and distribution, brood their young, and produce young that are capable of both swimming or settling upon hatching. It is unclear why these species have become less competitive in the present day environment, but their very low numbers in the last several years indicate that this is a major shift in the community as both species were numerically very dominant in the benthic community in the 1970's and 1980's. We have also shown plots of another species, the small clam *Gemma gemma* (Figures 20, 21 and 22) that reproduces by brooding their young and lives on the sediment surface. Unlike *A. abdita* and *S. benedicti*, there has been no significant decline in the abundance of *G. gemma*.

Reproduction of *Macoma balthica*

As seen in previous years (Hornberger et al. 1999), reproduction in *Macoma balthica* continues to reflect the concentration of silver found in the tissue of this clam. The time series of reproductive activity (Figure 23) shows that *M. balthica* continues to be highly reproductive relative to the 1970's with a high percentage of the animals being reproductively active at any one time and with normal seasonal cycling of reproduction occurring in spring and fall (see Appendix 2 for details of the recent two years of data). Unlike the earlier periods, animals do not stay reproductively inactive for longer than a month or two.

Value of Long Term Monitoring

Both portions of this study show the value of long-term monitoring that incorporates seasonal sampling. Changes and trends in community structure that may be related to anthropogenic stressors such as was seen in this study, can only be established given a study of sufficient length in time and frequency of sampling that the natural stressors can be characterized and separated from those introduced by man.

BIBLIOGRAPHY

- Ahn, I. Y., Y. C. Kang, and J.W. Choi. 1995. The influence of industrial effluents on the intertidal benthic communities in Panweol, Kyeonggi Bay (Yellow Sea) on the west coast of Korea. *Marine Pollution Bulletin*, 30:200-206
- Alpine, A. E. and J.E. Cloern, 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. *Limnology and Oceanography*, 37:946-955.
- David, C.P., S. N. Luoma, C. Brown, D. J. Cain, M. Hornberger, I. Lavigne, 2002. Near-field receiving water monitoring of trace metals in clams (*Macoma balthica*) and sediments near the Palo Alto water quality control plant in South San Francisco Bay, California: 1999-2001. U. S. Geological Survey Open File 02-453, 107 pp.
- Hornberger, M., S. Luoma, D. Cain, F. Parchaso, C. Brown, R. Bouse, C. Wellise, and J. Thompson. 1999. Bioaccumulation of metals by the bivalve *Macoma balthica* at a site in South San Francisco Bay between 1977 and 1997: Long-term trends and associated biological effects with changing pollutant loadings. U.S. Geological Survey Open File Report 99-55, 42p.
- Hornberger, M., S. Luoma, D. Cain, F. Parchaso, C. Brown, R. Bouse, C. Wellise, and J. Thompson. 2000. Linkage of bioaccumulation and biological effects to changes in pollutant loads in South San Francisco Bay. *Environmental Science and Technology*, 34:2401-2409.
- Kennish, J.K. 1998. *Pollution impacts on marine biotic communities*. CRC Press, New York. 310 pp.
- Luoma, S.N., Y.B. Ho, and G. W. Bryan. 1995. Fate, bioavailability and toxicity of silver in estuarine environments. *Marine Pollution Bulletin*, 31:44-54
- Morrissey, D.J., A.J. Underwood, and L. Howitt. 1996. Effects of copper on the faunas of marine soft-sediments: an experimental field study. *Marine Biology* 125:199-213
- Nichols, F.N, and J.K. Thompson. 1985a. Persistence of an introduced mudflat community in South San Francisco Bay, California. *Mar. Ecol. Prog. Ser.* 24:83-97.
- Nichols, F.N, and J.K. Thompson. 1985b. Time scales of change in the San Francisco Bay benthos. *Hydrobiologia*. 129:121-138
- Parchaso, F. 1993. Seasonal reproduction of *Potamocorbula amurensis* in San Francisco Bay, California. M.S. Thesis, San Francisco State University, San Francisco.
- Rasmussen, E. 1956. The reproduction and larval development of some polychaetes for the Isefjord, with some faunistic notes. *Biol. Meddr.*, 23(1):1-84.
- Rygg, B. 1985. Effect of sediment copper on benthic fauna. *Mar. Ecol. Prog. Ser.* 25:83-89.

Shouse, Michelle K. 2002. The effects of decreasing trace metal concentrations on benthic community structure. Master's Thesis, San Francisco State University. 177pp.

Simon, T.P. 2002. *Biological response signatures*. CRC Press, Boca Raton, Florida, U.S.

Thompson, J.K., F. Parchaso, and M.K. Shouse. 2002. Near field receiving water monitoring of benthic community near the Palo Alto Water Quality Control Plant in South San Francisco Bay: February 1974 through December 2000. U.S. Geological Survey Open File Report 02-394, 117pp.

Thomson, E.A., S.N. Luoma, C.E. Johansson, and D.J. Cain. 1984. Comparison of sediments and organisms in identifying sources of biologically available trace metal contamination. *Water Resources*. 18(6):755-765.

Wang, W. and N. S. Fisher. 1999. Delineating metal accumulation pathways for marine invertebrates. *The Science of the Total Environment*. 237:459-472.

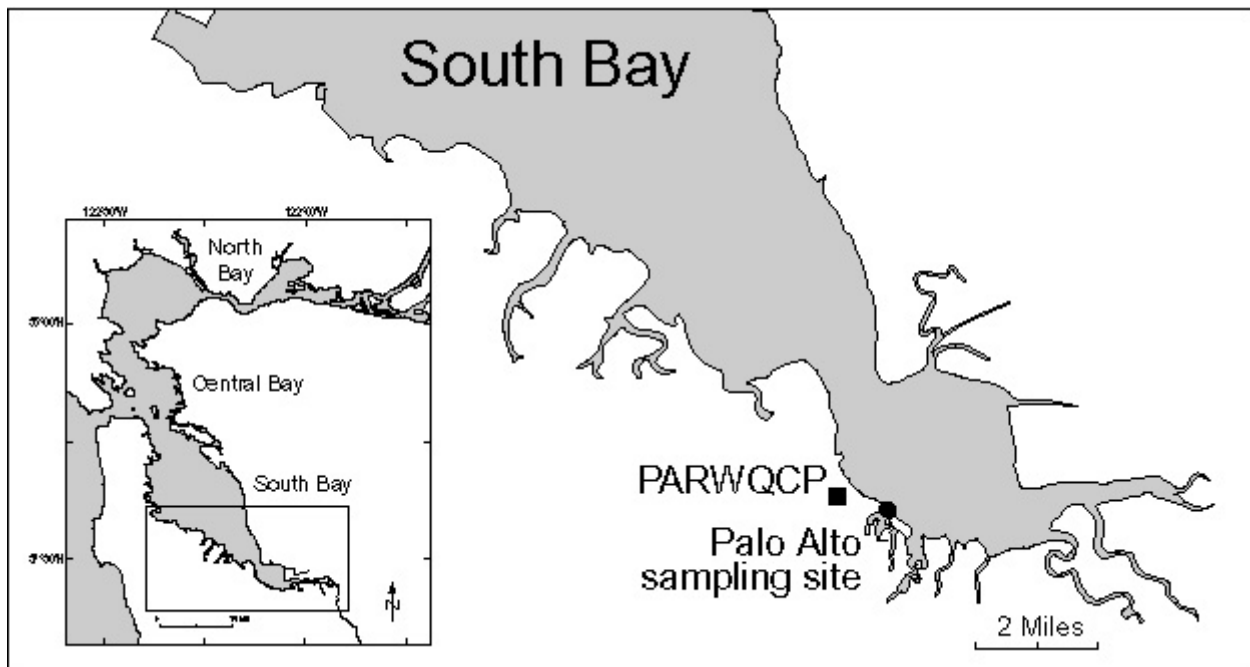


Figure 1. Map of sampling station at Palo Alto in South San Francisco Bay with location of Palo Alto Regional Water Quality Control Plant (PARWQCP) effluent noted.

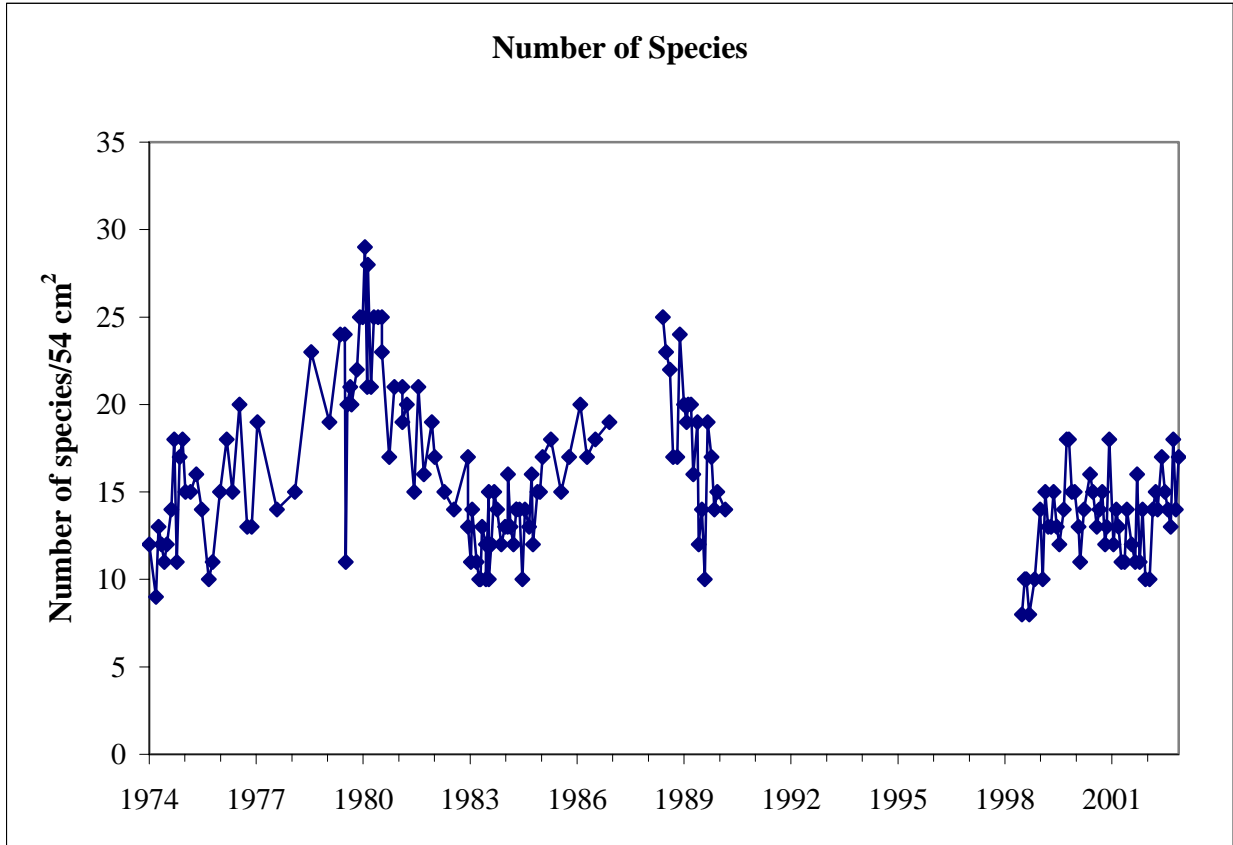


Figure 2. Number of species present in each sample period (1974-2002)

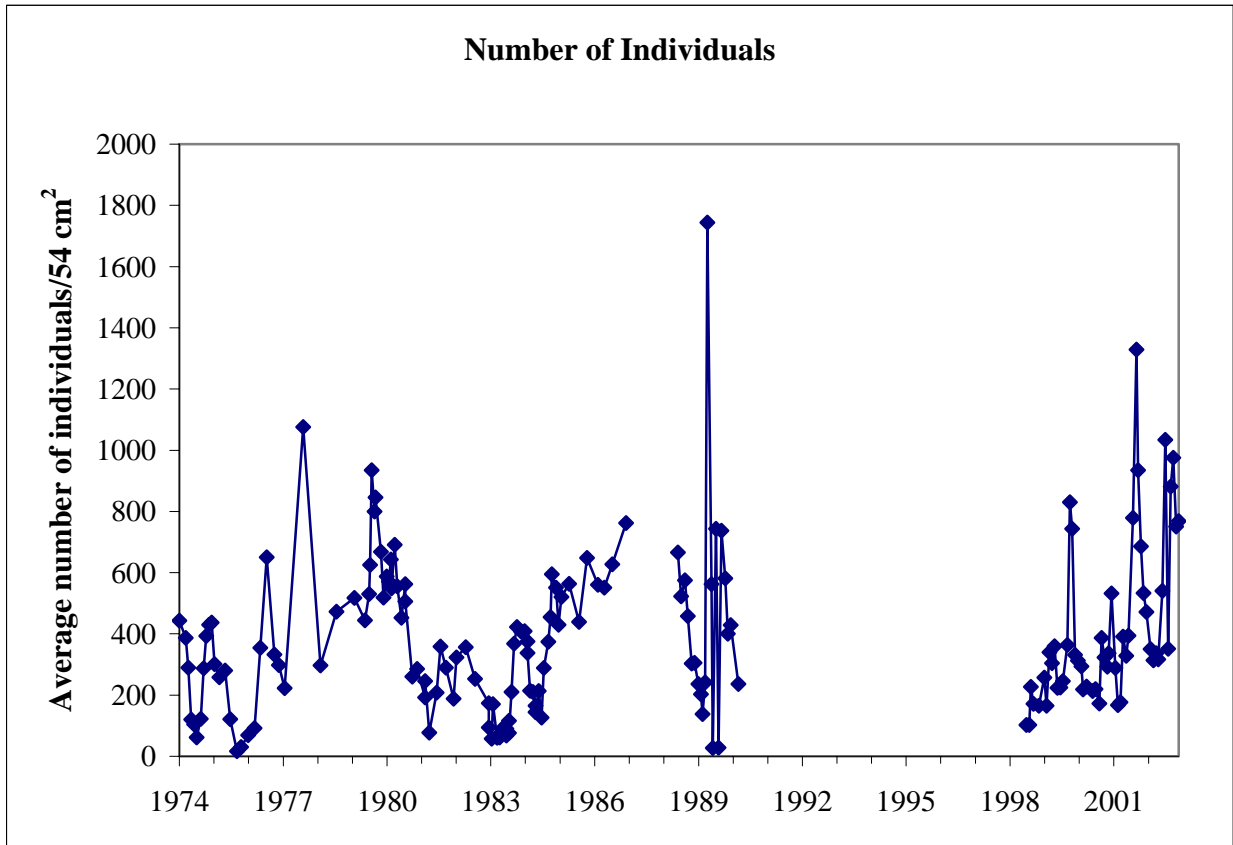


Figure 3. Total average number of individuals present in each sample period (1974-2002)

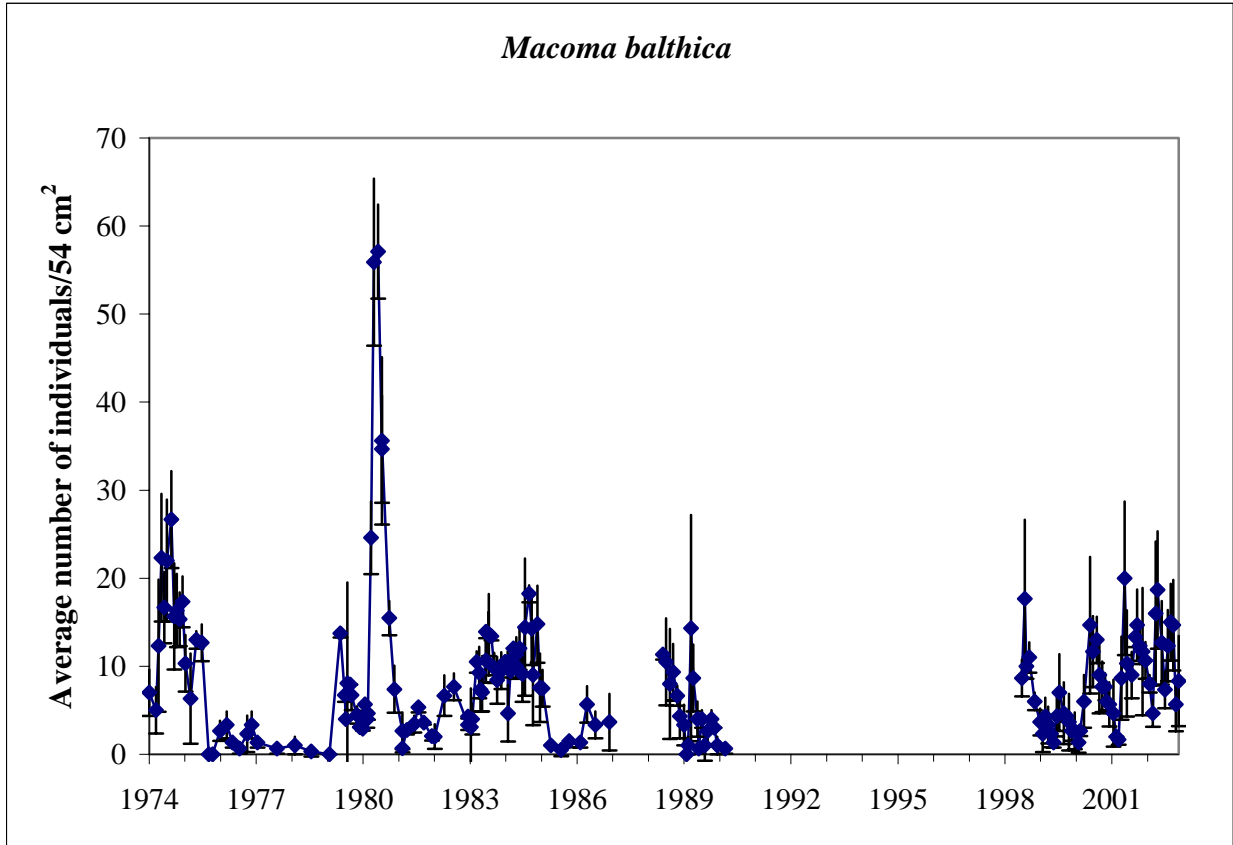


Figure 4. Average abundance and standard deviation of *Macoma balthica* in each sampling period (1974-2002)

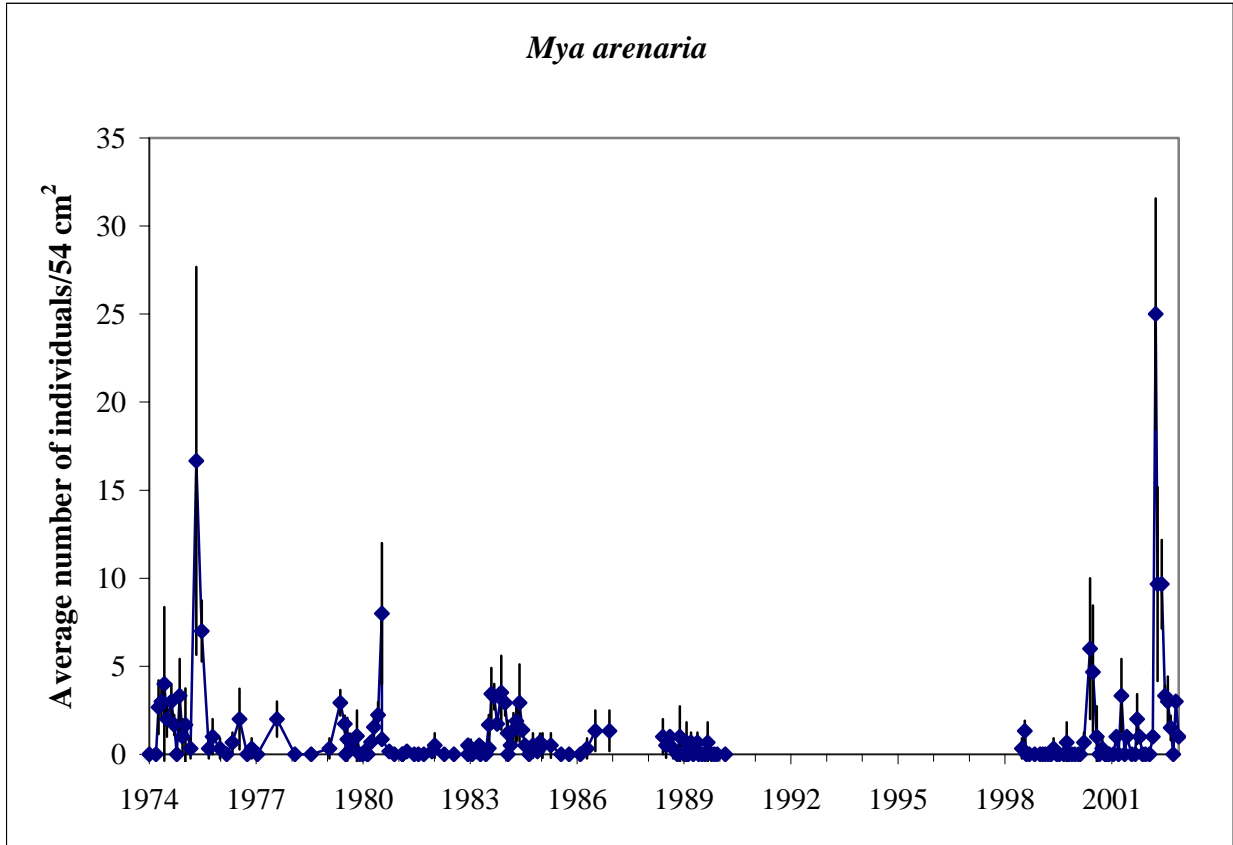


Figure 5. Average abundance and standard deviation of *Mya arenaria* in each sampling period (1974-2002)

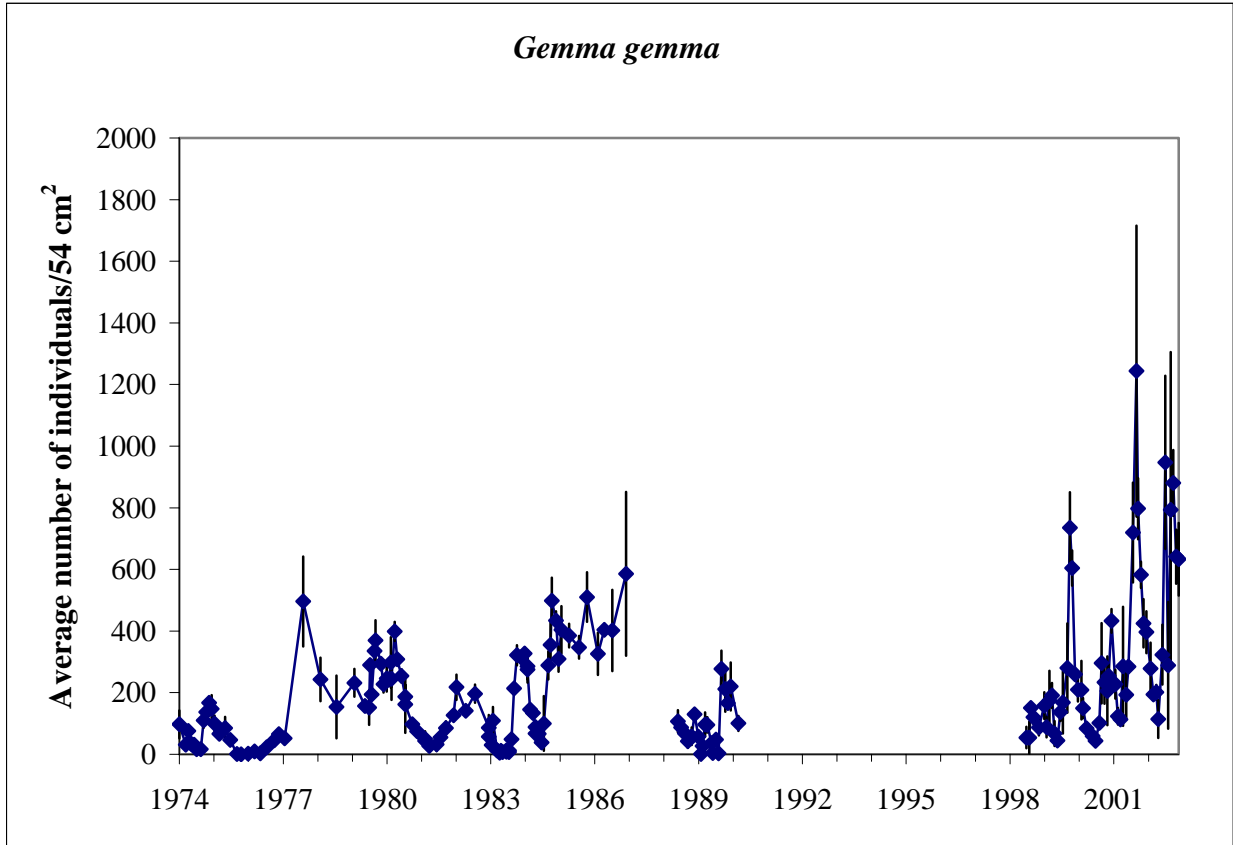


Figure 6. Average abundance and standard deviation of *Gemma gemma* in each sampling period (1974-2002)

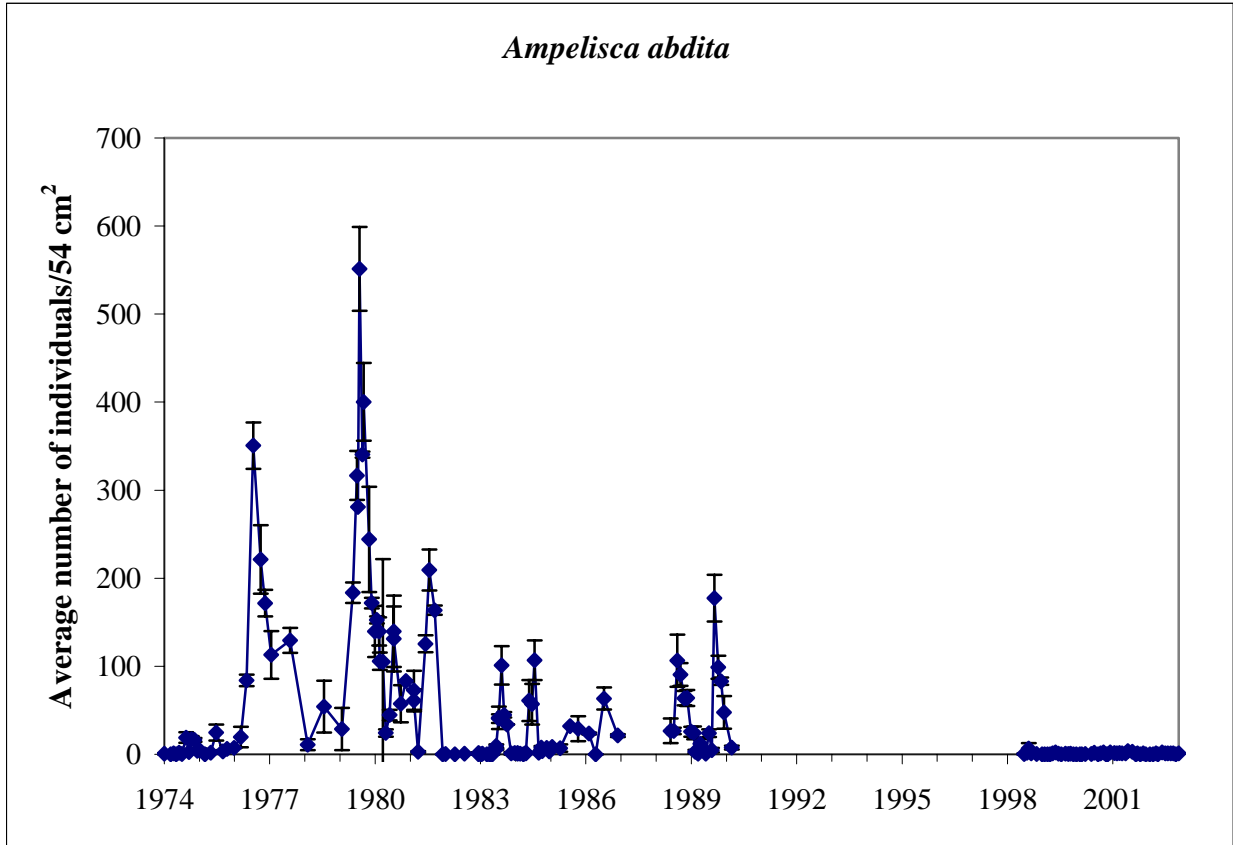


Figure 7. Average abundance and standard deviation of *Ampelisca abdita* in each sampling period (1974-2002)

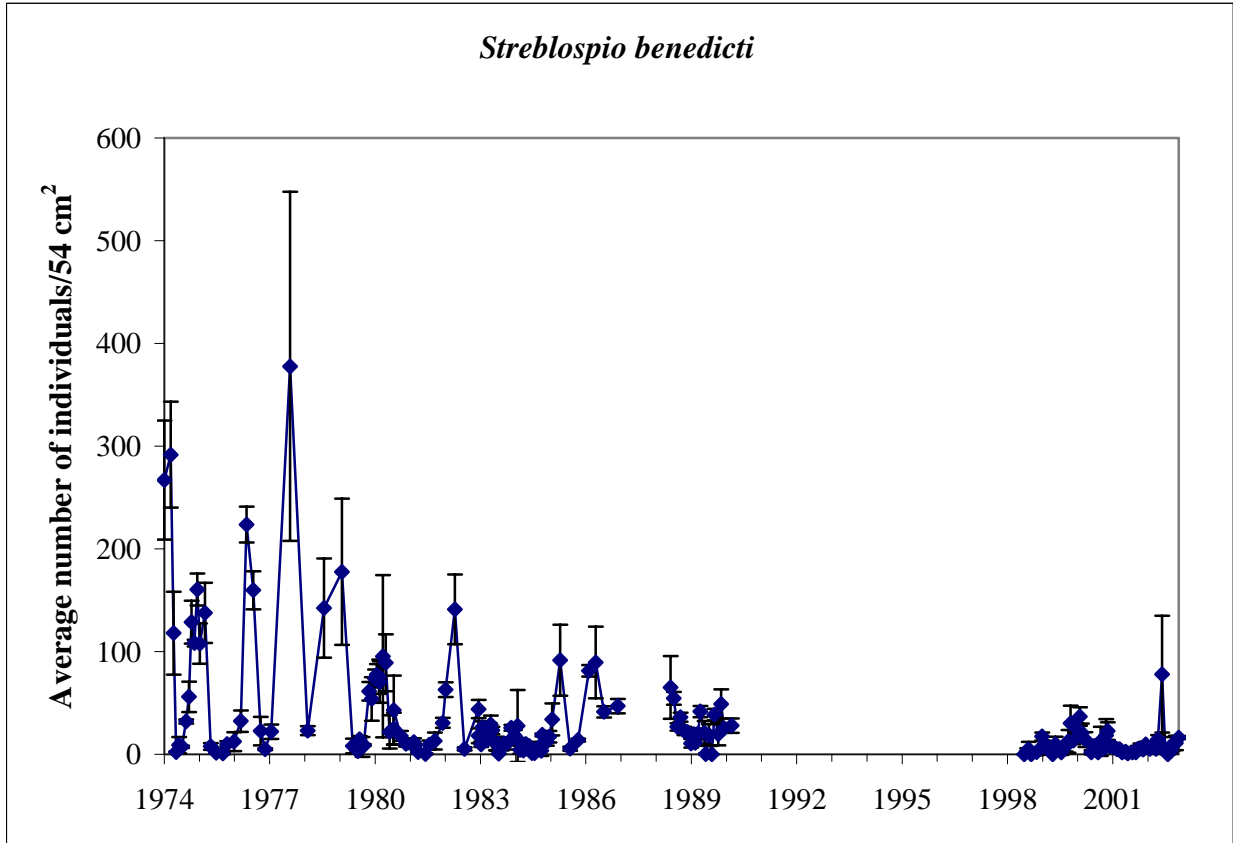


Figure 8. Average abundance and standard deviation of *Streblospio benedicti* in each sampling period (1974-2002)

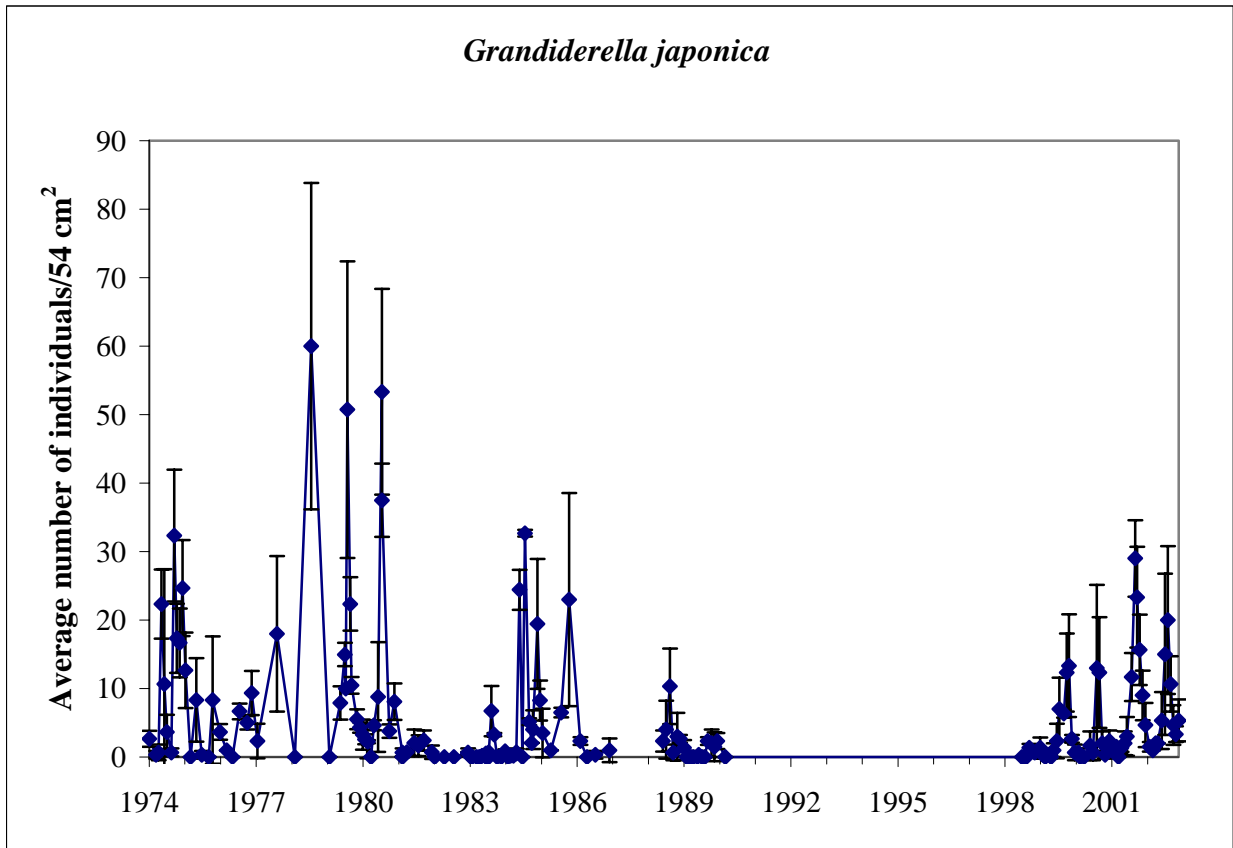


Figure 9. Average abundance and standard deviation of *Grandiderella japonica* in each sampling period (1974-2002)

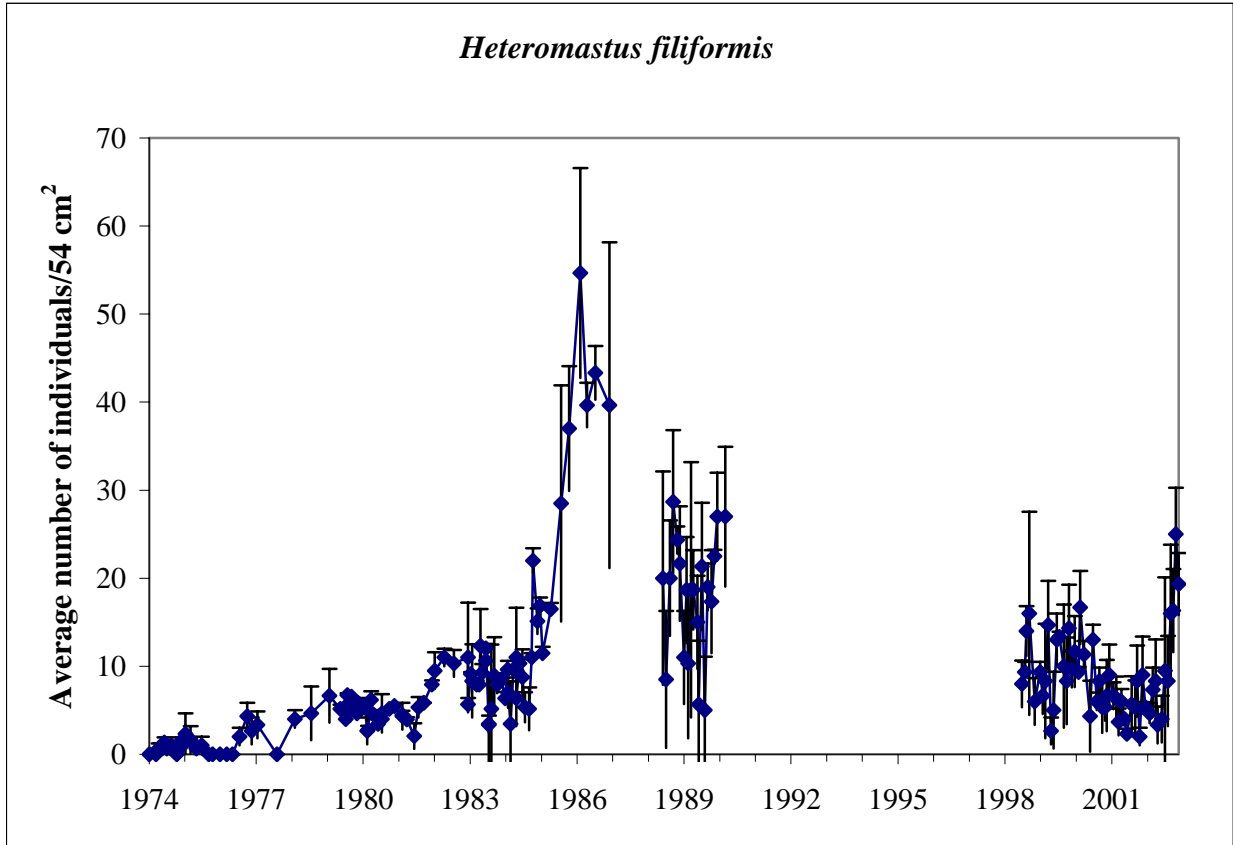
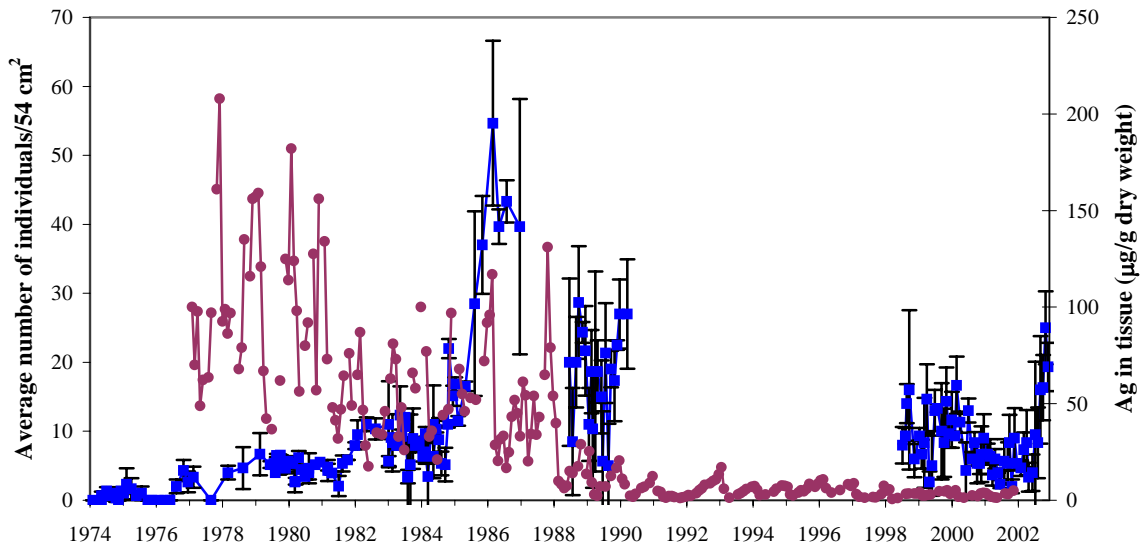


Figure 10. Average abundance and standard deviation of *Heteromastus filiformis* in each sampling period (1974-2002)

Silver Concentration in *Macoma balthica* and
Heteromastus filiformis Abundance



Copper Concentration in *Macoma balthica* and
Heteromastus filiformis Abundance

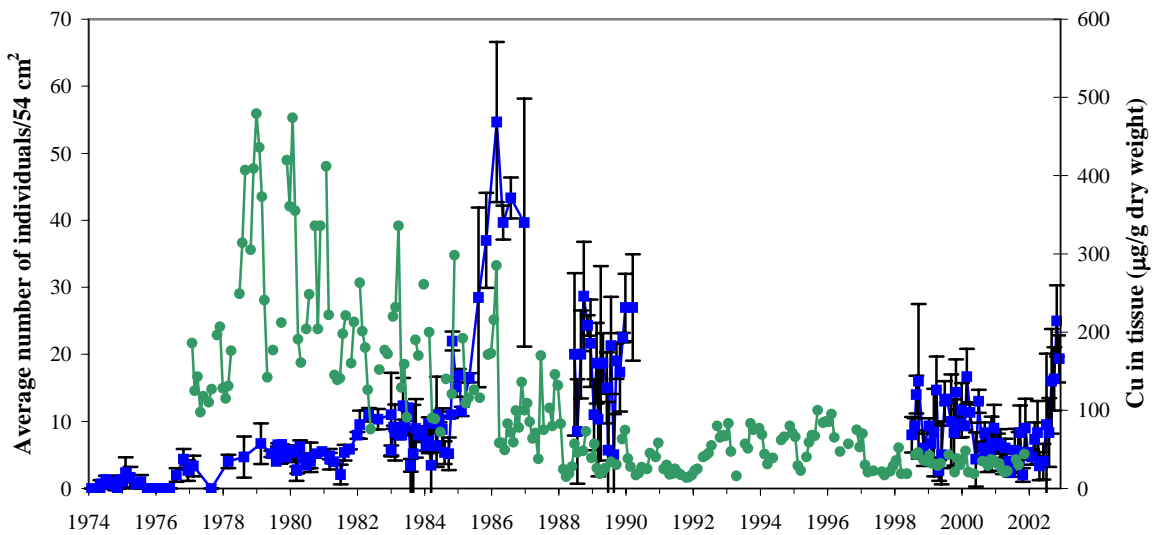
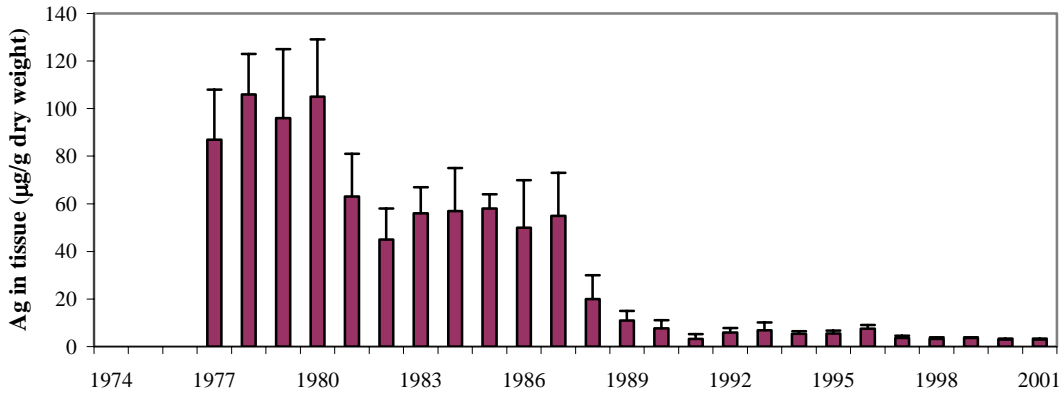
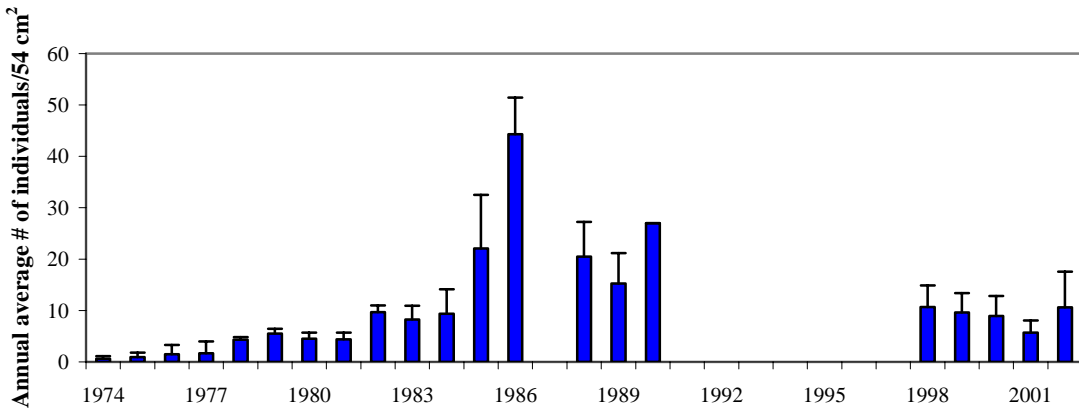


Figure 11. Time series of *Heteromastus filiformis* abundance with silver and copper tissue concentrations in *Macoma balthica*

Annual Average Silver Concentration in *Macoma balthica*



Annual Average Abundance of *Heteromastus filiformis*



Annual Average Silver Concentration in the Sediment

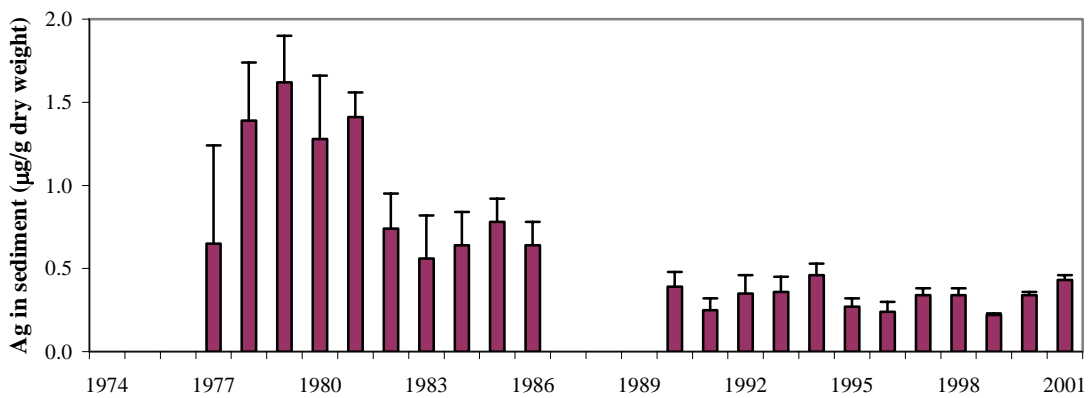


Figure 12. *Heteromastus filiformis* annual abundance with silver concentrations in *Macoma balthica* tissue and in sediment

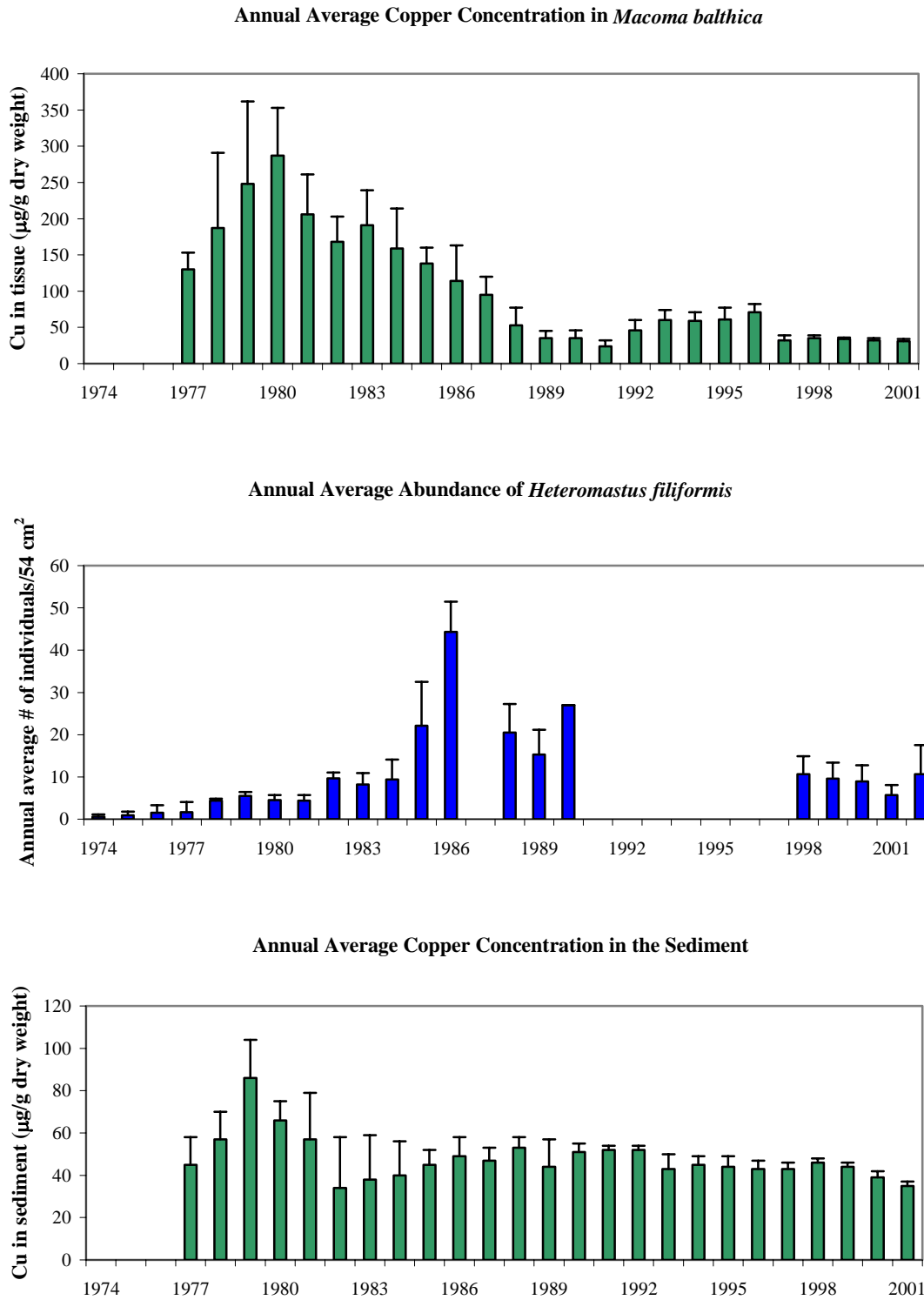
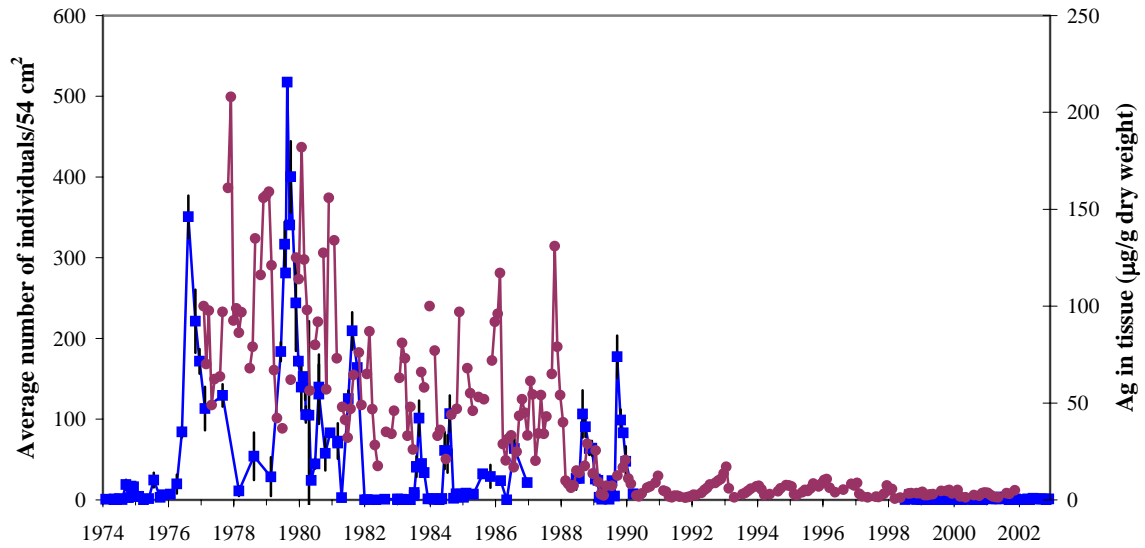


Figure 13. *Heteromastus filiformis* annual abundance with copper concentrations in *Macoma balthica* tissue and in sediment

**Silver Concentration in *Macoma balthica* and
Ampelisca abdita Abundance**



**Copper Concentration in *Macoma balthica* and
Ampelisca abdita Abundance**

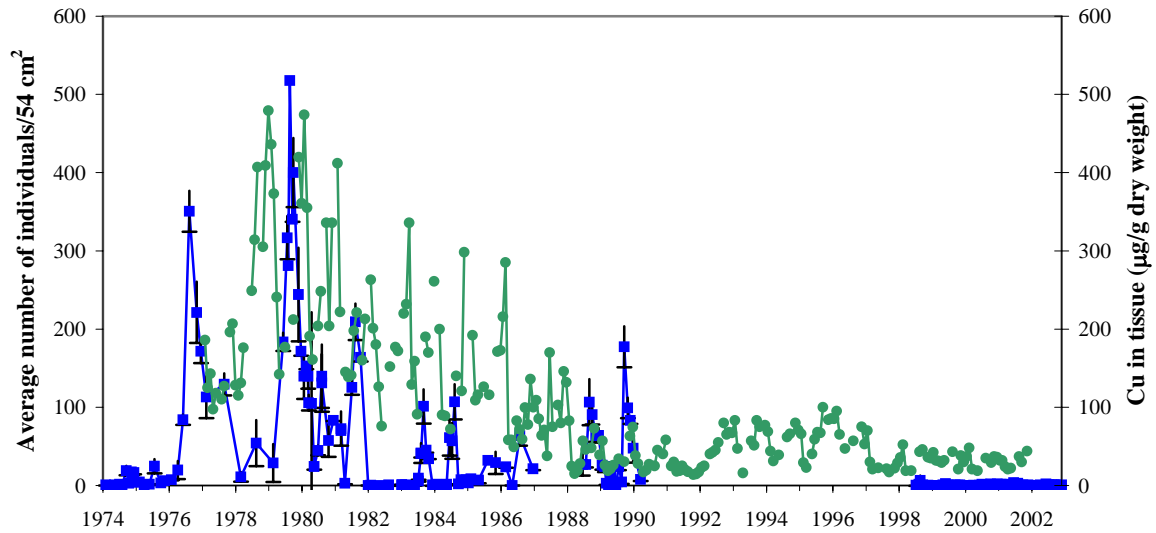
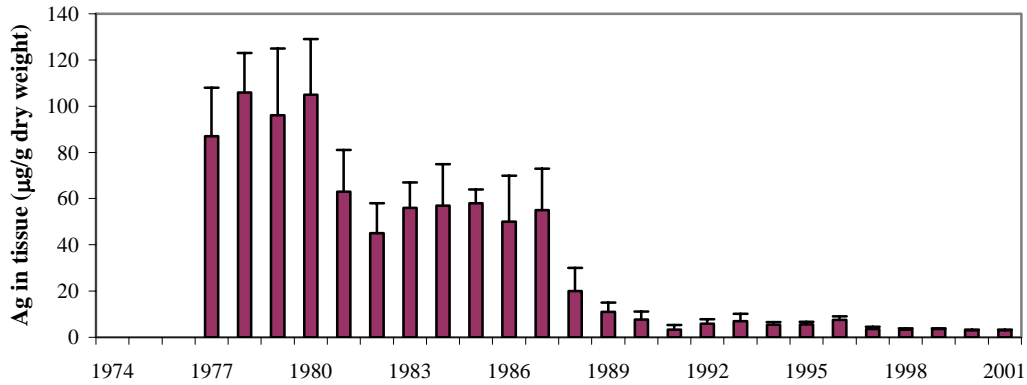
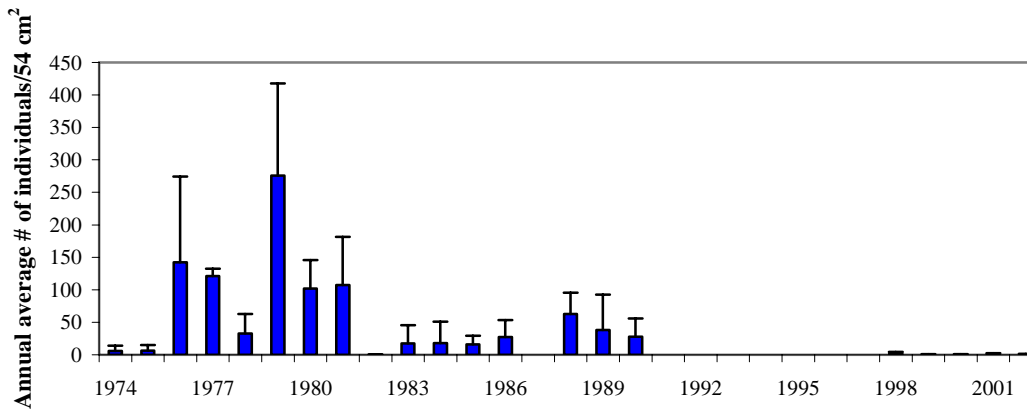


Figure 14. Time series of *Ampelisca abdita* abundance with silver and copper tissue concentrations in *Macoma balthica*

Annual Average Silver Concentration in *Macoma balthica*



Annual Average Abundance of *Ampelisca abdita*



Annual Average Silver Concentration in the Sediment

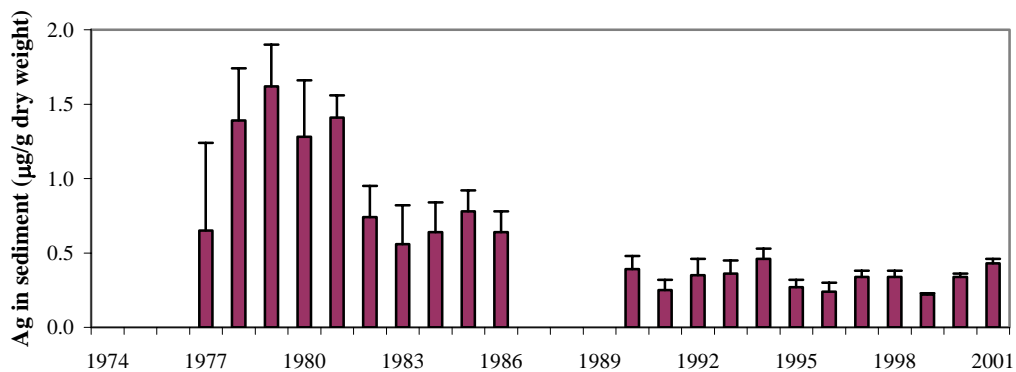
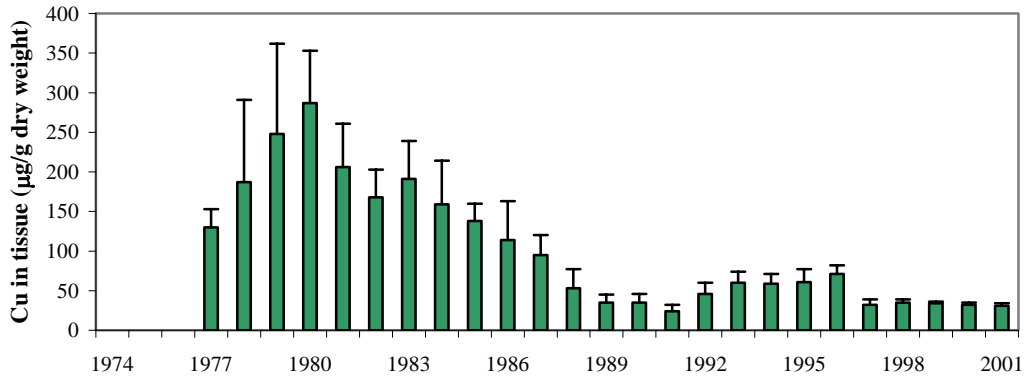
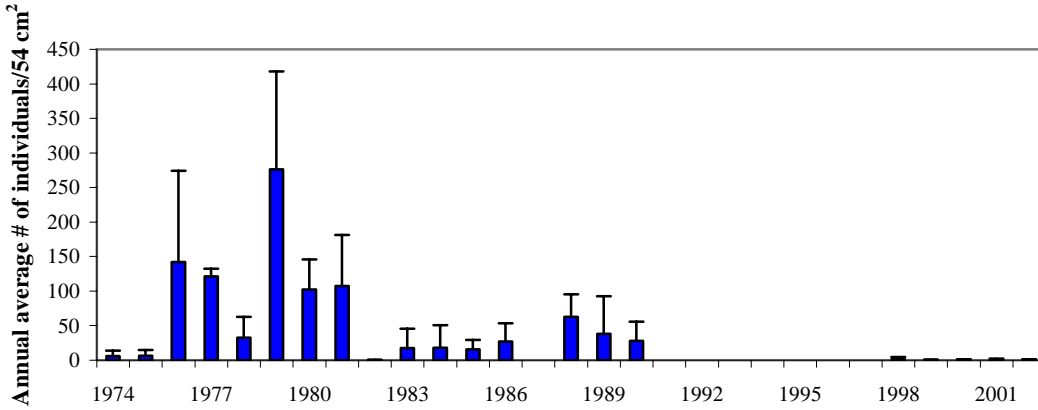


Figure 15. *Ampelisca abdita* annual abundance with silver concentrations in *Macoma balthica* tissue and in sediment

Annual Average Copper Concentration in *Macoma balthica*



Annual Average Abundance of *Ampelisca abdita*



Annual Average Copper Concentration in the Sediment

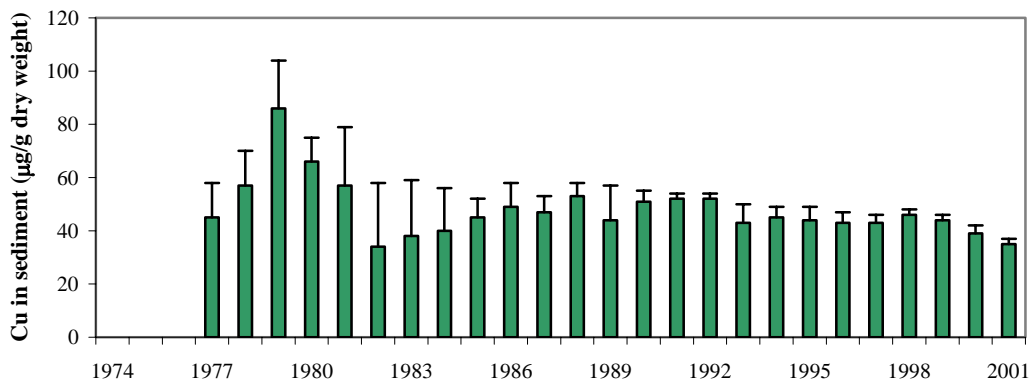
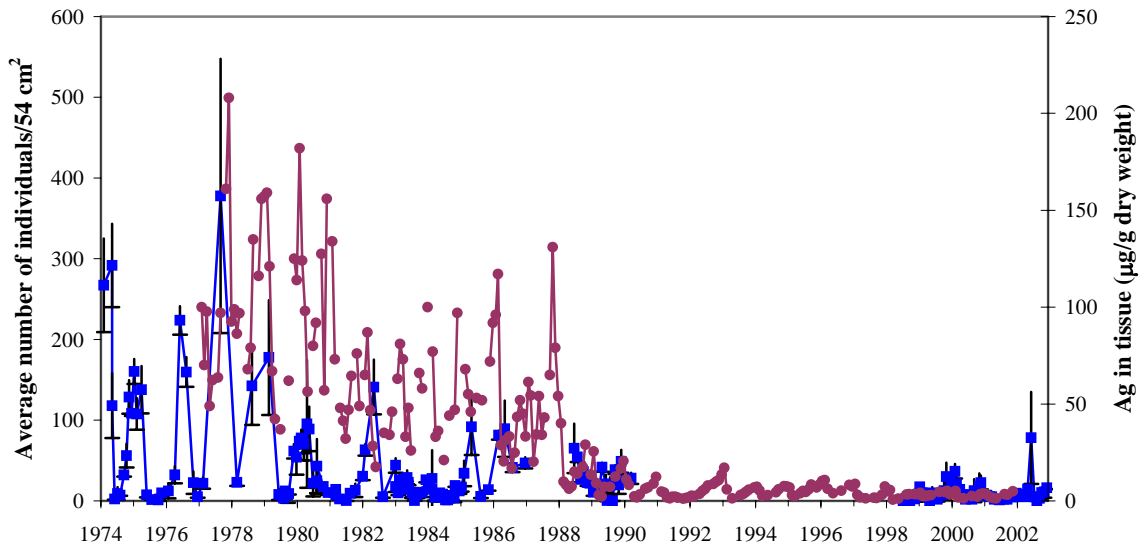


Figure 16. *Ampelisca abdita* annual abundance with copper concentrations in *Macoma balthica* tissue and in sediment

**Silver Concentration in *Macoma balthica* and
Streblospio benedicti Abundance**



**Copper Concentration in *Macoma balthica* and
Streblospio benedicti Abundance**

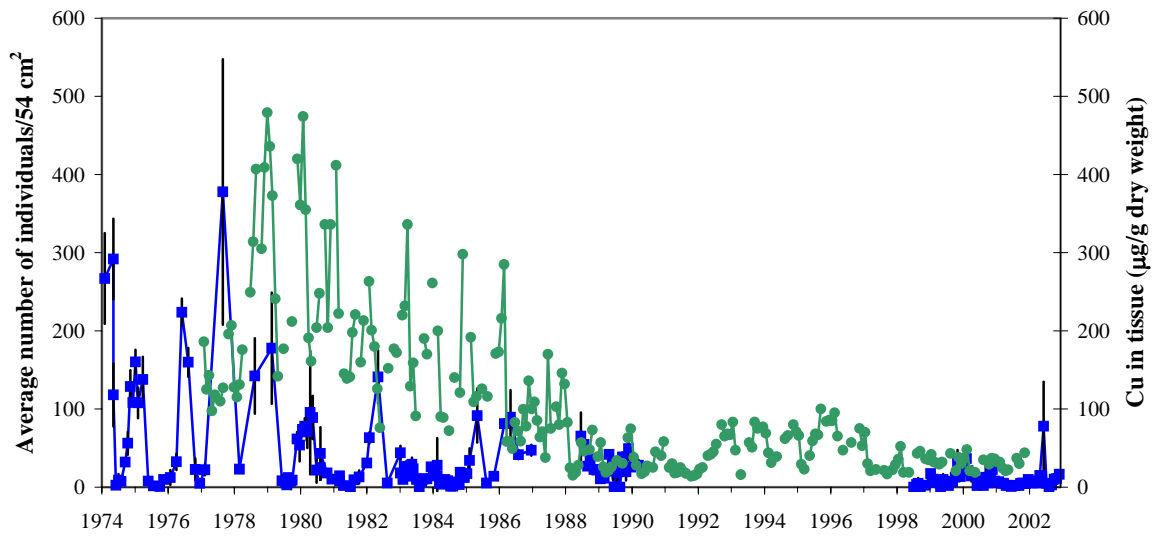
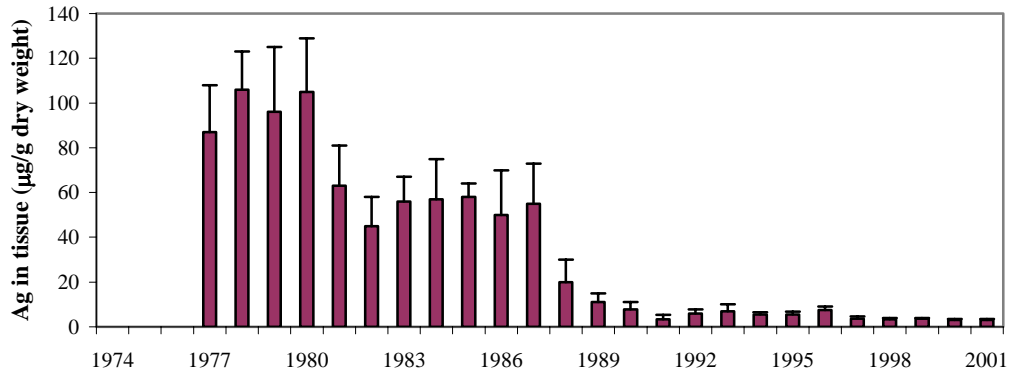
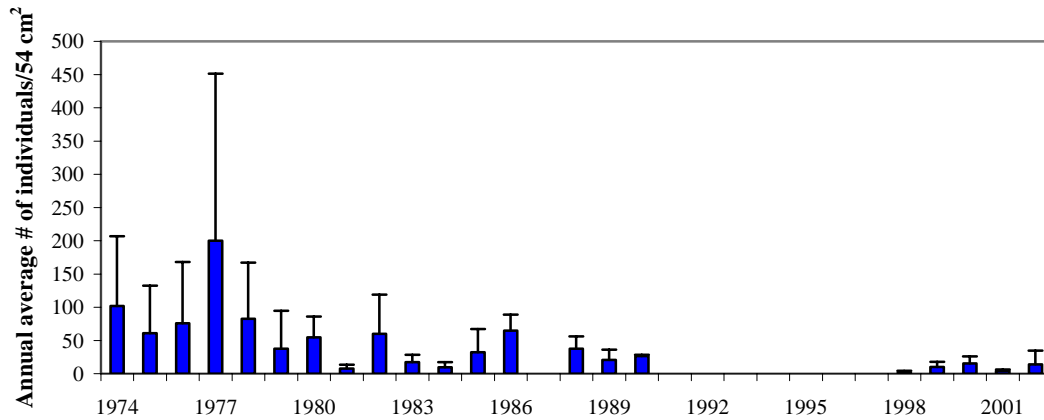


Figure 17. Time series of *Streblospio benedicti* abundance with silver and copper tissue concentrations in *Macoma balthica*

Annual Average Silver Concentration in *Macoma balthica*



Annual Average Abundance of *Streblospio benedicti*



Annual Average Silver Concentration in the Sediment

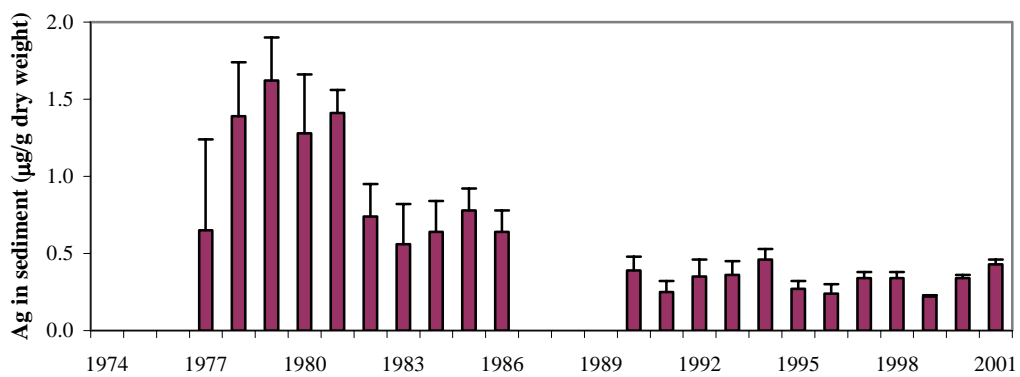
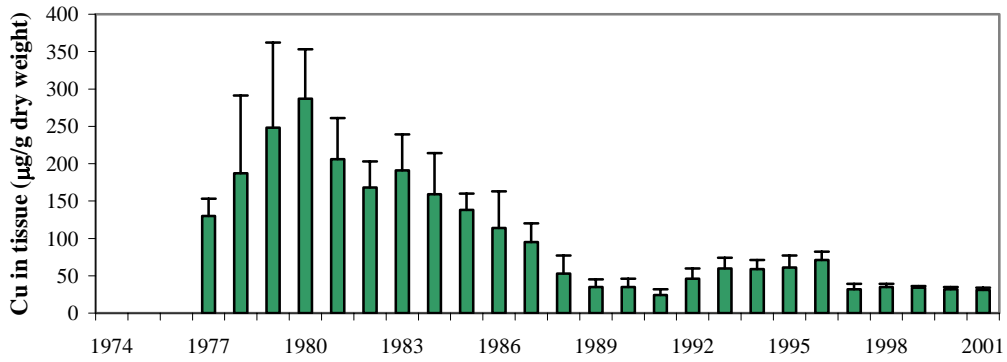
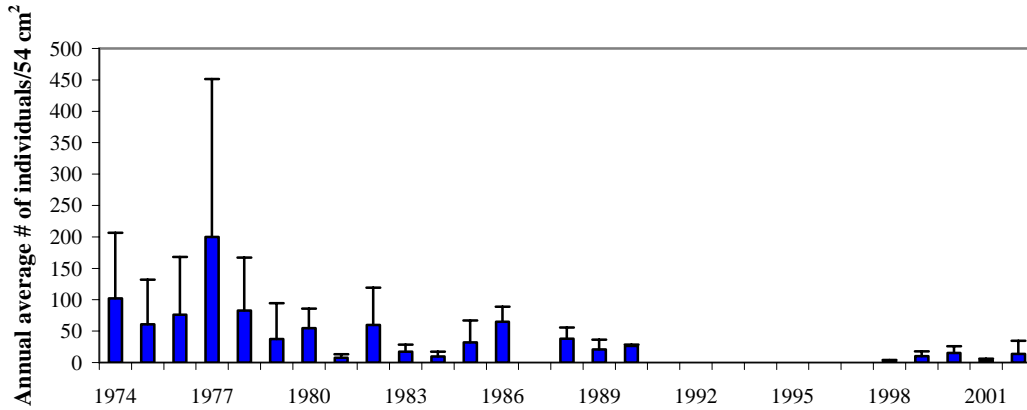


Figure 18. *Streblospio benedicti* annual abundance with silver concentrations in *Macoma balthica* tissue and in sediment

Annual Average Copper Concentration in *Macoma balthica*



Annual Average Abundance of *Streblospio benedicti*



Annual Average Copper Concentration in the Sediment

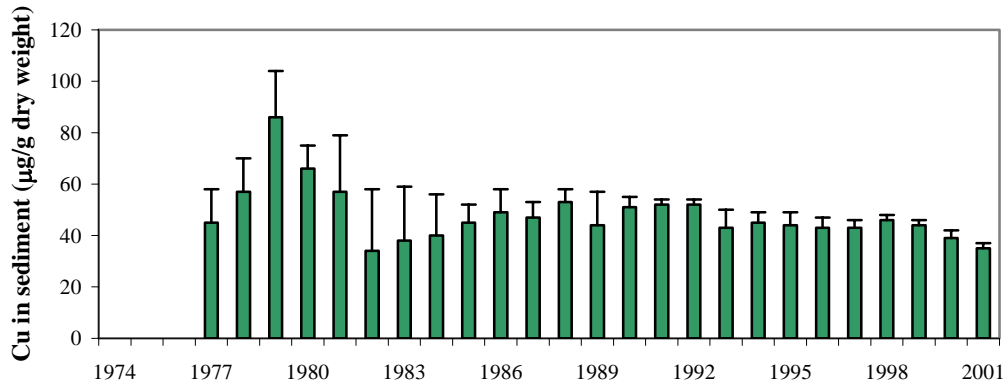
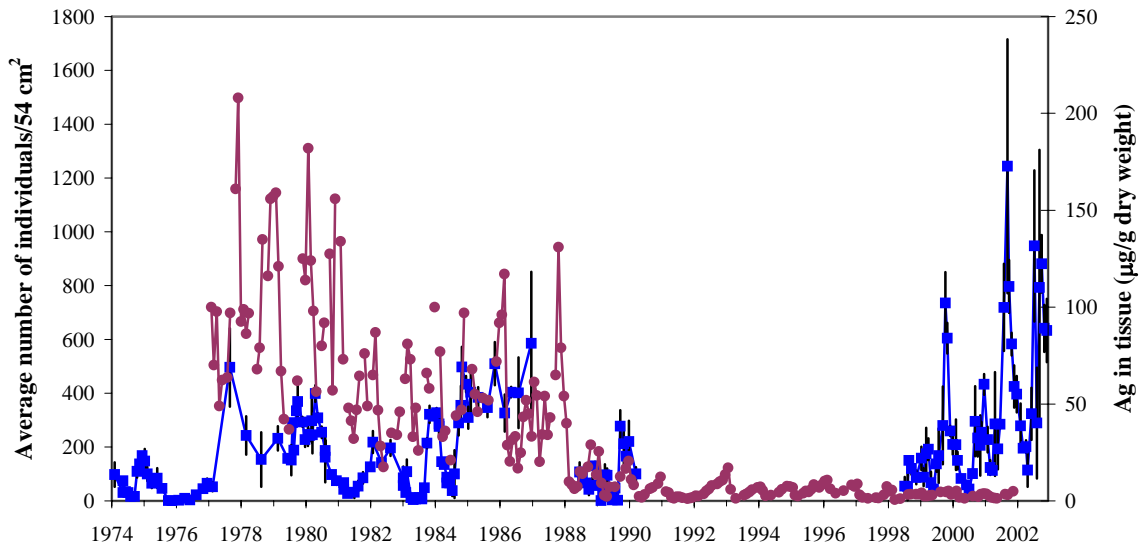


Figure 19. *Streblospio benedicti* annual abundance with copper concentrations in *Macoma balthica* tissue and in sediment

Silver Concentration in *Macoma balthica* and
Gemma gemma Abundance



Copper Concentration in *Macoma balthica* and
Gemma gemma Abundance

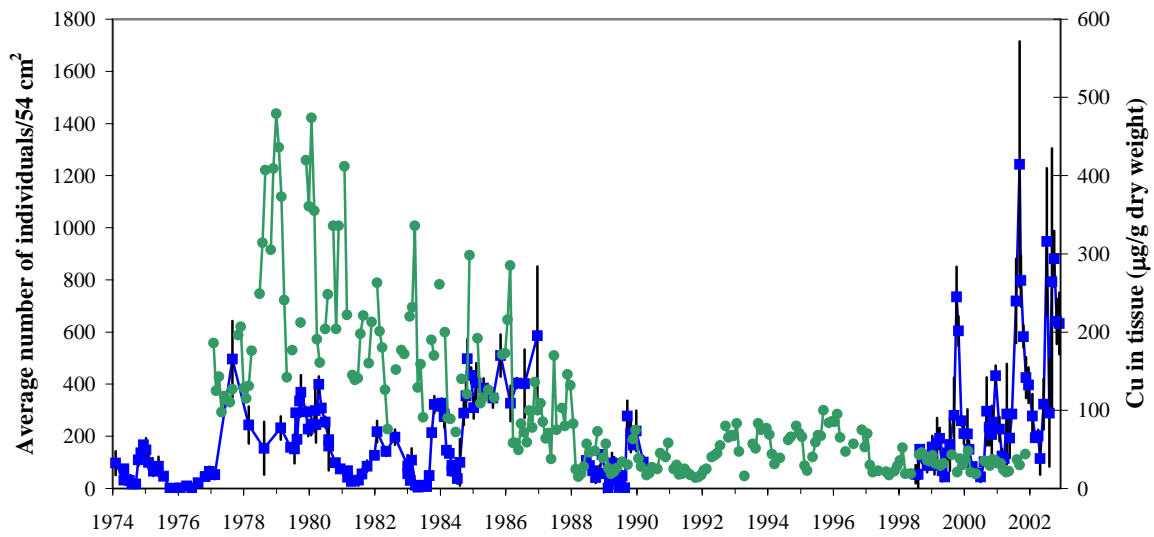
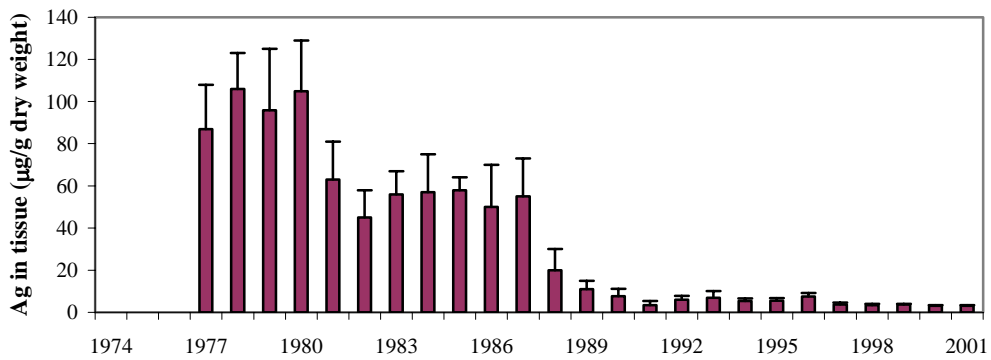
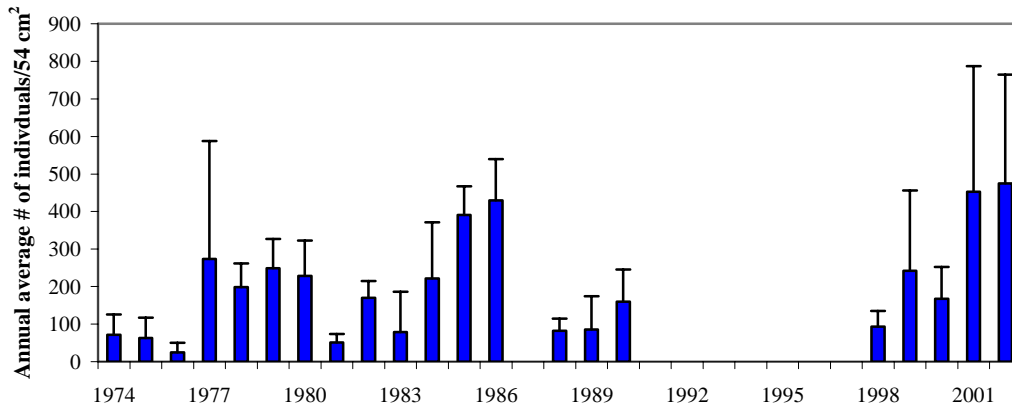


Figure 20. Time series of *Gemma gemma* abundance with silver and copper tissue concentrations in *Macoma balthica*

Annual Average Silver Concentration in *Macoma balthica*



Annual Average Abundance of *Gemma gemma*



Annual Average Silver Concentration in the Sediment

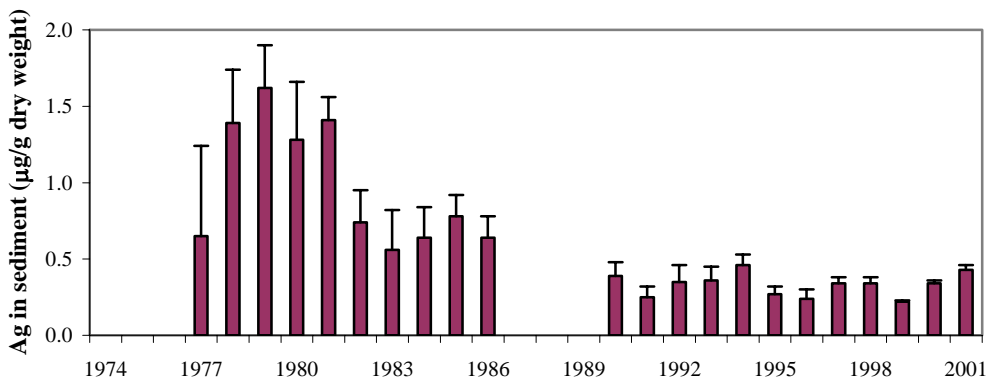
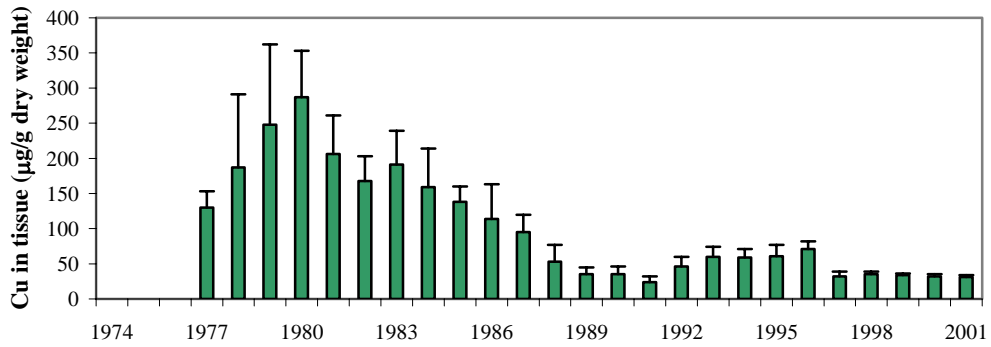
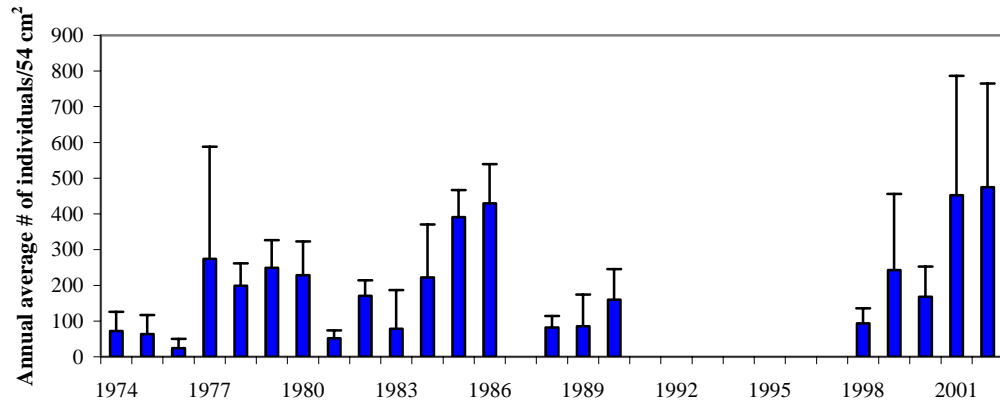


Figure 21. *Gemma gemma* annual abundance with silver concentrations in *Macoma balthica* tissue and in sediment

Annual Average Copper Concentration in *Macoma balthica*



Annual Average Abundance of *Gemma gemma*



Annual Average Copper Concentration in the Sediment

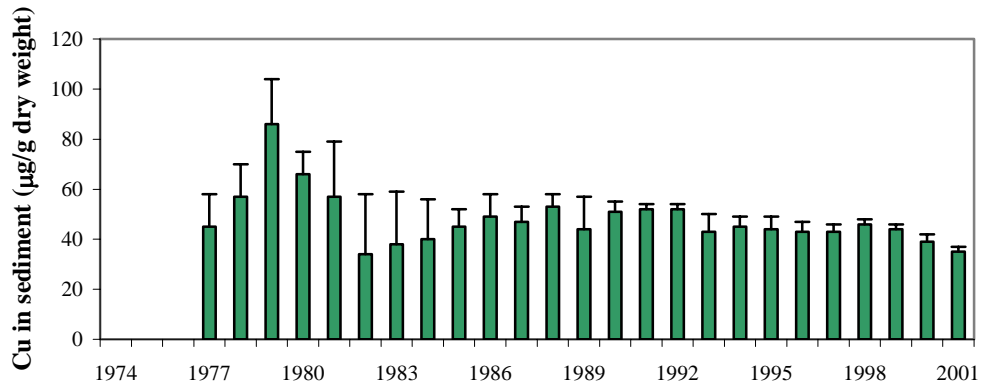


Figure 22. *Gemma gemma* annual abundance with copper concentrations in *Macoma balthica* tissue and in sediment

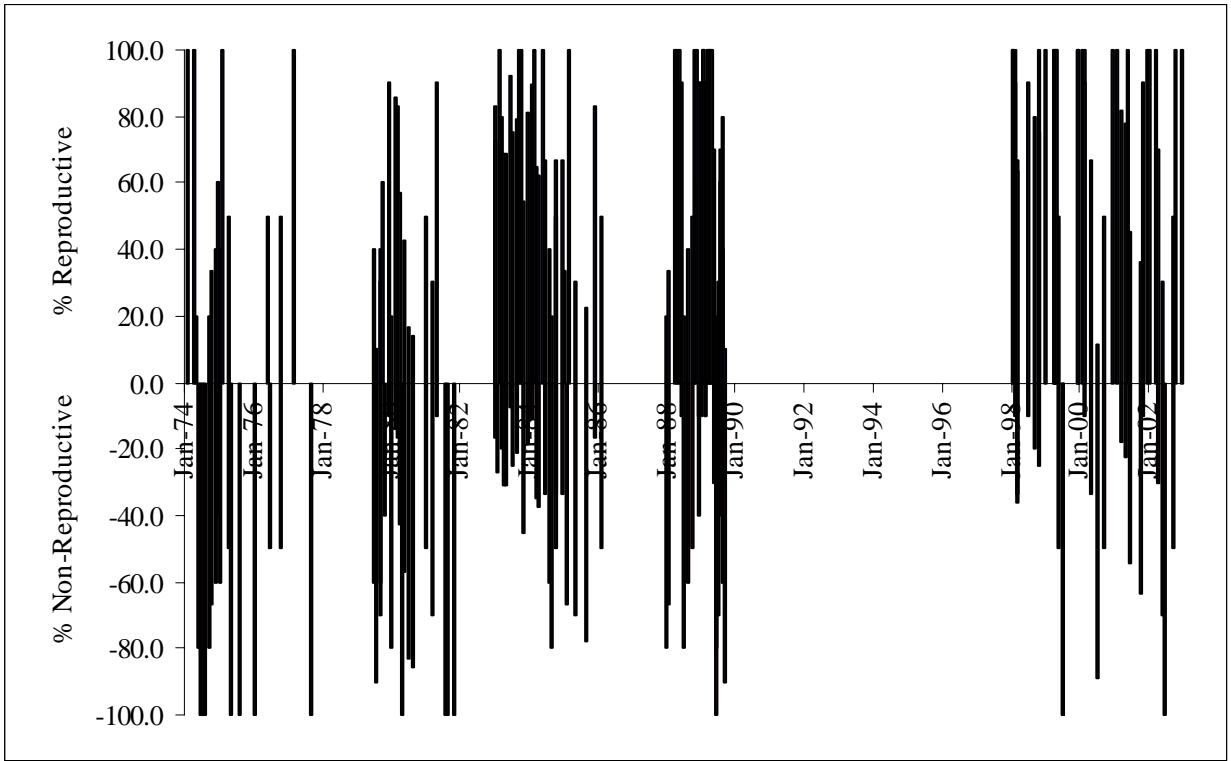


Figure 23. Reproductive activity of *Macoma balthica* (1974-2002)

APPENDIX 1: PALO ALTO BENTHIC COMMUNITY

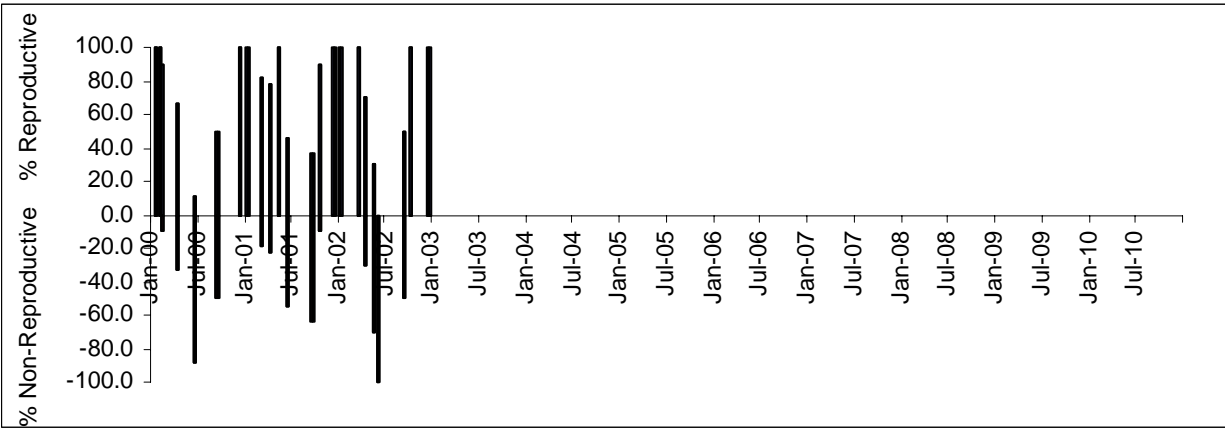
January 2001 through December 2002

(*data from larger core that have been standardized to the area of the smaller core)

See attached Excel file: Appendix 1

APPENDIX 2: PALO ALTO *MACOMA BALTHICA* REPRODUCTION

January 2001 through December 2002
See attached Excel file: Appendix 2



Appendix 2 Figure. Timeseries of reproductive activity for January 2000 through December 2002.