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Temporal variation in the carabid (Coleoptera:Carabidae) community structure at five sites east of a Kraft Paper mill in Thunder Bay Ontario

By

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Abstract

The purpose of this study was to re-examine the carabid community structure (the list of species and their relative abundances) at five sites east of the Avenor kraft paper mill in Thunder Bay Ontario. The null hypothesis was that there would be no change in the carabid community structure at each site between 1993 and 1994, but that due to particulate fallout from the Avenor mill flue stack there would be a change in the carabid community structure at the five sites since 1971.

During the summers of 1993 and 1994 carabids were collected at five sites east of the mill and a reference site to the west. Each site consisted of 100 pitfall traps arranged in four rows of 25.

During the winters of 1994 and 1995 snow core samples were taken from each site for the purpose of quantifying sulphate concentrations. Analysis for sulphate was done at the Ontario Ministry of the Environment and Energy Lab in Thunder Bay Ontario.

The carabid data was compared to carabid data collected from the same area in a similar study conducted in 1971. Sorenson's measure, Shannon's, Simpson's and Shannon's evenness index were used to compare the data of 1993/1994 with that collected in 1971.

A difference was found in the carabid community structure between 1993 and 1994, and between 1971 and 1993/94. The differences between 1993 and 1994 were attributed to natural fluctuations in carabid numbers, the traps being left overwinter, trapping artifacts, and the probability associated with using pitfall traps.

The difference between 1971 and 1993/1994 were larger than that observed for 1993 and 1994. These differences were attributed to the invasion of *Pterostichus melanarius* and its competitive advantages in a polluted environment.

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INTRODUCTION

The purpose of this study was to re-examine the carabid community structure, the list of species present and their relative abundances, at five sites east of the Avenor kraft paper mill in Thunder Bay Ontario. The present study was based on two separate studies carried out in the early 1970's by Hastings et al. (1972) and Freitag et al. (1973), and a comparison of the two studies by Freitag and Hastings (1973).

In an unpublished 1969-1970 study (Hastings et al. 1972) sodium sulphate was found in large quantities near a kraft mill in Thunder Bay Ontario. In a subsequent study during the winter of 1971 analysis for sulphate ions in collected snow samples was used to measure the rate of fallout of sodium sulphate near the same mill (Hastings et al. 1972). Snow cores 10cm in diameter extending from the snow surface down to the soil beneath were taken at 28 sites located at intervals of 275m on North, South, East and West transects which intersected at the mill. The closest site to the mill for each transect was 820m and the furthest 2400m. Thirty additional samples were taken at random within the Thunder Bay Area. The rate of fallout along each of the four transects decreased with increasing distance from the mill. The rate of emission by the kraft mill varied from day to day. Since the magnitude of this variation was not known, it was impossible to correlate the observed distribution in fallout

rates with the rate of emission, wind direction and strength. However during the collecting period the prevailing wind direction was West. This resulted in a high rate of fallout along the east transect. This observation supplied enough information for subsequent biological studies (Hastings et al. 1972).

In May, 1971, an undisturbed forest east of the kraft mill was selected for the establishment of five ground beetle collecting sites (Freitag et al. 1973). Freitag et al. (1973) described the area as quite flat, fairly well drained, and covered with admixtures of aspen, spruce, balsam fir, birch and some willow. There was a well developed undergrowth with a dense leaf litter covering the forest floor.

Freitag et al. (1973) arranged 5 sites east of the mill at distances of approximately 820, 1100, 1500, 1920 and 2470 m from the mill. A sixth site (reference) was set up 16 km West in a forest similar to that around sites 1 to 5. The reference site differed from the others in that it was near a cultivated field and also tended to be quite wet.

Each site consisted of four parallel rows 15m apart. Within each row were 25 pitfall traps placed 4m apart. A 1.5cm wire mesh was placed over each trap to prevent the entry of small vertebrates. An aluminum pie plate was placed on top to keep out the rain.

The traps were cleaned out on 13 May, 1971, and emptied out weekly until 22 August, 1971 (Freitag et al. 1973).

Freitag et al. (1973) collected a total of 20 species of carabid, and found that there was a general increase in beetle numbers with distance from the mill.

Freitag and Hastings (1973) compared kraft mill fallout and ground beetle numbers. A negative association was shown between sodium sulphate fallout and beetle numbers. Freitag and Hastings (1973) concluded that fallout from the kraft mill reduced the number of ground beetles near the mill.

The area east of the kraft mill has been receiving particulate fallout for the past 23 years. In addition the area has become more and more populated and urbanized. Therefore the hypothesis in this study is that there will be no change in the carabid community structure between 1993 and 1994 at the five sites, but that there has been a change in the carabid community structure at the five sites east of the mill since 1971. The alternative hypothesis is that there has been no change at these five sites in terms of community structure since 1971.

Materials and Methods

Site Location and Trap Set-Up

A site is defined as a rectangular area in which 100 pitfall traps are located. In accordance with the methodology used by Freitag et al (1973), five sites were established east of the Avenor Kraft Mill near Thunder Bay Ontario. As in the Freitag study (1973) the sites were located at distances of approximately 820, 1100, 1500, 1920, 2470 m from the mill, with site one being closest to the mill (820 m) and site five the furthest (2470 m). The sites were in a poplar forest between the Kamanistiquia River and Highway 61B, except for site 2 which was located on the opposite side of the highway. The area in which Freitag et al. (1973) located their reference site has been developed and is no longer usable. Therefore a new reference site had to be established for the present study in a different area. The reference site used in the present site was located 13 km west of the mill, approximately 1 km after Rossylyn Road becomes Harthstone Road. This site was chosen because of its similarity to the sites east of the mill in terms of vegetation.

Each site consisted of 100 pitfall traps arranged in four rows approximately 40 to 50 m long. The rows were approximately 7 m apart. Within each row were 25 pitfall traps placed approximately 1.5 to 2 m apart.

In the present study each site encompassed an area of approximately 840 to 1050 m^2. This is in contrast to Freitag et al (1973) where the rows were 100 meters long and 15 m apart. Each site in the Freitag study (1973) encompassed an area of 4500 m^2. The spring of 1993 was very wet. In order to have all traps located in a functional area on dry ground and not submerged in water, the length of the rows and the distance between rows were decreased.

The traps used in the present study and those used in Freitag et al. (1973) were plastic containers which were 7 cm deep with an 11 cm mouth diameter. Each trap was set into the ground so that the lip of the container was below the surface of the ground. A wire mesh was placed on top of each trap to prevent entry of predators into the trap. In addition each trap was covered by a alumminum plate supported 2 cm above the ground on sticks so that the traps would not collect rainwater.

Beetle Collection and Identification

On 6 May 1993 all traps were cleaned and set. Collection of beetles began on 13 May 1993 and continued weekly until 2 September 1993. The traps were left in the ground overwinter. The traps were cleaned and set on 6 May 1994 and weekly collections began on 13 May and continued to 2 September 1994. An additional collection was made on 16 September 1994 when the traps were being removed.

Beetles, along with hollow exoskeletons and elytra collected from each site were placed in an 8 oz. jar containing 70% ethanol. Each jar was labelled as to site and date of collection. The beetles were then brought back to the laboratory for identification.

The beetles were identified and classified using keys and descriptions of Lindroth (1969). Each beetle was pinned, identified and labelled as to species, sex, site and date collected.

Snow Sampling and Sulphate Concentration Analysis

Three samples of snow were collected from each site on 13 and 27 January 1994, 10 February 1994, 25 January 1995, 15 February 1995, and 8 March 1995. As in Hastings et al. (1972) a core sampler was used to collect the samples of snow. The sampler consisted of a 1 meter long plastic pipe with an internal diameter of 20 cm, and handles and a plunger at one end to remove the snow cores from the pipe.

Each sample was taken by pushing the sampler through the snow pack until it reached the ground. The collected sample was placed in a new, clean plastic bag and labelled as to site, date collected and depth of snow. Samples were stored in a freezer at below zero temperatures.

The melting and preparation of samples for analysis follows that outlined in the Ontario Ministry of the Environment and Energy Thunder Bay Laboratory Routine (1993). Snow samples were allowed to melt in clean plastic pails. The melted samples were stirred and two clean 90ml vials were used to collect a sample of the melted snow. The vials were capped, sealed and labelled as to site and date. All vials were stored at 4 degrees celsius in a refrigerator until analyzed.

The samples were then analyzed for sulphate by automated ion chromatography using the Dionex 2000i ion chromatography method at the Ontario Ministry of the Environment and Energy Laboratory in Thunder Bay. A detailed summary for the Dionex Method is given in the Ministry of the Environment and Energy Thunder Bay Laboratory Routine (1993).

Analysis of carabid community structure

Sorenson's measure, Shannon's index, Simpson's index and Shannon's evenness measure were used to analyze the carabid community structure in this study. The following is intended as a summary of these methods. For detailed descriptions refer to Begon et al. (1990), Krebs (1994), and Magurran (1988).

Sorenson's Measure

Sorenson's measure was used because all species count equally in the equation whether or not they are abundant or rare, and for

its simplicity in calculation. The version of Sorenson's measure used here was calculated using the equation

$$C= 2jN/ aN+bN$$

where an= the total number of individuals in site A, bN= the total number of individuals in site B, and jN= the sum of the lower of the two abundances recorded for a species found in both sites.

Simpson's Index

Simpson's diversity index was used to measure species dominance. It was chosen because it is commonly used in the literature, and it is simple to calculate. The index is calculated by using the equation

$$D= \text{Sum}[n_i(n-1)/N(N-1)]$$

Where n_i= the number of individuals in the i th species and N= the total number of individuals. The reciprocal form of the index was used to ensure the value of the index increased with increasing diversity.

Shannon's Index

Shannon's diversity index is a measure of species richness. It was chosen because it is commonly used in the literature, and because of its ease of calculation and inherent t test. The index is calculated using the equation

$$H= -\text{Sum}\ (p_i \ln p_i)$$

where pi= the proportional abundance of the ith species (ni/N).

The variance in diversity of a site can be estimated using the equation

$$\text{Var } H=[(\text{Sum } p_i \ln p_i)^2 - (\text{Sum } p_i \ln p_i)^2/N]-(S-1)/2N^2$$

A t test allows diversities of year 1 and year 2 to be compared using the equation

$$t= H_1-H_2/(\text{Var}H_1+\text{Var}H_2)^{0.5}$$

where H_1 is the diversity of year 1 and $\text{Var}H_1$ is its variance. The degrees of freedom are calculated using the equation

$$df= (\text{Var}H_1+\text{Var}H_2)^2/[(\text{Var } H_1)^2/N_1]+[(\text{Var } H_2)^2/N_2]$$

Shannon's Evenness Index

Species evenness was measured using Shannon's evenness measure. It was chosen because of its common use and its ease of calculation. The evenness measure is calculated using the equation

$$J= H/\ln S$$

were H is the Shannon index and S is the number of species.

Vegetation

Vegetation was sampled at each site using two 10 X 10 meter plots for trees and shrubs, while ten 1 X 1 meter plots were used for ground cover. The data was then grouped together to produce a list of plant species found at each site (Table 14).

Linear Regression and ANOVA

Linear Regression was used to correlate numbers of *Platynus*

decentis and *Pterostichus melanarius* collected with distance from the mill. Analysis of variance was used to examine the significance of any correlation between beetle numbers and distance.

RESULTS

Site 1

1971 vs. 1993

Seventeen carabid species were collected at site 1 in 1971, whereas 12 carabid species were collected in 1993 (Table 1: Table 2). Eight carabid species collected in 1971 were not collected in 1993: *Agonum errans*, *A. mannerheimi*, *A. piceolum*, *A. puncticeps*, *A. retractum*, *A. sordens*, *Harpalus fallax* and *Pterostichus lucublandus*. Two carabid species collected in 1993 at site 1 were not collected in 1971, these being *Pterostichus melanarius* and *Harpalus pleuriticus*. In 1971 *Platynus decentis* and *Pterostichus pensylvanicus* accounted for 23.4% and 11.1% of the catch. The remaining 15 species accounted for 65.5% of the catch. In 1993 *Pterostichus melanarius* dominated the catch composing 79.7% of the catch, while the remaining 11 species accounted for 20.3% of the catch.

Sorenson's measure calculated for site 1 1971 and 1993 was 0.15 (Table 4). The difference in the Shannon index calculated for 1971 (H'=2.4) and 1993 (H'=0.79) is significant at $p<.001$ (Table 5). Simpson's index calculated for 1971 (D=9) is 5.8 times greater than that calculated for 1993 (D=1.54) (Table 6). Shannon's evenness index calculated for 1971 (J=0.87) is 2.9 times greater than that calculated for 1993 (J=0.3) (Table 7).

1971 vs 1994

Seventeen carabid species were collected from site 1 in 1971, while 12 carabid species were collected in 1994 (Table 1: Table 3). Seven carabid species were collected at site 1 in 1971 which were not collected in 1994: *Agonum mannerheimi*, *A. piceolum*, *A. puncticeps*, *A. retractum*, *A. trigeminum*, *Pterostichus lucublandus*, and *Sphaeroderus nitidicollis*. Two carabid species collected in 1994 were not collected in 1971: *Loricera pilicornis* and *Pterostichus melanarius*. In 1971 *Platynus decentis* and *Pterostichus pensylvanicus* composed 23.4% and 11.1% of the catch at site 1. The remaining 15 species accounted for 65.5% of the catch. In 1994 *Pterostichus melanarius* composed 71.3% of the catch, while the remaining 11 species accounted for 28.7% of the catch.

Sorenson's measure calculated for site 1 1971 and 1994 was 0.18 (Table 4). The difference in the Shannon index calculated for 1971 (H'=2.4) and that for 1994 (H'=0.93) is significant at $p<.001$ (Table 5). Simpson's index calculated for 1971 (D=9) is 4.5 times greater than that calculated for 1994 (D=2) (Table 6). Shannon's evenness index calculated for 1971 (J=0.87) is 2.35 times greater than that calculated for 1994 (J=0.37) (Table 7).

1993 vs. 1994

Twelve carabid species were collected from site 1 in both 1993 and 1994 (Table 2: Table 3). Three carabid species were

collected at site 1 in 1993 which were not collected in 1994: *Agonum trigeminum*, *Harpalus pleuriticus* and *Sphaeroderus nitidicollis*. Three carabid species were collected in 1994 which were not collected in 1993: *Agonum errans*, *A. sordens* and *Loricera pilicornis*. *Pterostichus melanarius* composed the greatest proportion of the catch at site 1 in 1993 and 1994, 79.7% and 71.3% respectively.

Sorenson's measure calculated for site 1 1993 and 1994 was 0.86 (Table 4). The difference in Shannon's index calculated for 1993 (H'=0.79) and 1994 (H'=0.93) approaches significance at $0.02>p>0.01$ (Table 5). Simpson's index calculated for 1994 (D=2) is 1.29 times greater than that calculated for 1993 (D=1.54) (Table 6). Shannon's evenness index for 1994 (J=0.37) is 1.23 times greater than that calculated for 1993 (J=0.3) (Table 7).

Sulphate concentration at site 1: 1994 and 1995

In 1994 the sulphate concentration at site 1 ranged from 2.4 times the upper limit (7.27 ppm on 13 January) to 33.6 times the upper limit (100.82 ppm on 10 February) (Table 8). In 1995 the sulphate concentration ranged from 3.2 times greater than the upper limit (9.7 ppm on 25 January) to 5.6 times the upper limit (17.07 ppm on 8 March) (Table 8).

Site 2

1971 vs 1993

Thirteen carabid species were collected from site 2 in 1971, whereas twelve were collected in 1993 (Table 1: Table 2). Four carabid species were collected at site 2 in 1971 that were not collected in 1993: *Agonum piceolum, A. puncticeps, A. retractum* and *A. sordens*. Three carabid species were collected in 1993 that were not collected in 1971: *Harpalus pleuriticus, Loricera pilicornis* and *Pterostichus melanarius*. *Agonum sordens* and *Platynus decentis* composed 31.1% and 30.7% of the catch at site 2 in 1971. The remaining 10 species accounted for 38.2% of the catch. In 1993 *Pterostichus melanarius* accounted for 85.5% of the catch, while the remaining 11 species composed 14.5% of the catch.

Sorenson's measure calculated for 1971 and 1993 was 0.16 (Table 4). The difference in the Shannon index calculated for site 2 in 1971 (H'=1.7) and 1993 (H'=0.64) is significant at $p<.001$ (Table 5). Simpson's index for the carabids collected in 1971 (D=5.5) is 4 times that calculated for the carabids collected in 1993 (D=1.36) (Table 6). Shannon's evenness index calculated for 1971 (J=0.71) is 2.7 times greater than that calculated for 1993 (J=0.26) (Table 7).

1971 vs 1994

Thirteen carabid species were collected at site 2 in 1971, while 11 species were collected in 1994 (Table 1: Table 3). Four carabid species collected in 1971 were not collected in 1994: *Agonum piceolum, A. puncticeps, A. retractum* and *Pterostichus coracinus*. Two carabid species collected at site 2 in 1993 were not collected in 1971: *Loricera pilicornis* and *Pterostichus melanarius*. *Agonum sordens* and *Platynus decentis* respectively composed 31.1% and 30.7% of the catch at site 2 in 1971. The remaining 11 species composed the remaining 38.2% of the catch. In 1994 *Pterostichus melanarius* composed 78.7% of the catch. The remaining 10 species accounted for 21.3% of the catch.

Sorenson's measure calculated for 1971 and 1994 was 0.2 (Table 4). The difference in the Shannon index calculated for site 2 in 1971 (H'=1.7) and 1994 (H'=0.56) is significant at $p<.001$ (Table 5). Simpson's index calculated for the carabids collected in 1971 (D=5.5) is 2.1 times that calculated for the carabids collected in 1994 (D=2.6) (Table 6). Shannon's evenness index calculated for 1971 (J=0.71) is three times that calculated for the carabids collected in 1994 (J=0.23) (Table 7).

1993 vs. 1994

Twelve species of carabids were collected at site 2 in 1993, while 11 carabid species were collected in 1994 (Table 2: Table

3). Two carabid species collected in 1993 were not collected in 1994: *Harpalus pleuriticus* and *Pterostichus coracinus*. One carabid species collected in 1994 was not collected in 1993: *Agonum sordens*. *Pterostichus melanarius* accounted for the greatest proportion of the catch in both 1993 and 1994, 85.5% and 78.7% respectively.

Sorenson's measure calculated for 1993 and 1994 was 0.77 (Table 4). The difference between the Shannon index calculated for the carabids collected in 1993 (H'=0.64) and 1994 (H=0.56) is approaches significance at $0.2>p>0.1$ (Table 5). Simpson's index calculated for 1994 (D=2.6) is twice that calculated for 1993 (D=1.3) (Table 6). Shannon's evenness index calculated for 1993 (J=0.26) is 1.13 times greater than that calculated for 1994 (J=0.23) (Table 7).

Sulphate concentration at site 2: 1994 and 1995

In 1994 the sulphate concentration ranged from 3.5 times the upper limit (10.69 ppm on 13 January) to 10.43 times the upper limit (31.29 ppm on 10 February) (Table 8). In 1995 the sulphate concentration ranged from 3.45 times the upper limit (10.35 ppm on 25 January) to 5.66 times the upper limit (16.98 ppm on 8 March) (Table 8).

Site 3

1971 vs 1993

Fifteen carabid species were collected at site 3 in 1971, whereas eight carabid species were collected in 1993 (Table 1: Table 2). Nine carabid species collected at site 3 in 1971 were not collected in 1993: *Agonum errans, A. piceolum, A. puncticeps, A. retractum, A. sordens, A. trigeminum, Harpalus fallax, Pterostichus adstrictus* and *Sphaeroderus nitidicollis*. One carabid species was collected in 1993 that was not collected in 1971; *Pterostichus melanarius*. *Platynus decentis* and *Carabus nemoralis* composed 26.4% and 22.8% of the catch at site 3 in 1971. The remaining 13 carabid species accounted for 50.8% of the catch. In 1993 *Pterostichus melanarius* composed 81.5% of the catch. The remaining seven carabid species accounted for 18.5% of the catch.

Sorenson's measure calculated for 1971 and 1993 was 0.19 (Table 4). The difference in the Shannon index calculated for 1971 (H'=1.9) and 1993 (H'=0.72) is significant at $p<.001$ (Table 5). Simpson's index calculated for 1971 (D=8) is 5.4 times greater than that calculated for 1993 (D=1.48) (Table 6). Shannon's evenness index calculated for 1971 (J=0.72) is 2.1 times greater than that calculated for 1993 (J=0.34) (Table 7).

1971 vs. 1994

Sixteen carabid species were collected at site 3 in 1971, whereas

nine species were collected in 1994 (Table 1: Table 3). Nine species collected in 1971 were not collected in 1994: *Agonum errans, A. piceolum, A. puncticeps, A. retractum, A. sordens, A. trigeminum, Harpalus fallax, Pterostichus adstrictus* and *Sphaeroderus nitidicollis*. Two species collected in 1994 were not collected in 1971: *Loricera pilicornis* and *Pterostichus melanarius*. In 1971 *Platynus decentis* and *Carabus nemoralis* composed 26.4% and 22.8% of the catch respectively, while 14 species composed the remaining 50.8% of the catch. In 1994 *Pterostichus melanarius* composed 73.4% of the catch. The remaining eight carabid species accounted for 26.6% of the catch.

Sorenson's measure calculated for 1971 and 1994 was 0.25 (Table 4). The difference between the Shannon index calculated for 1971 (H'=1.9) and 1994 (H'=0.79) is significant at $p<.001$ (Table 5). Simpson's index calculated for 1971 (D=8) is 4.2 times greater than that calculated for 1994 (D=1.9) (Table 6). Shannon's evenness index calculated for 1971 (J=0.72) is twice that calculated for 1994 (J=0.36) (Table 7).

1993 vs. 1994

Eight carabid species were collected at site 3 in 1993, while nine were collected in 1994 (Table 2: Table 3). *Loricera pilicornis* was the only carabid species not to be collected from site 3 in both years. *Pterostichus melanarius* composed the

greatest proportion of the catch in 1993 and 1994, 81.5% and 73.4% respectively.

Sorenson's measure calculated for 1993 and 1994 was 0.68 (Table 4). The difference between the Shannon index calculated for 1993 (H'=0.72) and for 1994 (H'=0.79) approaches significance at 0.2>p>0.1 (Table 5). Simpson's index calculated for 1994 (D=1.9) is 1.28 times greater than that calculated for 1993 (D=1.48) (Table 6). Shannon's evenness index is calculated for 1994 (J=0.36) is 1.05 times greater than that calculated for 1993 (J=0.34) (Table 7).

Sulphate concentration at site 3: 1994 and 1995

In 1994 the sulphate concentration at site 3 ranged from 2.2 times the upper limit (6.85 ppm on 13 January) to 11.59 times the upper limit (34.78 ppm on 10 February) (Table 8). In 1995 the sulphate concentration ranged from 3.38 times the upper limit (10.14 ppm on 25 January) to 4.84 times the upper limit (14.52 ppm on 8 March) (Table 8).

Site 4

1971 vs. 1993

Nineteen carabid species were collected from site 4 in 1971, where as 10 carabid species were collected in 1993 (Table 1: Table 2). Twelve species collected in 1971 were not collected in 1993: *Agonum errans, A. mannerheimi, A. puncticeps, A. retractum,*

A. sordens, A. trigeminum, Harpalus fallax, Patrobus longicornis, Pterostichus coracinus, P. lucublandus, Scaphinotus bilobus and *Sphaeroderus nitidicollis*. Three carabid species collected in 1993 were not collected in 1971: *Harpalus pleuriticus, Loricera pilicornis* and *Pterostichus melanarius*. In 1971 *Platynus decentis* and *Carabus meander* accounted for 29.6% and 16.3% of the catch respectively. The remaining 54.4% of the catch was composed of 17 species. In 1993 *Pterostichus melanarius* accounted for 89.1% of the catch, while nine species composed the remaining 10.9% of the catch.

Sorenson's measure calculated for 1971 and 1993 was 0.11 (Table 4). The difference between the Shannon index calculated for 1971 (H'=2.2) and 1993 (H'=0.5) is significant at $p<.001$ (Table 5). Simpson's index calculated for 1971 (D=6.9) is 5.5 times greater than that calculated for 1993 (D=1.25) (Table 6). Shannon's evenness index for 1971 (J=0.77) is 3.5 times greater than that calculated for 1993 (J=0.22) (Table 7).

1971 vs. 1994

Nineteen carabid species were collected from site 2 in 1971, where as 11 carabid species were collected in 1994 (Table 1: Table 3). Eleven carabid species collected in 1971 were not collected in 1994: *Agonum errans, A. mannerheimi, A. punticeps, A. retractum, A. trigeminum, Harpalus fallax, Patrobus longicornus, Pterostichus coracinus, P. lucublandus, Scaphinotus*

bilobus and *Sphaeroderus nitidicollis*. Three carabid species collected in 1994 were not collected in 1971: *Harpalus affinis*, *Loricera pilicornis*, and *Pterostichus melanarius*. In 1971 *Platynus decentis* and *Carabus meander* composed 29.6% and 16.3% of the catch. The remaining 17 species composed 54.1% of the catch. In 1994 *Pterostichus melanarius* accounted for 84.2% of the catch. The remaining 10 species accounted for 15.8% of the catch.

Sorenson's measure calculated for 1971 and 1994 was 0.15 (Table 4). The difference in the Shannon index calculated for 1971 (H'=2.2) and 1994 (H'=0.71) is significant at $p<.001$ (Table 5). The Simpson index calculated for the carabids collected in 1971 (D=6.9) is 4.9 times greater than that calculated for 1994 (D=1.4) (Table 6). The Shannon evenness index calculated for 1971 (J=0.77) is 2.6 times greater than that calculated for 1994 (J=0.29) (Table 7).

1993 vs 1994

Ten species of carabid were collected in 1993 while 11 species were collected in 1994 (Table 2: Table 3). One carabid species was collected in 1993 which was not collected in 1994: *Harpalus pleuriticus*. Two carabid species were collected in 1994 which were not collected in 1993: *Agonum sordens* and *Harpalus affinis*. *Pterostichus melanarius* composed the greatest proportion of the catch at site 4 in 1993 and 1994, 89.1% and 84.2% respectively.

Sorenson's measure calculated for 1993 and 1994 was 0.88 (Table 4). The difference in the Shannon index calculated for 1993 (H'=0.5) and 1994 (H'=0.71) is significant at p<.001 (Table 5). Simpson's index calculated for 1994 (D=1.4) is 1.12 times greater than that calculated for 1993 (D=1.25) (Table 6). Shannon's evenness index calculated for 1994 (J=0.29) is 1.3 times greater than that calculated for 1993 (J=0.22) (Table 7).

Sulphate concentration at site 4: 1994 and 1995

In 1994 the sulphate concentration at site 4 ranged from 1.7 times the upper limit (5.26 ppm on 13 January) to 11.51 times the upper limit (34.53 ppm on 10 February) (Table 8). In 1995 the sulphate concentration ranged from 2.66 times the upper limit (7.99 ppm on 15 February) to 4.85 times the upper limit (14.56 ppm on 15 February) (Table 8).

Site 5

1971 vs. 1993

Seventeen species were collected from site 5 in 1971 while eleven species were collected from site 5 in 1993 (Table 1: Table 3). Ten carabid species collected in 1971 were not collected in 1993: *Agonum mannerheimi, A. puncticeps, A. retractum, A. sordens, A. trigeminum, Harpalus fallax, Patrobus longicornis, Pterostichus coracinus, Scaphinotus bilobus* and *Sphaeroderus nitidicollis*. Four species collected in 1993 were not collected in 1971:

Calosoma frigidum, Harpalus pleuriticus, Loricera pilicornis, and *Pterostichus melanarius.* In 1971 *Platynus decentis* and *Carabus nemoralis* composed 39.4% and 21.6% of the catch, while the remaining 15 species composed 39% of the catch. In 1993 *Pterostichus melanarius* composed 93.3% of the catch, while the remaining ten species composed 6.1% of the catch.

Sorenson's measure calculated for 1971 and 1993 was 0.068 (Table 4). The difference between the Shannon index calculated for 1971 (H'=2) and 1993 (H'=0.35) is significant at $p<.001$ (Table 5). The Simpson's index calculated for 1971 (D=4.4) is 3.8 times greater than that calculated for 1993 (D=1.14) (Table 6). Shannon's evenness index calculated for 1971 (J=0.69) is 4.9 times greater than that calculated for 1993 (J=.14) (Table 7).

1971 vs. 1994

Seventeen carabid species were collected at site 5 in 1971 while fifteen species were collected in 1994 (Table 1: Table 3). Eight carabid species were collected at site 5 in 1971 which were not collected in 1994: *Agonum mannerheimi, A. puncticeps, A. retractum, Harpalus fallax, Patrobus longicornis, Pterostichus coracinus, Scaphinotus bilobus,* and *Sphaeroderus nitidicollis.* Six carabid species were collected in 1994 which were not collected in 1971: *Agonum errans, Calasoma frigidum, Harpalus affinis, Harpalus pleuriticus, Loricera pilicornis,* and *Pterostichus melanarius.* In 1971 *Platynus decentis* and *Carabus*

nemoralis accounted for 39.4% and 21.6% of the catch respectively. The remaining 15 species accounted for 39% of the catch. In 1994 *Pterostichus melanarius* composed 92.5% of the catch, while the remaining 14 species accounted for 7.5% of the catch.

Sorenson's measure calculated for 1971 and 1994 was 0.078 (Table 4). The difference between Shannon's index calculated for 1971 (H'=2) and 1994 (H'=0.39) is significant at $p<.001$ (Table 5). Simpson's index calculated for 1971 (D=4.4) is 3.6 times greater than that calculated for 1994 (D=1.2) (Table 6). Shannon's evenness index calculated for 1971 (J=0.69) is 4.6 times greater than that for 1994 (J=0.15) (Table 7).

1993 vs 1994

Eleven carabid species were collected from site 5 in 1993 while fifteen species were collected in 1994 (Table 2: Table 3). Three carabid species were collected from site five in 1994 which were not collected in 1993: *Agonum errans, A. trigeminum,* and *Harpalus affinis*. *Pterostichus melanarius* accounted for 93.3% of the catch at site 5 in 1993 and 92.5% in 1994.

Sorenson's measure for site 5 1993 and 1994 was calculated to be 0.92 (Table 4). The difference in Shannon's index for 1993 (H'=0.35) and 1994 (H'=0.39) is significant at $p<.001$ (Table 5). Simpson's index calculated for 1994 (D=1.8) is 1.28 times greater

than that calculated for 1993 (D=1.4) (Table 6). Shannon's evenness index calculated for 1994 (J=0.15) is 1.07 times greater than that calculated for 1993 (J=0.14) (Table 7).

Sulphate concentration at site 5: 1994 and 1995

In 1994 the sulphate concentration at site 5 ranged from 2.2 times the upper limit (6.6 ppm on 13 January) to 10.18 times the upper limit (30.56 ppm on 10 February) (Table 8). In 1995 the sulphate concentration ranged from 1.2 times the upper limit (3.84 ppm on 25 January) to 5.2 times the upper limit (10.74 ppm on 8 March) (Table 8).

Reference Sites

1971

Seventeen carabid species were collected from the 1971 reference site (Table 1). *Platynus decentis* and *Carabus nemoralis* accounted for 31.4% and 27.9% of the catch respectively. The remaining 15 carabid species accounted for 59.3% of the catch.

Shannon's index was calculated to be 2.1 (Table 5). Simpson's index was calculated to be 2.7 (Table 6), while Shannon's evenness index was calculated to be 0.72 (Table 7).

1993 vs. 1994

Eleven carabid species were collected from the reference site in 1993, whereas 16 species were collected in 1994 (Table 2: Table

3). The five carabid species collected in 1994 which were not collected in 1993 were: *Agonum errans, A. sordens, Harpalus affinis, Pterostichus lucublandus* and *Scaphinotus bilobus*. In 1993 *Pterostichus coracinus* and *Pterostichus melanarius* composed 30.5% and 29.3% of the catch respectively. In 1994 *Pterostichus melanarius* and *Pterostichus coracinus* accounted for 29.5% and 18% of the catch respectively.

Sorenson's measure for the reference site 1993 and 1994 was 0.76. The difference between Shannon's index calculated for 1993 (H'=1.8) and 1994 (H'=2.2) approaches significance at 0.1>p>.05. Simpson's index calculated for 1994 (D=5.4) is 1.12 times greater than that calculated for 1993 (D=4.78) (Table 6). Shannon's evenness index was the same for 1993 and 1994 (J=0.75) (Table 7).

Sulphate concentration at the reference site: 1994 and 1995

In 1994 the sulphate concentration at the reference site ranged from 0.6 times the upper limit (1.8 ppm on 13 January) to the upper limit (3 ppm on 10 February) (Table 8). In 1995 the sulphate concentration ranged from .80 times the upper limit (2.41 ppm on 15 February) to 1.6 times the upper limit (5 ppm on 8 March) (Table 8).

Discussion

The purpose of this study was to re-examine the carabid community structure at five sites east of the Avenor kraft paper mill. The null hypothesis was that there would be no change in the carabid community structure between 1993 and 1994, but that there would be a change in the carabid community structure at the five sites east of the mill since 1971. All methods used to investigate community structure show a difference between 1971 and 1993/1994, as well as in the carabid community structure between 1993 and 1994.

The differences between 1993 and 1994 are relatively small in comparison to those between 1971 and 1993/1994. These differences can be attributed to the natural year to year fluctuations in animal numbers, the traps being left overwinter, trapping artifacts, and random events.

No natural population remains static from year to year in terms of numbers of individuals. Predation, fecundity, reproductive success, natality, mortality and weather are all factors which affect the number of individuals of a species present in a certain area from year to year. Therefore any observed change between any two years must take into account this natural fluctuation in numbers.

The second factor which may account for the observed differences between 1993 and 1994 is that the traps were left in the ground over winter. This means that there was less disturbance to the environment in the second year in comparison to the first year when the traps were installed. Moreover after one summer and one winter in the exact same locations the traps in the second year would be more a part of the environment than they would have been in the first year. This would result in the traps being more efficient in terms of being able to capture carabids in general and in particular smaller carabid adults. There is evidence which supports this: when there were changes in the number of species collected between 1993 and 1994, there were almost always an increase in the number of species collected between 1993 and 1994 (except at site 2)(Table 2: Table 3). This is seen not only in the sites east of the mill, but also at the reference site. Moreover there was an increase in the number of *Loricera pilicornis*, a small carabid 7-8 millimetres in length, and *Pterostichus pensylvanicus*, another small carabid 9-12 millimeters in length, collected at sites 1 to 5 between 1993 and 1994 (Table 2: Table 3).

The third factor which may account for the observed differences between 1993 and 1994 is the trapping artifact. A trapping artifact is what is observed in a community after a trapping season where the collected individuals are not returned to the environment. The number of individuals of a particular species

in the second year may be artificially low because of the inability for individuals of that species to fill the void left by the removal of the previous year's individuals. For example, there was a large number of *Pterostichus melanarius* collected from the five sites east of the mill in 1993 (Table 2). In 1994 the number of *P. melanarius* decreased at all sites, including the reference site. Moreover if the total number of individual carabids collected at each site in 1993 and 1994 were examined, one would see a decrease in numbers at all sites (Figure 7). Still more evidence is given by the fact that *Calathus ingratus* (Figure 8) and *Carabus meander* (Figure 9) decrease in the number of individuals collected between 1993 and 1994 at all sites.

The final factor which may account for the observed differences between 1993 and 1994 may simply be random events. The catchability of a carabid depends on whether or not it encounters a trap. In this study the trap mouth diameter was 11 cm, the distance between traps was 1-2m and the distance between rows was 7 m. Even though there were 100 traps per site, there was a large area within a site where a carabid could traverse and not encounter a trap. Random events may be the greatest factor accounting for differences in carabid numbers collected from a site from one year to the next.

The differences between 1971 and 1993/1994 are greater than those observed between 1993 and 1994. The differences between 1971 and

1993/1994 are attributed to the invasion of *Pterostichus melanarius* and the continued pollution of the environment by the Avenor kraft paper mill.

Pterostichus melanarius was introduced from Europe to both the west and east coasts of North America (Lindroth, 1969). *P. melanarius* is the most abundant and widely distributed of the 21 native European ground beetles established in western Canada (Spence and Spence, 1988). Its success is attributed to a combination of flexible habitat use, strong migratory abilities and moderate competitive effects (Spence and Spence, 1988). Spence and Spence (1988) found a weak negative effect of abundance of exotic species on the overall abundance of native species in anthropogenic habitats, and a rather stronger negative pairwise association between *P. melanarius* and the native *P. adstrictus*.

It is apparent that *Pterostichus melanarius* is the major cause of the differences between the present study (1993/1994) and the 1971 study.

If *P. melanarius* is removed from the present data set the number of total carabids collected at each site is well below those collected from each site in 1971 (Figure 10). Sorenson's measure calculated for 1971 and 1993/94 are much lower than those calculated for 1993 and 1994 (Table 9). The differences found

between the Shannon's index calculated for 1971 and 1993 are significant at $p<.001$, except for site 2 which is significant at $.05>p>.025$ (Table 10). The differences found between the Shannon's index calculated for 1971 and 1994 at sites 1 and 4 are significant at $p<.001$, for site 3 at $.025>p>.01$, while there was no difference for sites 2 and 5 (Table 10). Simpson's index is lower at all sites for 1993 in comparison to 1971 (Table 11). Simpson's index for 1994 is lower than that for 1971 at sites 1 to 3, virtually the same at site 4, and higher at site 5 (Table 11). Shannon's evenness index is lower at all sites for 1993 in comparison to 1971 (Table 12). Shannon's evenness index for 1994 is greater than those for 1971 at all sites except site 1 (Table 12).

Though the difference's between 1971 and the present study are greater when *Pterostichus melanarius* is left in the data set, the differences observed between 1971 and the present data set without *P. melanarius* suggests that *P. melanarius* not only is the cause of the observed differences in community structure, but through some factor has had an effect in changing the carabid community structure by its presence. This effect is shown best by examining the distribution of *Pterostichus melanarius* and that of *Platynus decentis* in the present study and in 1971.

In 1971 *Platynus decentis* was the most abundant carabid species collected at the five sites east of the Avenor kraft paper mill,

with its numbers increasing with distance from the mill (Figure 11). Linear regression on the data shows a correlation between the numbers of *P. decentis* collected with distance from the mill (Table 13). In the present study (1993/1994) *P. decentis* numbers are well below those of 1971. Furthermore *P. decentis* shows a decrease in numbers with distance from the mill, the exact opposite distribution that it showed in 1971 (Figure 11). Linear regression on the present data shows a correlation between *P. decentis* numbers and distance from the mill (Table 13). This change in the numbers of *P. decentis* may be caused by *Pterostichus melanarius* whose numbers increase with distance from the Avenor kraft paper mill (Figure 12), much the same as *P. decentis* did in 1971. Linear regression shows a correlation in the number of *P. melanarius* collected and distance from the mill. The above suggests that *P. melanarius* has had a negative effect on *P. decentis*.

Since the numbers of *Pterostichus melanarius* are so great at the sites east of the Avenor kraft paper mill in comparison to the reference site. Why then has *Pterostichus melanarius* been so successful east of the Avenor kraft paper mill?

All five sites exhibit concentrations of sulphate which are greater than the upper limit of concentration, 3ppm (Table 8). Furthermore sulphate concentrations increase with time at all sites (Figures 13, 14). Sulphate concentration is a measure of

the amount of sodium sulphate present. Sodium sulphate is a white particulate which is emitted from the Kraft mill flue stack as part of the krafting process. Kraft mill flue stacks also emit compounds of sulphur and nitrogen, and other compounds and elements (Bruly, 1974). Moreover, during the spring of 1995, between the time the snow melted and the first rain, a blanket of metallic coloured ash covered all of the sites east of the mill, with the greatest amount being observed at site 3. The ash, along with the other compounds and elements most likely increase with time, following the pattern observed with the sodium sulphate; which suggests that the sites east of the mill have been receiving and accumulating particulate fallout since the opening of the mill in 1964.

Changes in ecosystems which result from pollution are complex. However, the first parameter which generally seems to be affected is diversity (Woodwell, 1969). There is evidence of this type of change occurring in the area east of the mill. Shannon's index, Simpson's index and Shannon's evenness index together show a decrease in carabid diversity at the five sites east of the mill between 1971 and 1993/1994.

The species first affected by pollution are those with low reproductive rates, those linked by multiple bonds to other elements in the ecosystem and those with little ecological amplitude (Smith, 1971). There is evidence for this in the area

east of the mill. In the majority of carabid species activity is closely related to reproduction (Muller and Kashuba, 1986). *Carabus meander* had an activity period from mid/late May to mid August (Figure 15). *Carabus nemoralis* had an activity period from early May to mid/late July (Figure 16). *Platynus decentis* had an activity period from early/mid May to mid/late July (Figure 17). These species have relatively short activity/reproductive periods, especially in comparison to *Pterostichus melanarius* which showed an activity period which lasted from early May to at least mid September (Figures 1-6). Out of all the carabid species collected *P. melanarius* had the higher reproductive rate. Consequently *P. melanarius* would be the least affected by pollution, and the best able to colonize habitats left by the decrease in numbers of other carabid species. This would partially account for its numbers east of the mill.

The loss of structure in a polluted environment involves a shift away from complex arrangements of specialized species toward the generalists (Woodwell, 1969). Again there is evidence of this occurring in the area east of the mill. However, the initial difficulty encountered in studying many insects is the paucity of information on ecology and life history of the species (Buse, 1988), and carabids are no exception. A sharp classification of carabids into specialists and generalists is difficult and probably no carabid fits only into one classification. However,

all the species which decreased in numbers between 1971 and 1994, except *Carabus nemoralis*, may be considered habitat specialists in that they are all hydrophilic (Ball, 1963; Rivard, 1964; Lindroth, 1969; Barlow, 1970; and Niemela et al. 1992). *Carabus nemoralis* has been found in various habitats and is considered a habitat generalist (Rivard, 1964; Johnson et al. 1966; Lindroth, 1969; Martel et al. 1991). *Pterostichus melanarius* has also been found in various habitats and is considered a habitat generalist (Lindroth, 1969; Barlow, 1970; Martel et al. 1991; Niemela and Spence, 1991; Niemela and Halme, 1992; Carcamo et al. 1995). Therefore in terms of habitat use *P. melanarius* and *C. nemoralis* would be best suited to survive in a variety of environments and/or environments which are in constant change. This would, in part, account for the numbers of *P. melanarius* found east of the mill.

Sodium sulphate is an anhydrous particulate, and may be locking up moisture making it unavailable to carabids. Though there are no studies to support this, it is not out of the realm of possibility. A decrease in the water content of the soil may directly effect those species of carabid which are hydrophilic, and thereby cause a decrease in the numbers of these carabids. Moreover a change in the soil moisture regime and continued particulate fallout may also effect carabids indirectly by impacting on their food base. A decrease in soil moisture may affect the numbers of slugs and snails in a given area. In a

study on the effect of ash on soil fauna, earthworm mortality and reproduction were negatively affected by low amounts of ash, and fresh ash was shown to be toxic to soil fauna (Eijsackers et al. 1983). Though there are no studies in the area east of the mill which deal with slug, snail or earthworm numbers, the decrease in their numbers over the past 20 plus years due to continues pollution is not implausible. A decrease in the numbers and densities of slugs, snails and earthworms would impact greatly on carabids such as *Sphaeroderus nitidicollis* which is a specialized feeder of slugs and snails (Lindroth, 1969), and *Carabus nemoralis* which feeds upon worms and slugs (Glendenning, 1952). Such effects would not impact upon *Pterostichus melanarius* because it feeds on a variety of plant and animal matter (Johnson and Cameron, 1969; Thiele, 1977; Hagley et al. 1982; Ovaska and Smith, 1988). This might also account for the numbers of *P. melanarius* observed east of the mill.

Caution must be taken in accepting the conclusions about causes for the observed changes in the carabid community structure east of the Avenor kraft paper mill between 1971 and 1993/1994. The first reason is that since the same reference site used in 1971 could not be used in the present study, it is impossible to prove that the observed changes east of the mill are a result of the presence of *Pterostichus melanarius* or continuous pollution from the Avenor kraft paper mill, and not a result of natural changes in fauna. This also ties into the second reason which is stand

age. Even though the forest stands east of the mill are poplar dominated as they were in 1971, 20 plus years have passed, and the decrease in numbers of some of the species might be related to the aging of the stands. The third reason concerns random events. As discussed earlier the changes in community structure may be due to the randomness associated with using pitfall traps. However, due to the great numbers of *Pterostichus melanarius* collected east of the mill in comparison to the reference site, it can be concluded that the carabid community structure has changed in the area east of the Avenor kraft paper mill over the past 20 plus years, and that this change is probably due to the invasion of *Pterostichus melanarius* and its competitive advantages in a polluted environment.

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Table 1. Carabid species collected in the summer of 1971 from 5 sites east of the Avenor kraft paper mill in Thunder Bay Ontario (adapted from Freitag et al. 1973). Numbers in brackets represent percent of catch.

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Reference
Agonum errans Say	1 (0.3)	0	1 (0.2)	2 (0.4)	0	11 (1.3)
Agonum mannerheimi Dejean	3 (1.2)	0	0	11 (2.1)	26 (2.8)	4 (0.5)
Agonum piceolum Leconte	16 (6.3)	6 (2.1)	9 (1.6)	7 (1.3)	20 (2.2)	12 (1.5)
Agonum puncticeps Casey	3 (1.2)	6 (2.1)	1 (0.2)	1 (0.2)	3 (0.3)	0
Agonum retractum Leconte	16 (6.3)	6 (2.1)	9 (1.6)	7 (1.3)	20 (2.2)	12 (1.5)
Agonum sordens Kirby	24 (9.5)	87 (31.1)	11 (2)	11 (2.1)	18 (2)	12 (1.5)
Agonum trigeminum Lindroth	2 (0.8)	0	4 (0.7)	19 (3.6)	12 (1.3)	11 (1.3)
Calathus ingratus Dejean	14 (5.6)	5 (1.8)	25 (4.5)	3 (0.6)	8 (0.9)	4 (0.5)
Carabus meander Fischer	7 (2.8)	4 (1.4)	10 (1.8)	85 (16.3)	44 (4.8)	10 (1.2)
Carabus nemoralis Muller	19 (7.5)	36 (12.9)	127 (22.8)	61 (11.7)	199 (21.6)	228 (27.9)
Harpalus fallax	0	0	1 (0.2)	6 (1.1)	3 (0.3)	6 (0.7)

Leconte						
Patrobus longicornis Say	0	0	0	2 (0.4)	1 (0.1)	0
Platynus decentis Say	59 (23.4)	86 (30.7)	147 (26.4)	144 (29.6)	363 (39.4)	257 (31.4)
Pterostichus adstrictus Eschscholtz	9 (3.6)	4 (1.4)	66 (11.9)	52 (10)	40 (4.3)	178 (21.8)
Pterostichus coracinus Newman	21 (8.3)	13 (4.6)	24 (4.3)	35 (6.7)	88 (9.6)	27 (3.3)
Pterostichus lucublandis Say	1 (0.3)	0	0	1 (0.2)	0	6 (0.7)
Pterostichus pensylvanicus Leconte	28 (11.1)	9 (3.2)	75 (13.4)	38 (7.3)	31 (3.4)	17 (2.1)
Scaphinotus bilobus Say	0	0	0	1 (0.2)	3 (0.3)	2 (0.2)
Sphaeroderus nitidicollis Chevrolat	23 (9.1)	12 (4.3)	23 (4.1)	22 (4.2)	25 (2.7)	5 (0.6)
Synuchus impunctatus Say	6 (2.4)	6 (2.1)	23 (4.1)	14 (2.7)	17 (1.8)	16 (2)
Total for Sites	252	280	556	522	921	818

Table 2. Carabid species collected in the summer of 1993 from 5 sites east of the Avenor kraft paper mill in Thunder Bay Ontario. Numbers in brackets represents percent of catch.

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Ref.
Agonum trigeminum Lindroth	2 (0.2)	0	0	0	0	0
Calathus ingratus Dejean	14 (1.1)	17 (1.6)	56 (5.1)	37 (2.8)	16 (1)	16 (5.7)
Calosoma frigidum Kirby	0	0	0	0	1 (0.06)	2 (0.7)
Carabus meander Fischer	88 (7)	25 (2.4)	17 (1.5)	55 (4.1)	54 (3.1)	0
Carabus nemoralis Muller	34 (2.7)	42 (4.1)	96 (8.7)	10 (0.7)	17 (1)	13 (4.7)
Harpalus pleuriticus Kirby	2 (0.2)	2 (0.2)	0	1 (0.1)	1 (0.1)	1 (0.4)
Loricera pilicornis Fabricius	0	1 (0.1)	0	4 (0.3)	5 (0.3)	0
Platynus decentis Say	101 (8)	58 (5.6)	23 (2.1)	26 (1.9)	8 (0.5)	27 (9.7)
Pterostichus adstrictus Eschscholtz	4 (0.3)	2 (0.2)	0	3 (0.2)	1 (0.1)	17 (6.1)
Pterostichus coracinus Newman	3 (0.2)	2 (0.2)	2 (0.2)	0	0	85 (30.5)
Pterostichus melanarius (Illiger)	1001(79.7)	882(85.5)	899(81.5)	1192(89.1)	1649(93.3)	82 (29.3)
Pterostichus pensylvanicus Leconte	4 (0.3)	3 (0.3)	2 (0.2)	7 (0.5)	2 (0.1)	26 (9.3)

Sphaeroderus nitidicollis Chevrolat	1 (0.1)	1 (0.1)	0	0	0	5 (1.8)
Synuchus impunctatus Say	1 (0.1)	2 (0.2)	7 (0.6)	1 (0.1)	12 (0.7)	2 (0.7)
Total for Sites	**1255**	**1037**	**1102**	**1337**	**1766**	**279**

Table 3. Carabid species collected in the summer of 1994 from 5 sites east of the Avenor kraft paper mill in Thunder Bay Ontario. Numbers in brackets represent percent of catch.

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Reference
Agonum errans Say	8 (0.7)	0	0	0	1 (0.06)	1 (0.5)
Agonum sordens Say	11 (0.9)	2 (0.2)	0	4 (0.3)	7 (0.4)	6 (3)
Agonum trigeminum Lindroth	0	0	0	0	1 (0.06)	0
Calathus ingratus Dejean	4 (0.3)	5 (0.5)	13 (2)	20 (1.6)	6 (0.4)	9 (4.5)
Calosoma frigidum Kirby	0	0	0	0	2 (0.1)	2 (1)
Carabus meander Fischer	76 (6.5)	6 (0.7)	9 (1.4)	37 (3)	15 (0.9)	0
Carabus nemoralis Muller	31 (2.7)	33 (3.6)	86 (13.5)	13 (1.1)	34 (2.1)	8 (4)
Harpalus affinis Shrank	0	0	0	1 (0.08)	2 (0.1)	1 (0.5)
Harpalus pleuriticus Kirby	0	0	0	0	1 (0.06)	1 (0.5)
Loricera pilicornis Fabricius	35 (3)	18 (2)	9 (1.4)	31 (2.5)	8 (0.5)	0
Platynus decentis Say	138 (11.8)	91 (10)	10 (1.6)	34 (2.8)	2 (0.1)	18 (9)
Pterostichus adstrictus Eschscholtz	6 (0.5)	2 (0.2)	0	1 (0.08)	2 (0.1)	10 (5)
Pterostichus coracinus						

Newman	1 (0.09)	0	4 (0.6)	0	0	36 (18)
Pterostichus lucublandus Say	0	0	0	0	0	1 (0.5)
Pterostichus melanarius (Illiger)	828 (71.3)	713 (78.7)	467 (73.4)	1027(84.2)	1509(92.5)	59 (29.5)
Pterostichus pensylvanicus Leconte	18 (1.5)	24 (2.6)	18 (2.8)	44 (3.6)	15 (0.9)	30 (15)
Scaphinotus bilobus Say	0	0	0	0	0	3 (1.5)
Sphaeroderus nitidicollis Chevrolat	0	2 (0.2)	0	0	0	6 (3)
Synuchus impunctatus Say	6 (0.5)	10 (1.1)	20 (3.1)	7 (0.6)	26 (1.6)	9 (4.5)
Total for Sites	1162	906	636	1219	1631	200

Table 4. Sorenson's measure for carabids collected during the summers of 1971, 1993 and 1994 from 5 sites east of the Avenor kraft paper mill in Thunder Bay Ontario.

Site	1971/1993	1971/1994	1993/1994
1	0.15	0.18	0.86
2	0.16	0.2	0.77
3	0.19	0.25	0.68
4	0.11	0.15	0.88
5	0.068	0.078	0.92
Reference	0.25	0.26	0.76

Table 5. Shannon's index for carabids collected during the summers of 1971, 1993 and 1994 from 5 sites east of the Avenor kraft paper mill in Thunder Bay Ontario.

Site	1971	H 1993	1994	t	p
1	2.4	0.79		21.18	p<.001
2	1.7	0.64		13.36	p<.001
3	1.9	0.72		19.46	p<.001
4	2.2	0.5		32.5	p<.001
5	2	0.35		35.25	p<.001
Reference	-	-		-	-
1	2.4		0.93	19.6	p<.001
2	1.7		0.56	15.56	p<.001
3	1.9		0.79	12.44	p<.001
4	2.2		0.71	27.4	p<.001
5	2		0.39	32.6	p<.001
Reference	-		-	-	-
1		0.79	0.93	1.75	.05>P>.025
2		0.64	0.56	1.5	.2>p>.1
3		0.72	0.79	0.85	p>.1
4		0.5	0.71	4.06	p<.001
5		0.35	0.39	1	p>.1
Reference		1.8	2	2.98	0.1>p>0.05

Table 6. Simpson's index for carabids collected during the summers of 1971, 1993 and 1994 from 5 sites east of the Avenor kraft paper mill in Thunder Bay Ontario.

	Site					
	1	2	3	4	5	Reference
1971	0.87	0.71	0.72	0.77	0.69	0.72
1993	0.3	0.26	0.34	0.22	0.14	0.75
1994	0.37	0.23	0.36	0.29	0.15	0.75

Table 7. Shannon's evenness index for carabids collected during the summers of 1971, 1993, and 1994 from 5 sites east of the Avenor kraft paper mill in Thunder Bay Ontario.

	Site					
	1	2	3	4	5	Reference
1971	9	5.5	8	6.9	4.4	2.7
1993	1.54	1.36	1.48	1.25	1.14	4.78
1994	2	2.6	1.9	1.4	1.2	5.4

Table 8. Sulphate concentrations at 5 sites east of the Avenor kraft paper mill and a reference site to the west (X>3ppm = times greater than the upper limit).

Date	Site	Sulphate (ppm)	x > 3 ppm
1/13/94	1	7.27	2.4
		24.56	8.1
		7.98	2.6
	2	10.69	3.5
		13.06	4.3
		18.75	6.2
	3	6.85	2.2
		12.85	4.2
		7.64	2.5
	4	5.26	1.7
		8.34	2.7
	5	6.6	2.2
	Reference	2.1	0.7
		1.8	0.6
		2.5	0.83
1/27/94	1	20.21	6.7
		25.23	8.4
		20.29	6.7

	2	18.12	6.04
		16.83	5.6
		19.36	6.5
	3	20.59	6.8
		18.24	6.08
		23.76	7.9
	4	24.38	8.1
		20.09	6.6
		25.17	8.3
	5	16.3	5.4
		9.1	3
		20.78	6.9
	Reference	2.9	0.96
		2.7	0.9
		2	0.66
2/10/94	1	100.82	33.6
		77.66	25.6
		30.44	10.14

	2	22.51	7.5
		31.29	10.43
		24.97	8.32
	3	25.99	8.6
		23.62	7.8
		34.78	11.5
	4	34.53	11.5
		32.51	10.8
		19.11	6.3
	5	26.13	8.7
		24.46	8.1
		30.56	10.1
	Reference	3	/
		3.7	1.2
		2.8	0.93
1/25/95	1	11.22	3.7
		10.2	3.4
		9.71	3.2
	2	10.35	3.4

		10.68	3.5
		10.92	3.6
	3	12.98	4.3
		11.11	3.7
		10.14	3.3
	4	10.12	3.3
		9.24	3.08
		8.35	2.7
	5	3.84	1.2
		4.03	1.3
		5.67	1.8
	Reference	2.43	0.81
		2.47	0.82
		2.43	0.81
2/15/95	1	13.94	4.6
		12.73	4.2
		12.3	4.1
	2	13.52	4.5

		15.15	5.05
		11.86	3.9
	3	11.77	3.9
		11.22	3.7
		11.59	3.8
	4	9.52	3.1
		7.99	2.6
		14.56	4.8
	5	5.63	1.8
		6.47	2.1
		5.62	1.8
	Reference	2.46	0.82
		2.41	0.8
		2.41	0.8
3/8/95	1	14.88	4.9
		8.79	2.9
		17.07	5.6
	2	16.98	5.6
		14.42	4.8

	16.61	5.53
3	14.47	4.8
	12.46	4.1
	14.52	4.8
4	10.52	3.5
	12.17	4.05
	12.21	4.07
5	10.86	3.6
	10.74	3.5
	15.62	5.2
Reference	4.41	1.4
	5	1.6
	3.95	1.3

Table 9. Sorenson's measure without *Pterostichus melanarius* in the data set.

Site	1993/1994	1971/1993	1971/1994
1	0.77	0.44	0.45
2	0.66	0.49	0.46
3	0.51	0.41	0.29
4	0.65	0.3	0.34
5	0.54	0.16	0.16
Reference	0.64	0.24	0.24

Table 10. Shannon's index without *Pterostichus melanarius* in the data set.

Site	1971	H 1993	1994	t	p
1	2.4	1.4		12.59	p<.001
2	1.7	1.5		1.88	.05>p>.025
3	1.9	1.3		7.35	p<.001
4	2.2	1.5		8	p<.001
5	2	1.5		4.82	p<.001
Reference	-	-		-	-
1	2.4		1.5	10.19	p<.001
2	1.7		1.7	0.74	p>.1
3	1.9		1.7	2.1	.025>p>.01
4	2.2		1.8	5.8	p<.001
5	2		2	0	p>.1
Reference	-		-	-	-
1		1.4	1.5	1.25	p>.1
2		1.5	1.7	1.24	p>.1
3		1.3	1.7	3.78	p<.001
4		1.5	1.8	3.77	p<.001
5		1.5	2	4.12	p<.001
Reference		1.6	2.1	4	p<.001

Table 11. Simpson's index without *Pterostichus melanarius* in the data set.

	Site					
	1	2	3	4	5	Reference
1971	9	5.5	8	6.9	4.4	2.7
1993	1	1.03	1.01	1.04	1.02	1.03
1994	1.05	1.01	1.03	1.03	1.11	1.01

Table 12. Shannon's evenness index without *Pterostichus melanarius* in the data set.

	Site					
	1	2	3	4	5	Reference
1971	0.87	0.71	0.72	0.77	0.69	0.72
1993	0.58	0.62	0.68	0.68	0.65	0.72
1994	0.62	0.73	0.81	0.78	0.75	0.78

Table 13. R square, F and p values for *Platynus decentis* and *Pterostichus melanarius*.

	R Square	F	p
Platynus decentis			
1971	0.84	16.26	0.027
1993	0.79	11.42	0.043
1994	0.69	6.97	0.077
Pterostichus melanarius			
1993	0.74	8.57	0.061
1994	0.39	1.94	0.25

Table 14. Plant species collected at five sites east of the Avenor kraft paper mill and a reference site to the west.

Species	Site					
	1	2	3	4	5	Ref.
Abies balsamea					x	
Aralia nudicaulis			x			
Aster lanceleotus			x			
Aster macrophyllus	x		x		x	x
Aster puniceus		x	x			
Athyrium filix-femina	x	x		x		x
Betula papyrifera	x	x	x		x	x
Clintonia borealis	x	x				x
Corylus cornuta	x	x		x	x	
Epilobium angustifolium	x	x	x		x	
Equisetum arvense	x	x			x	
Equisetum sylvaticum	x	x		x		x
Fraxinus nigra			x			
Mianthemum canadense		x	x	x	x	
Populus tremuloides	x	x	x	x	x	x
Prenanthes alba			x			
Pteridium aquilinum	x		x			

Pyrola sp.		x	x	x		
Ranunculus sp.					x	
Rubus parviflorus			x			
Rubus pubescens	x				x	x
Salix sp.	x			x	x	
Solidago sp.		x	x	x	x	
Vicia americana			x			
Total Number of Species	**12**	**12**	**13**	**10**	**12**	**7**

Figure 1. Activity/Abundance diagram for *Pterostichus melanarius* collected at site 1.

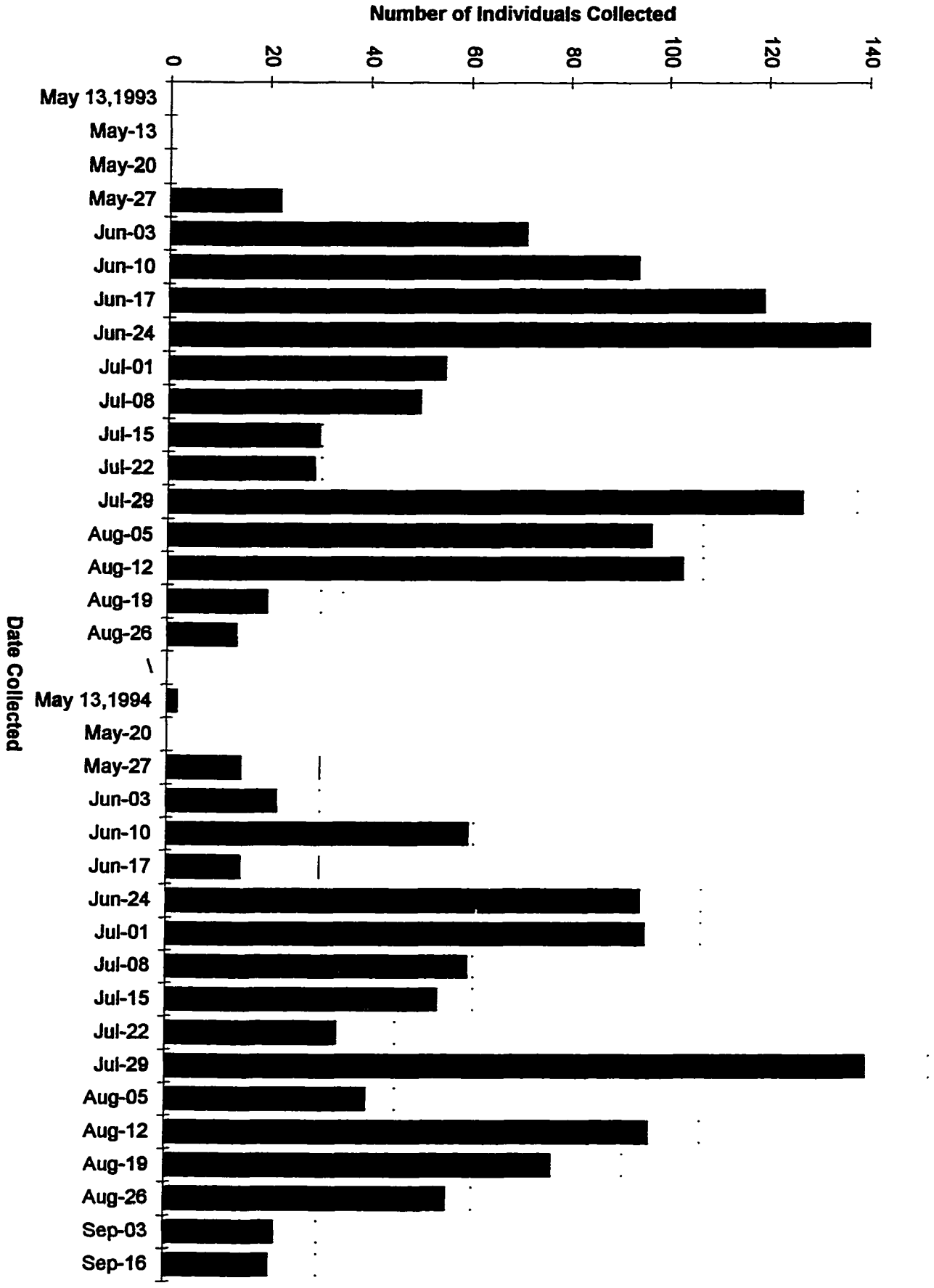


Figure 2. Activity/Abundance diagram for *Pterostichus melanarius* collected at site 2.

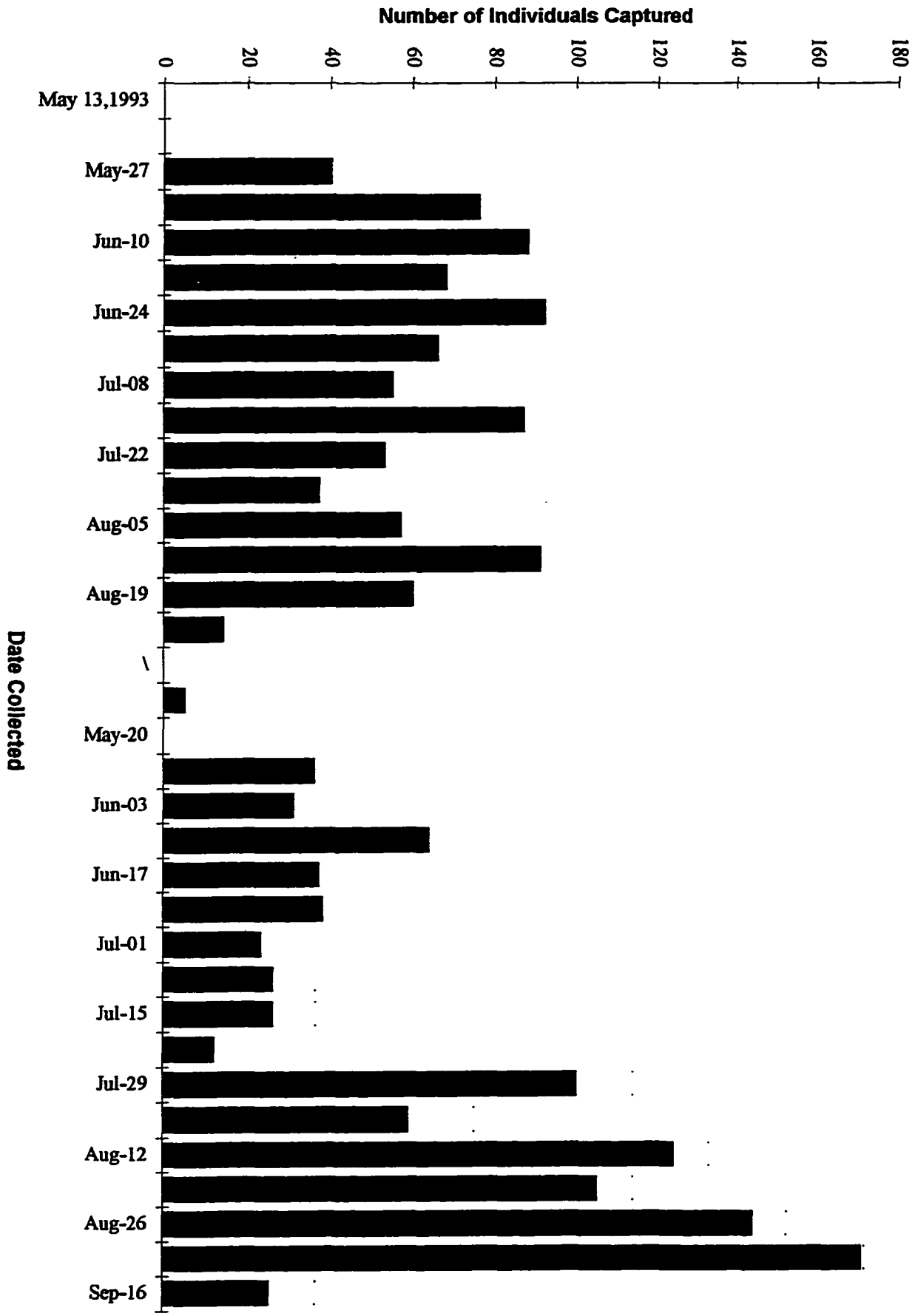


Figure 3. Activity/Abundance diagram for *Pterostichus melanarius* collected at site 3.

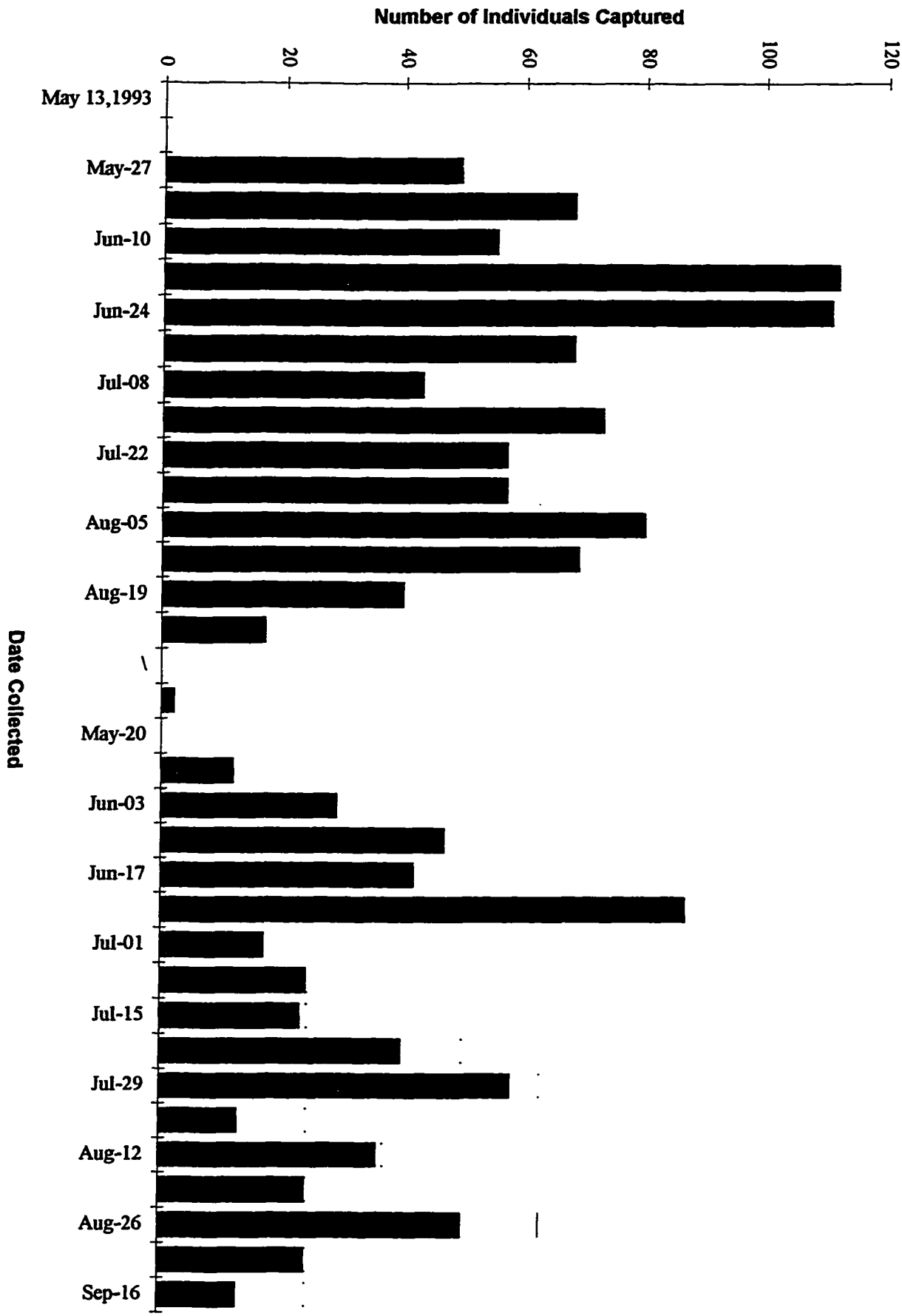


Figure 4. Activity/Abundance diagram for *Pterostichus melanarius* collected at site 4.

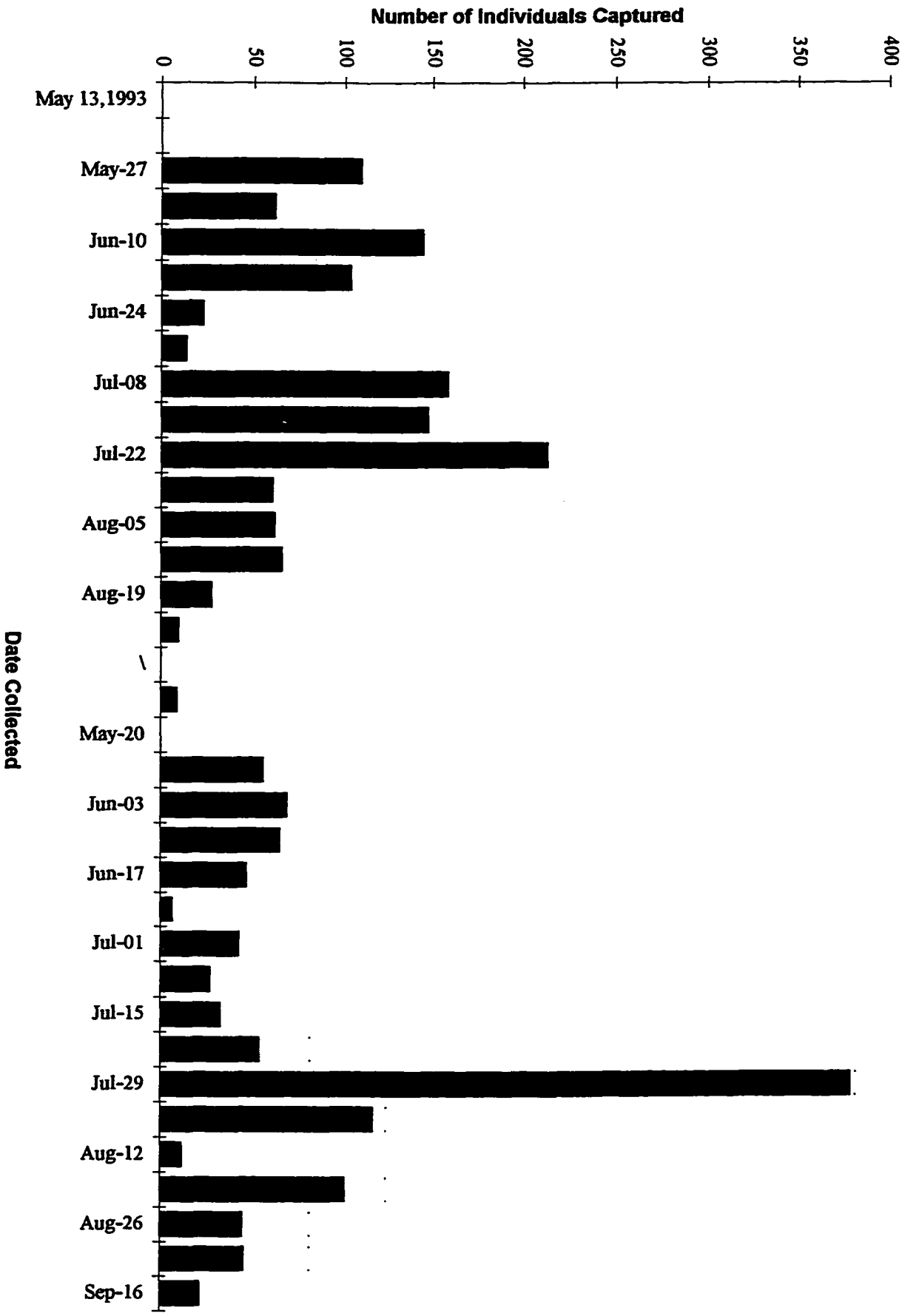


Figure 5. Activity/Abundance diagram for *Pterostichus melanarius* collected at site 5.

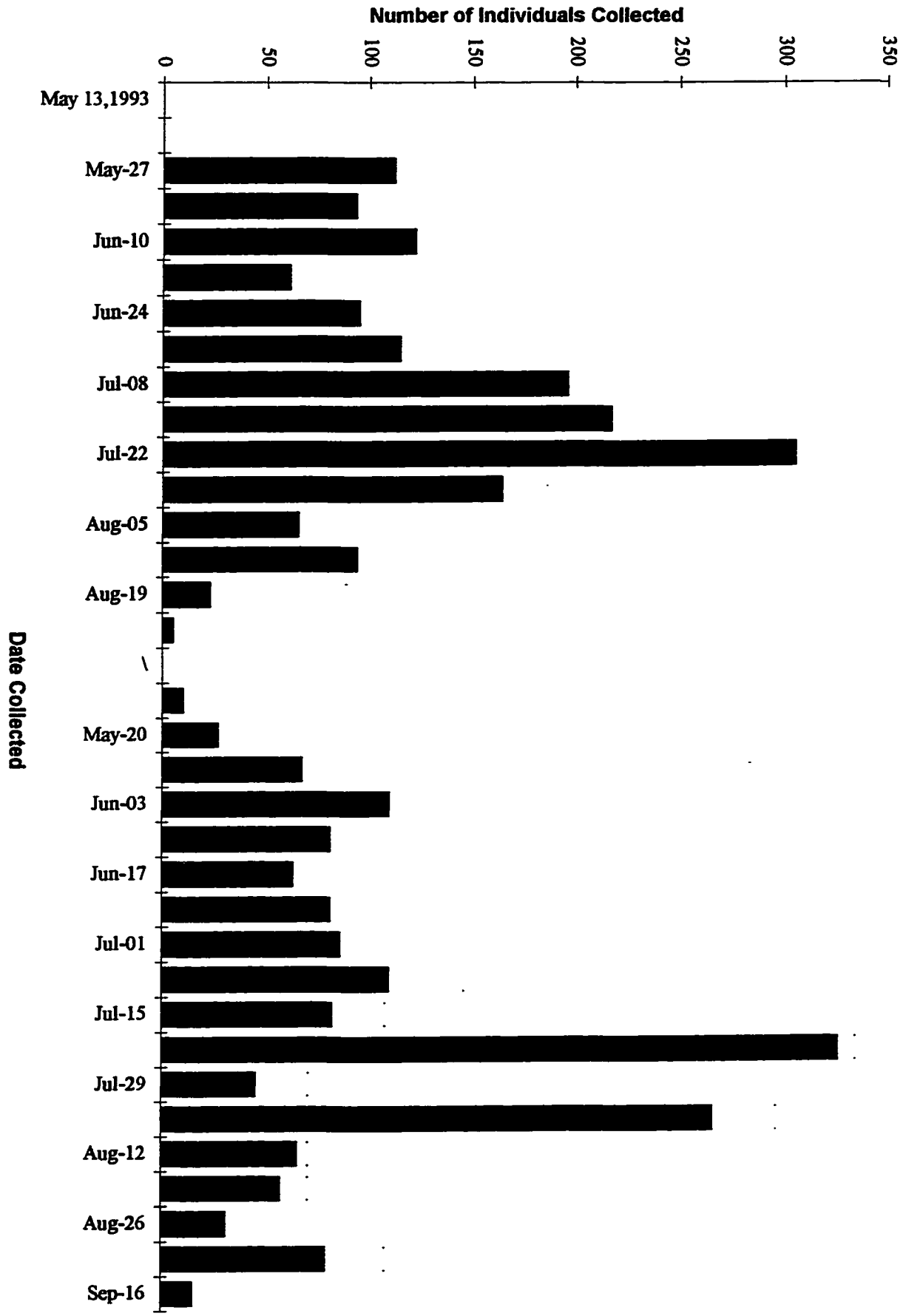


Figure 6. Activity/Abundance diagram for *Pterostichus melanarius* collected at the reference site.

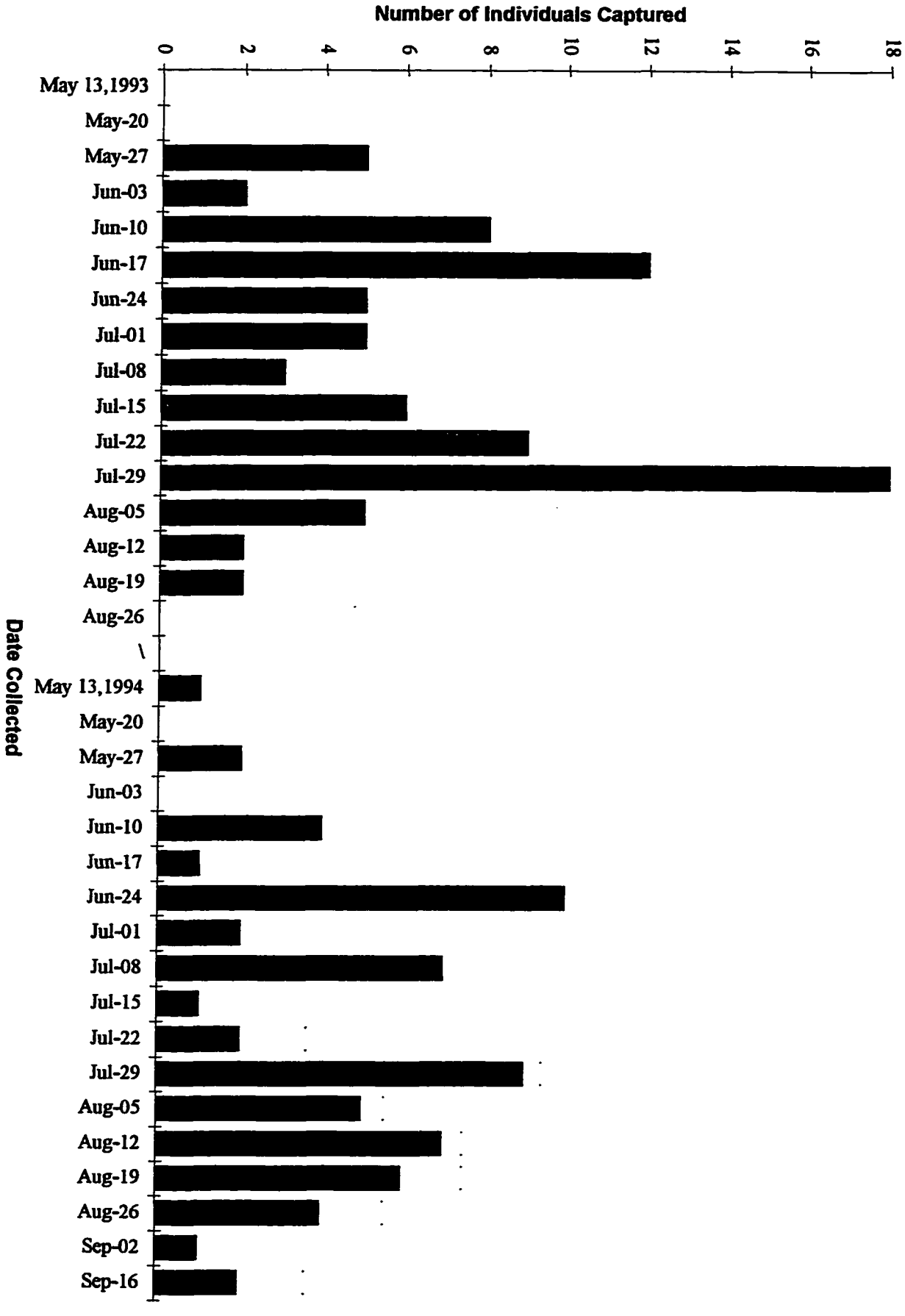


Figure 7. Total carabid individual/trap/year collected in 1993 and 1994 from each site (site 6=reference site).

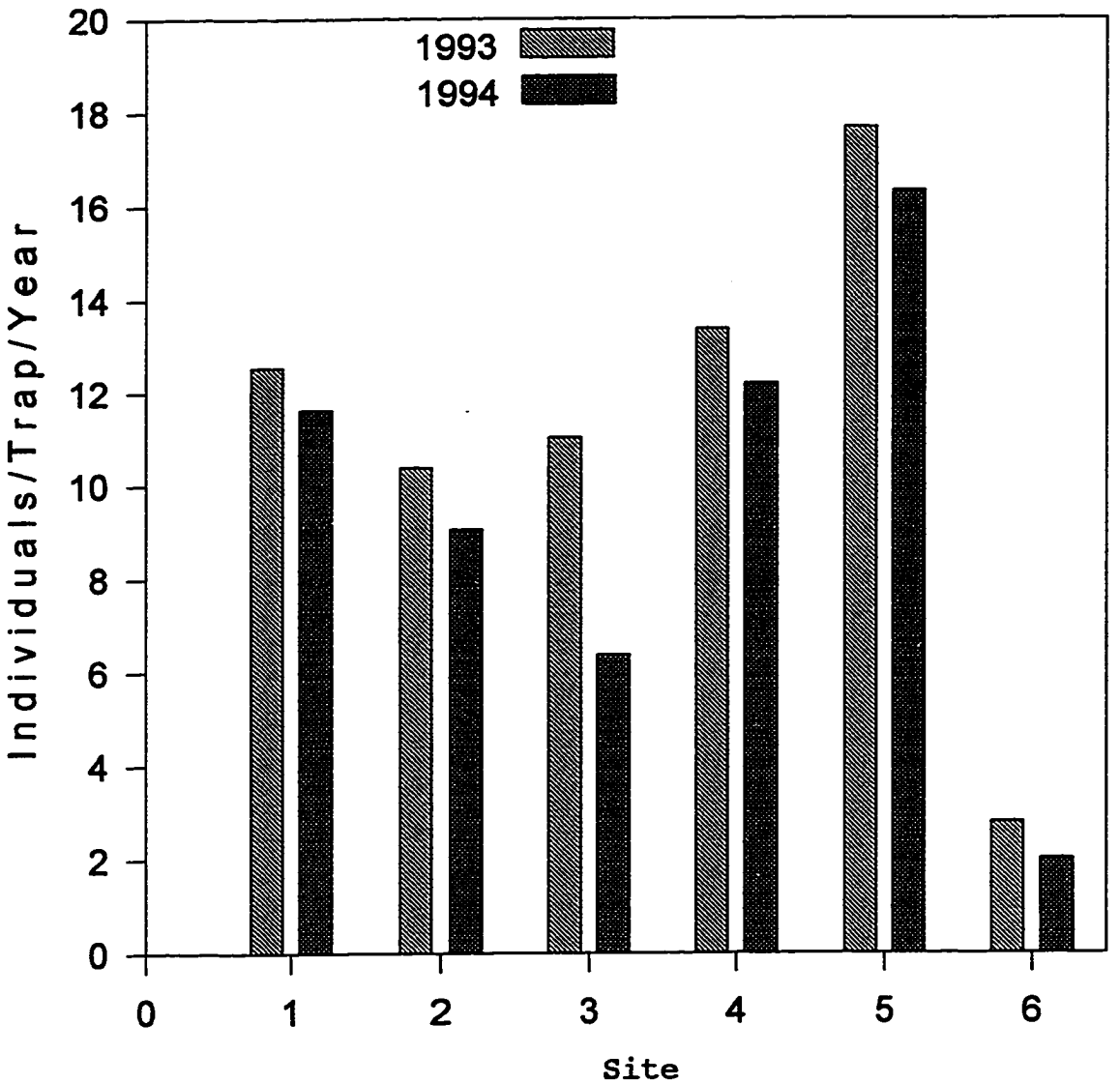


Figure 8. Individuals/trap/year collected from each site of *Calathus ingratus* in 1993 and 1994 (site 6=reference site).

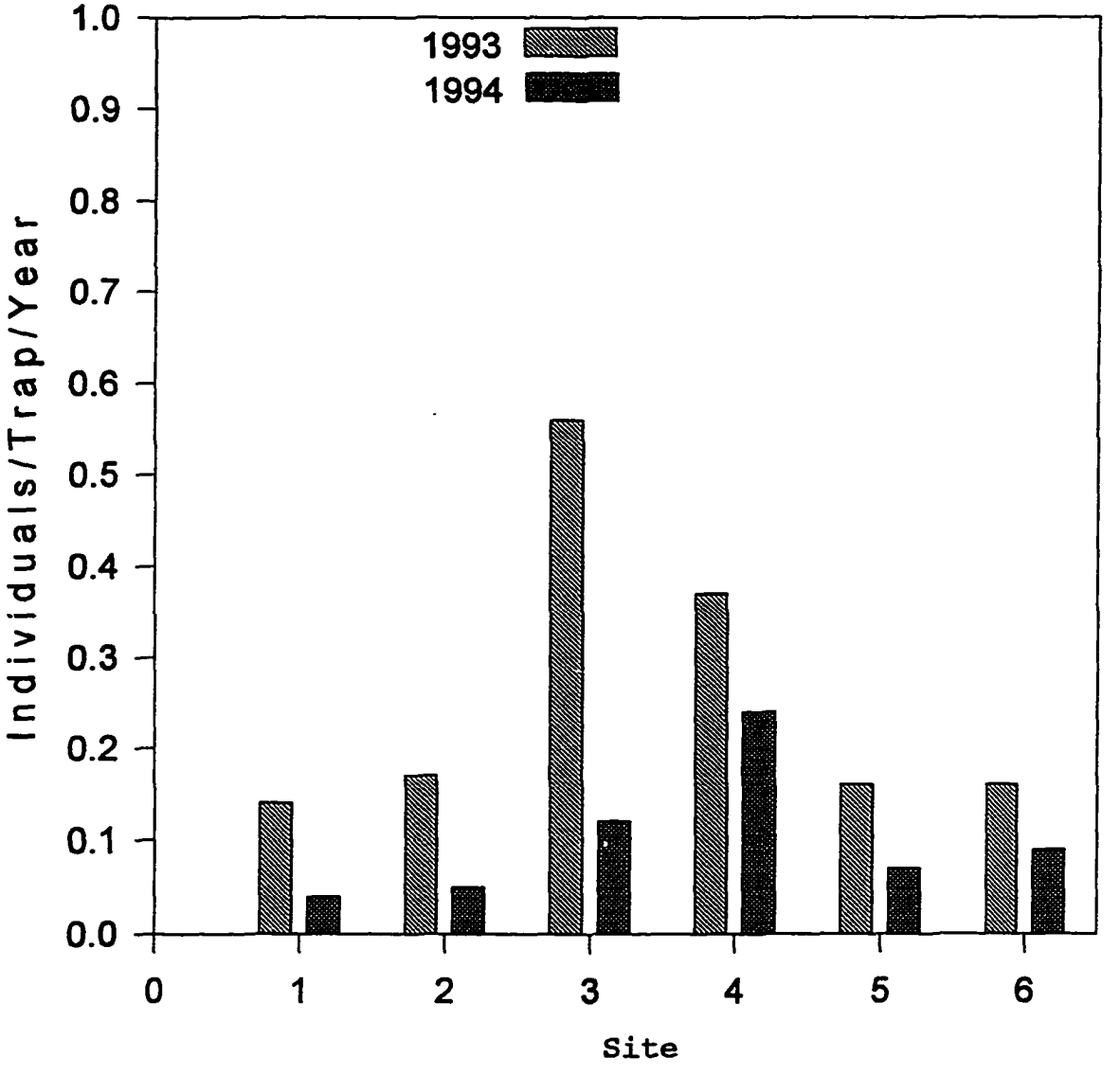


Figure 9. Individuals/trap/year collected from each site of *Carabus meander* in 1993 and 1994 (site 6=reference site).

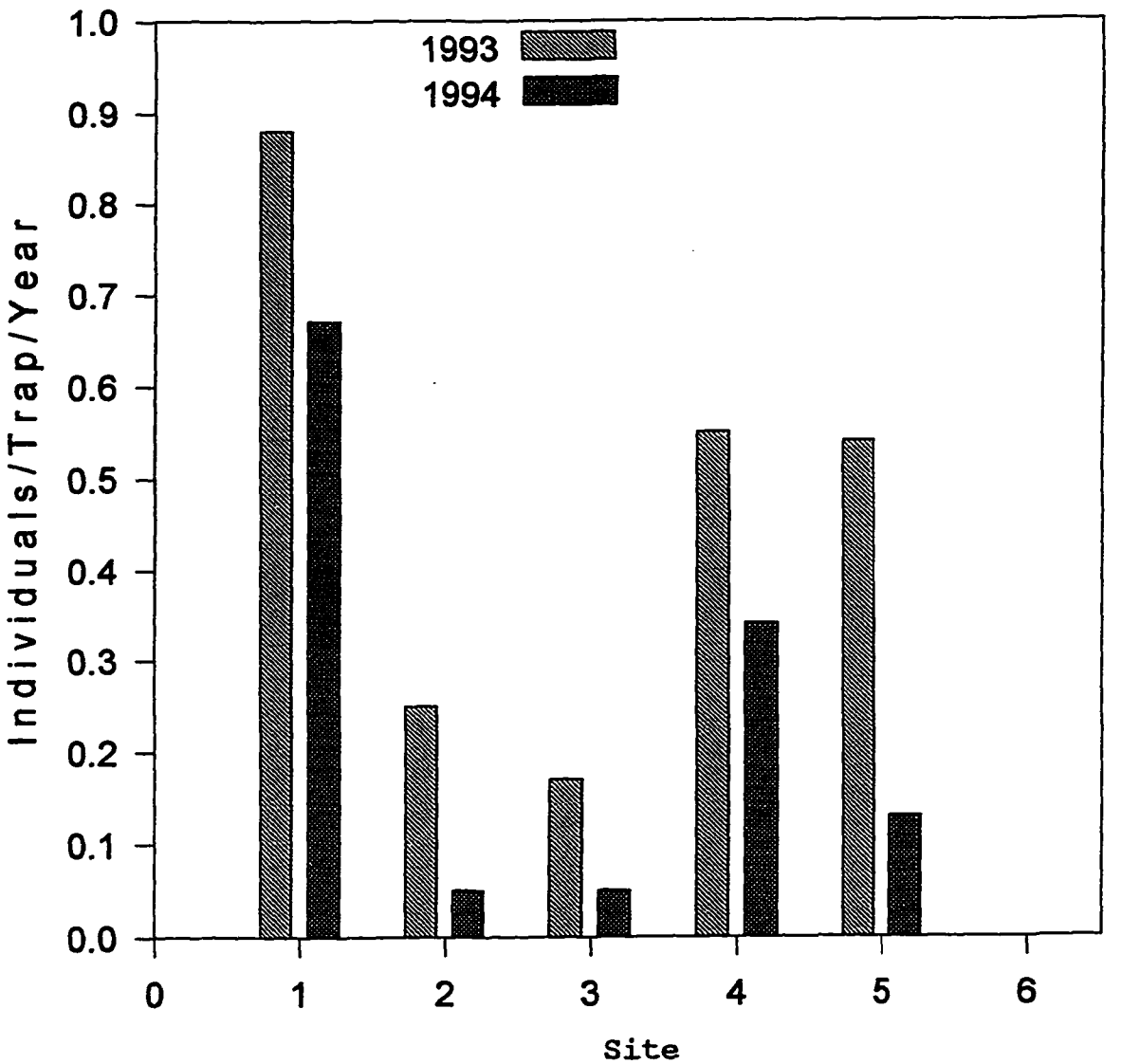


Figure 10. Total carabid individuals/trap/year collected in 1971, 1993 and 1994 (1993 and 1994 data is minus *Pterostichus melanarius*).

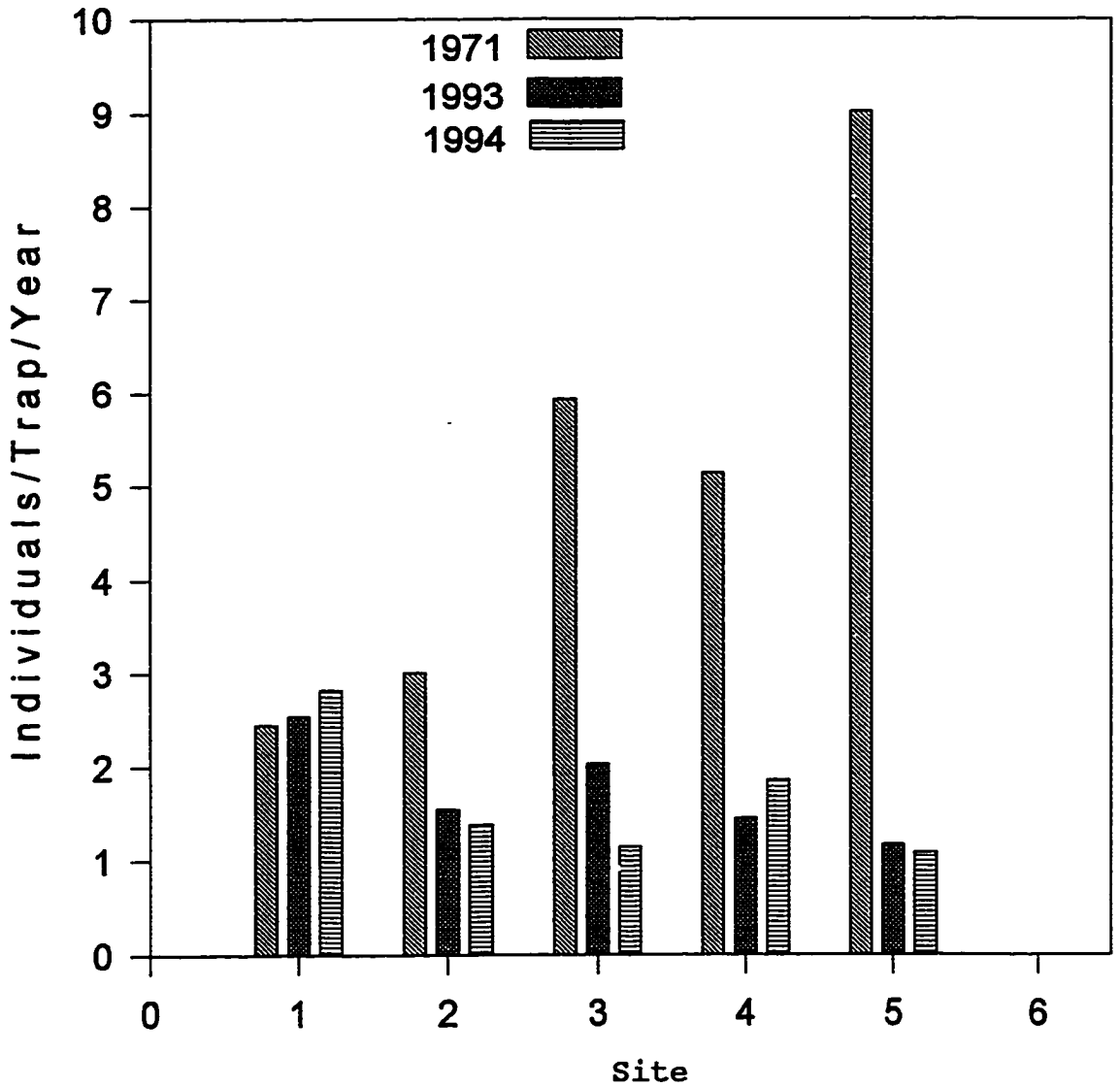


Figure 11. Number of individuals/trap/year for *Platynus decentis* collected in 1971, 1993 and 1994 vs. distance from the Avenor kraft paper mill in Thunder Bay Ontario.

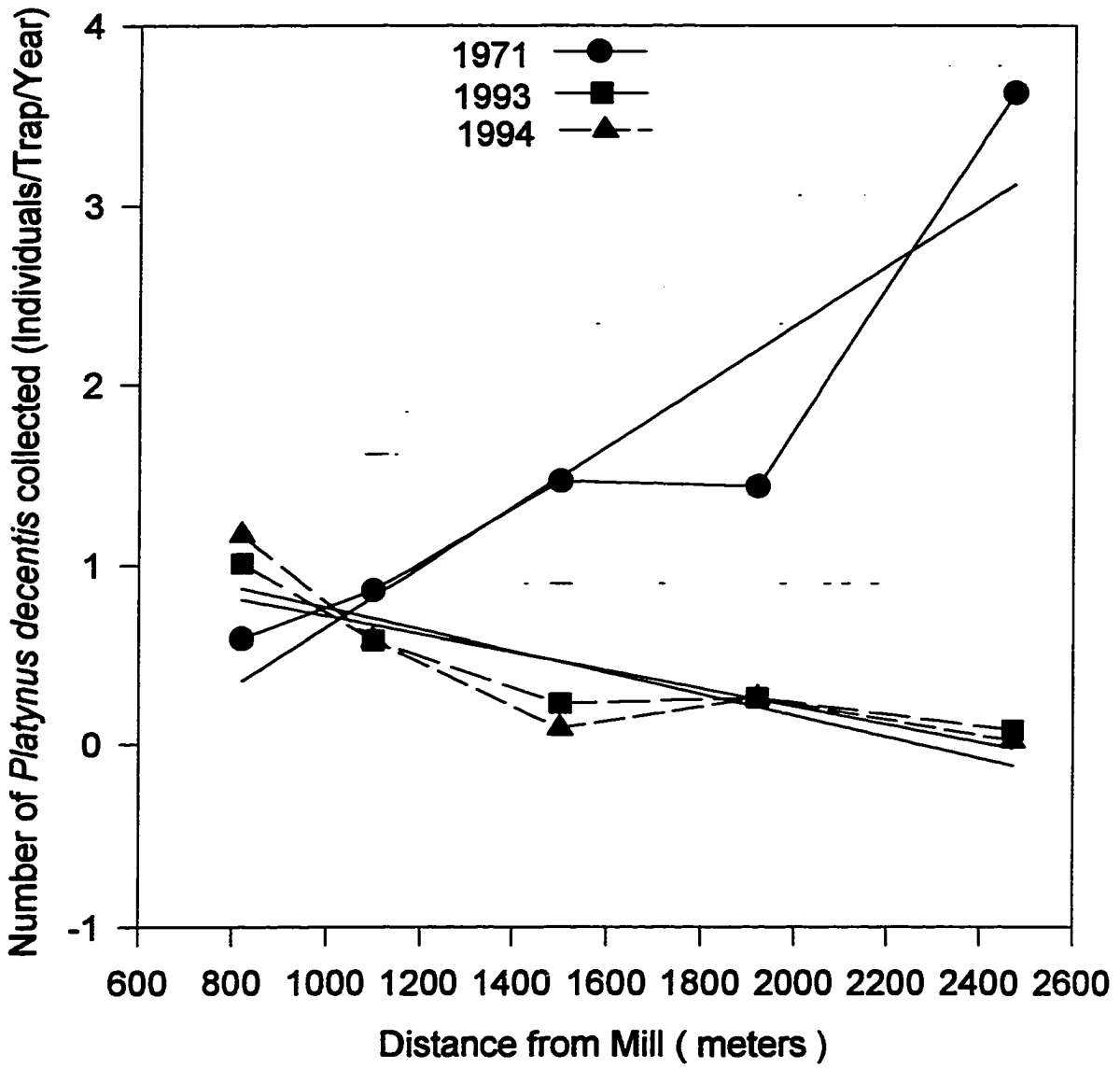


Figure 12. Number of individuals/trap/year for *Pterostichus melanarius* collected in 1993 and 1994 vs. distance from the Avenor kraft paper mill in Thunder Bay Ontario.

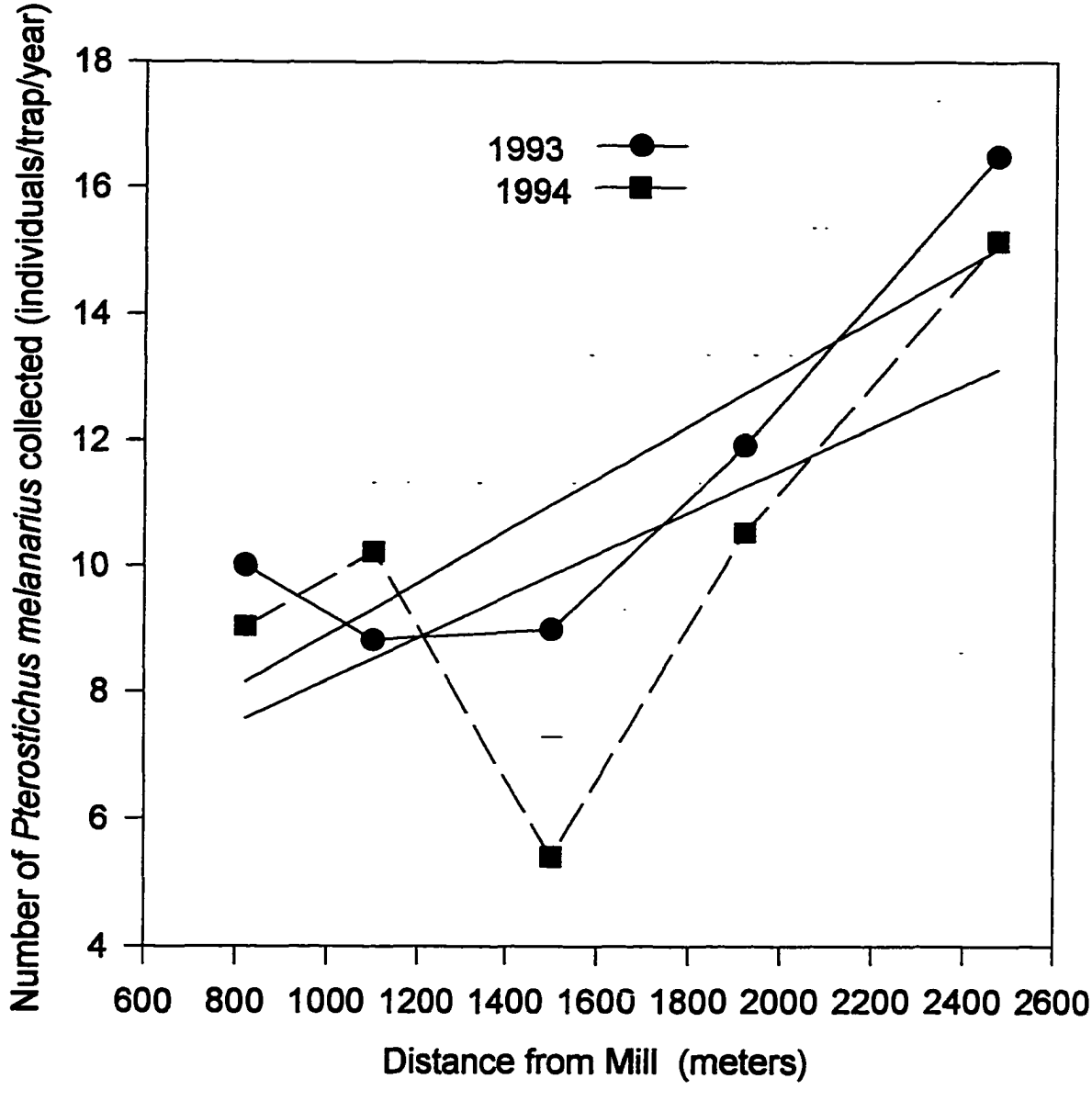


Figure 13. Mean sulphate concentration (ppm) found in snow samples collected from each site in 1994 (site 6=reference site). Solid line indicates the upper limit of concentration.

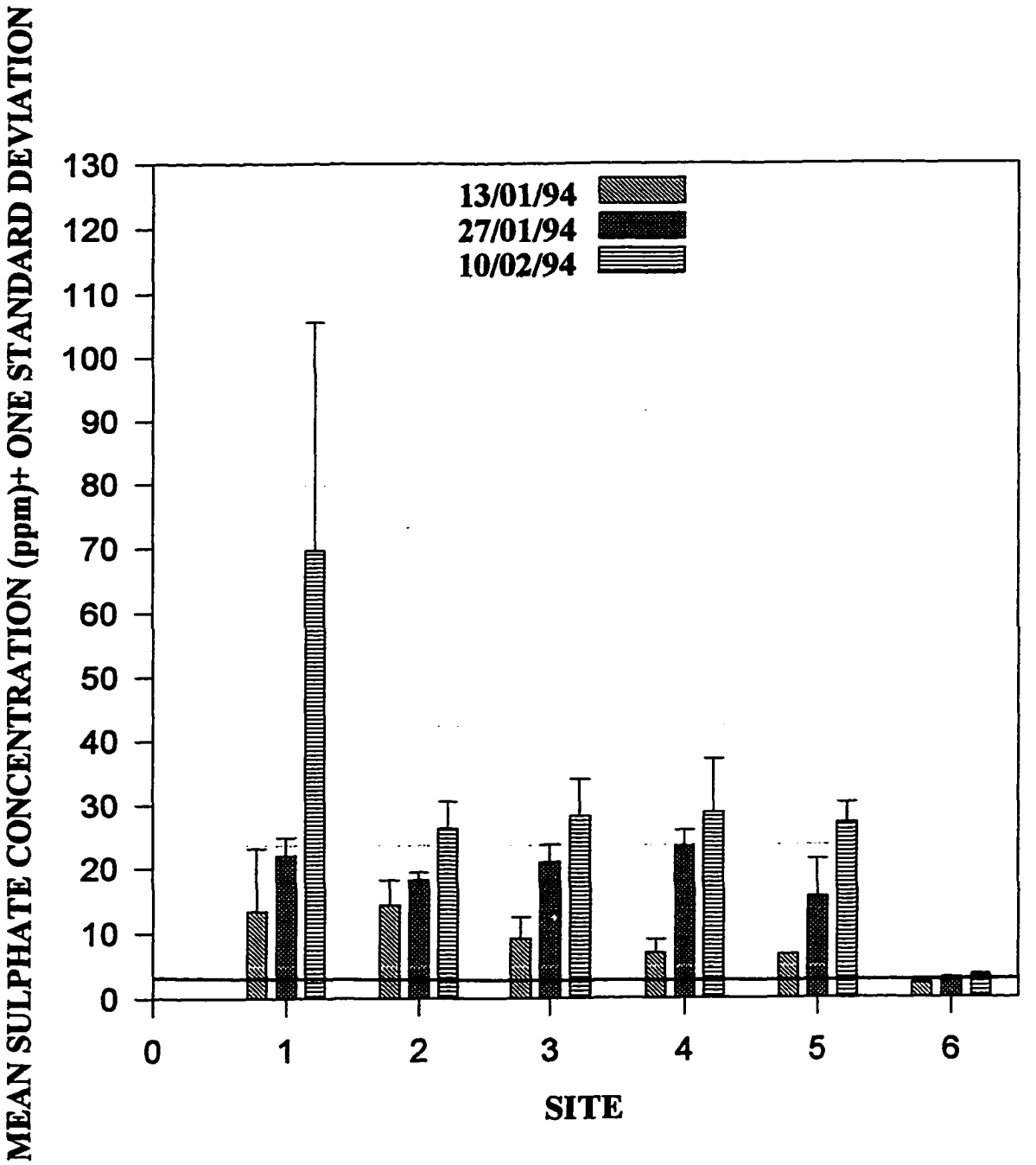


Figure 14. Mean sulphate concentration (ppm) found in snow samples collected from each site in 1995 (site 6=reference site). Solid line indicates the upper limit of concentration.

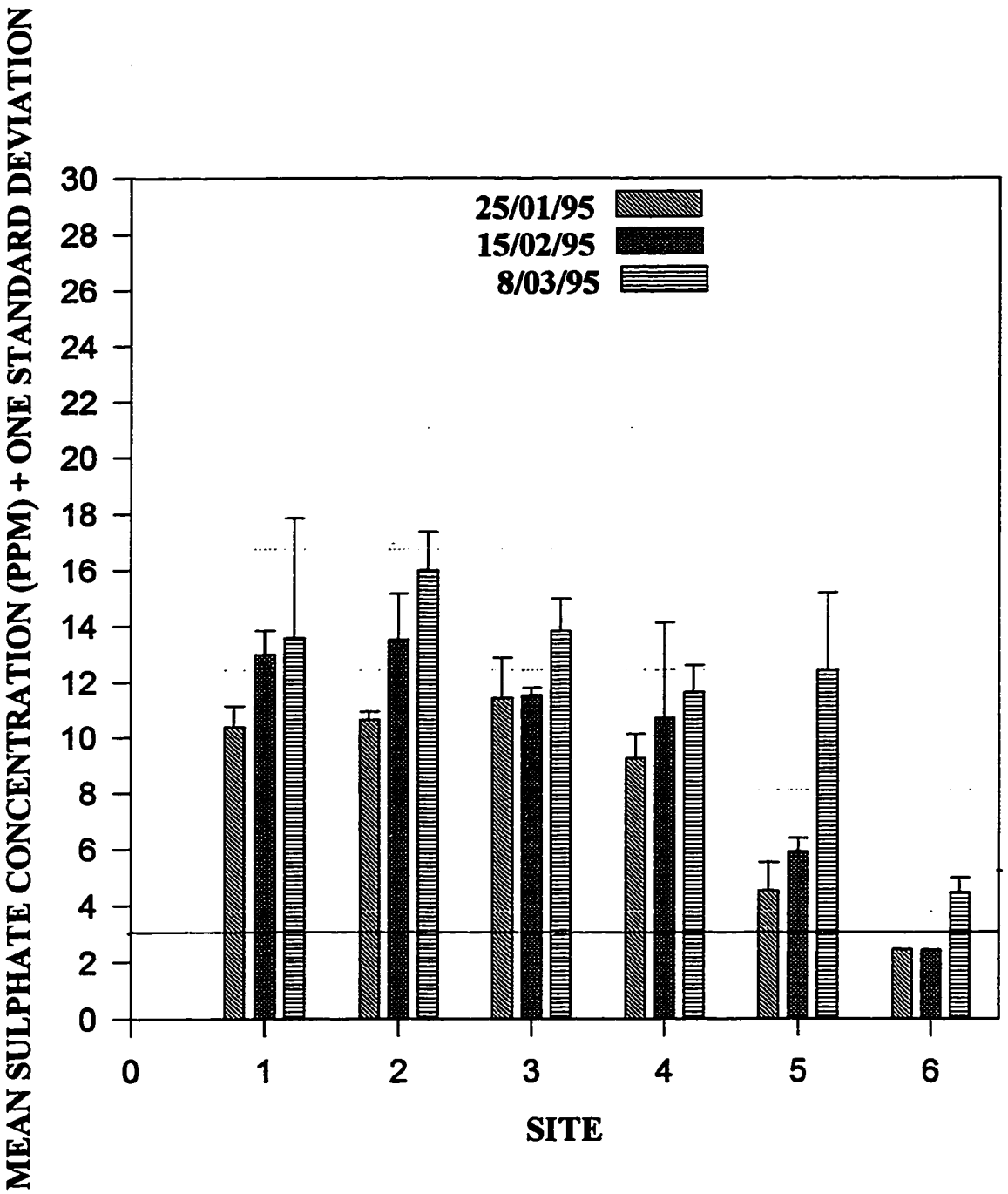


Figure 15. Activity/Abundance diagram for *Carabus meander* collected at site 1 in 1993 and 1994.

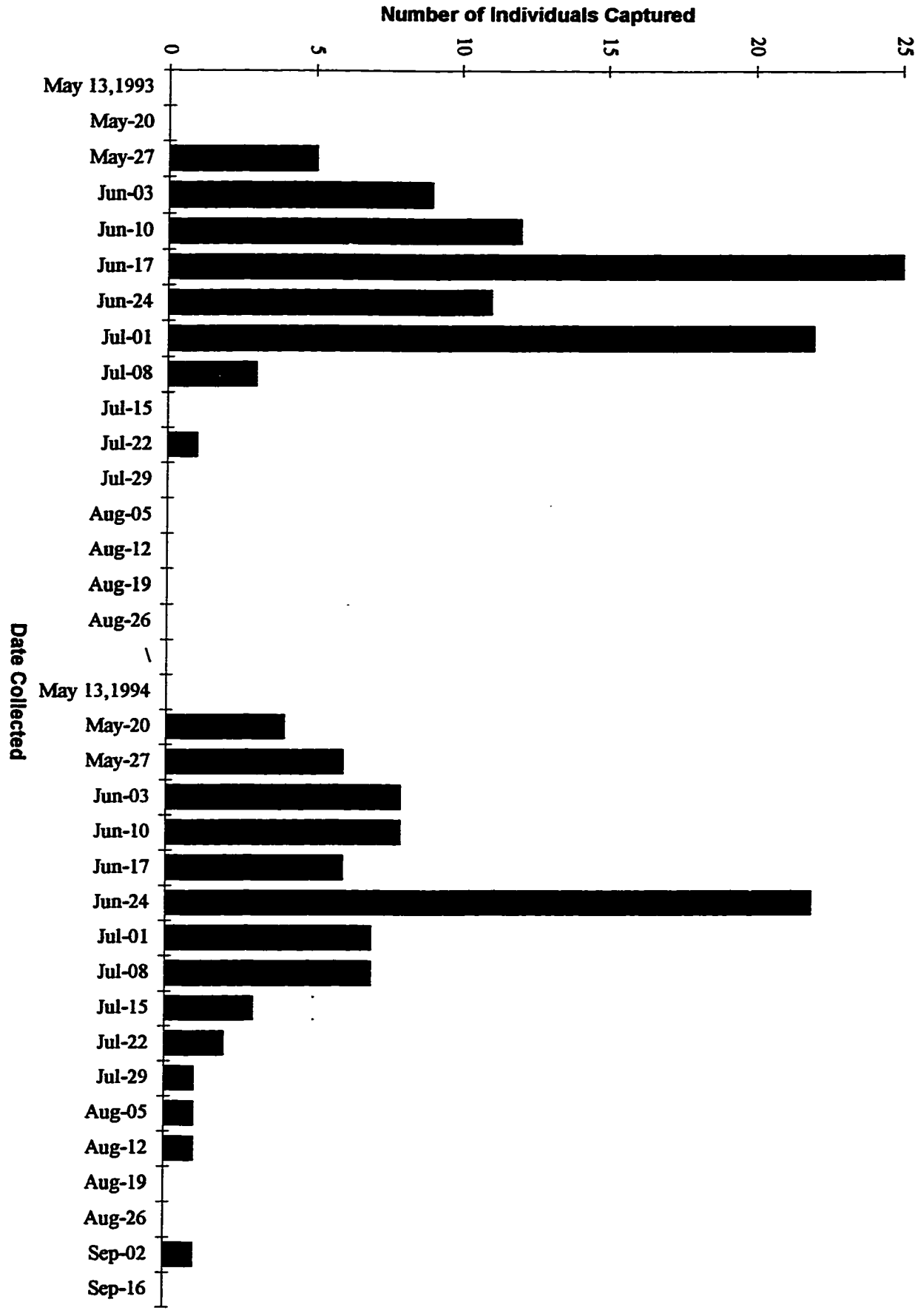


Figure 16. Activity/Abundance diagram for *Carabus nemoralis* collected at site 3 in 1993 and 1994.

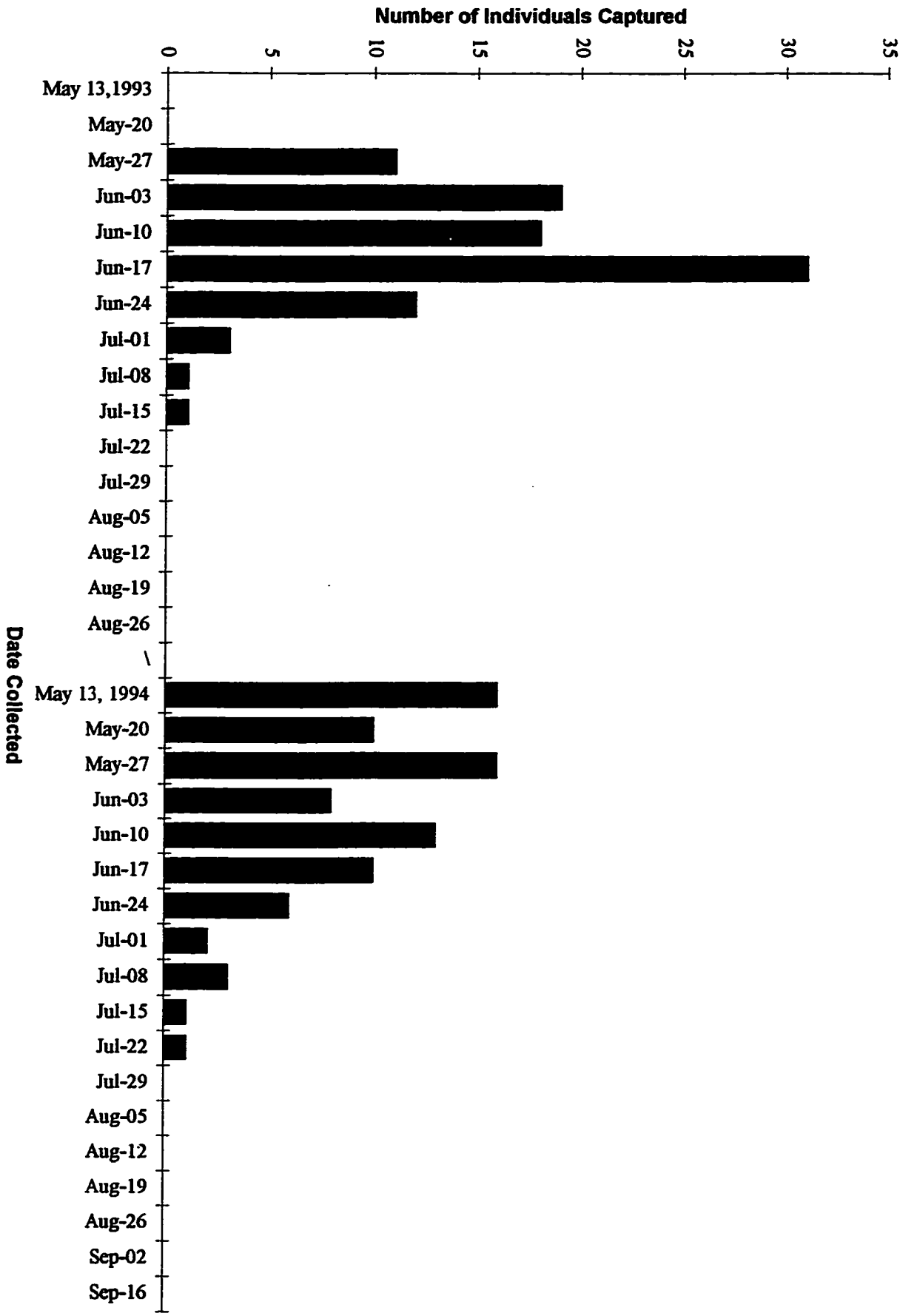


Figure 17. Activity/Abundance diagram for *Platynus decentis* collected at site 1 in 1993 and 1994.

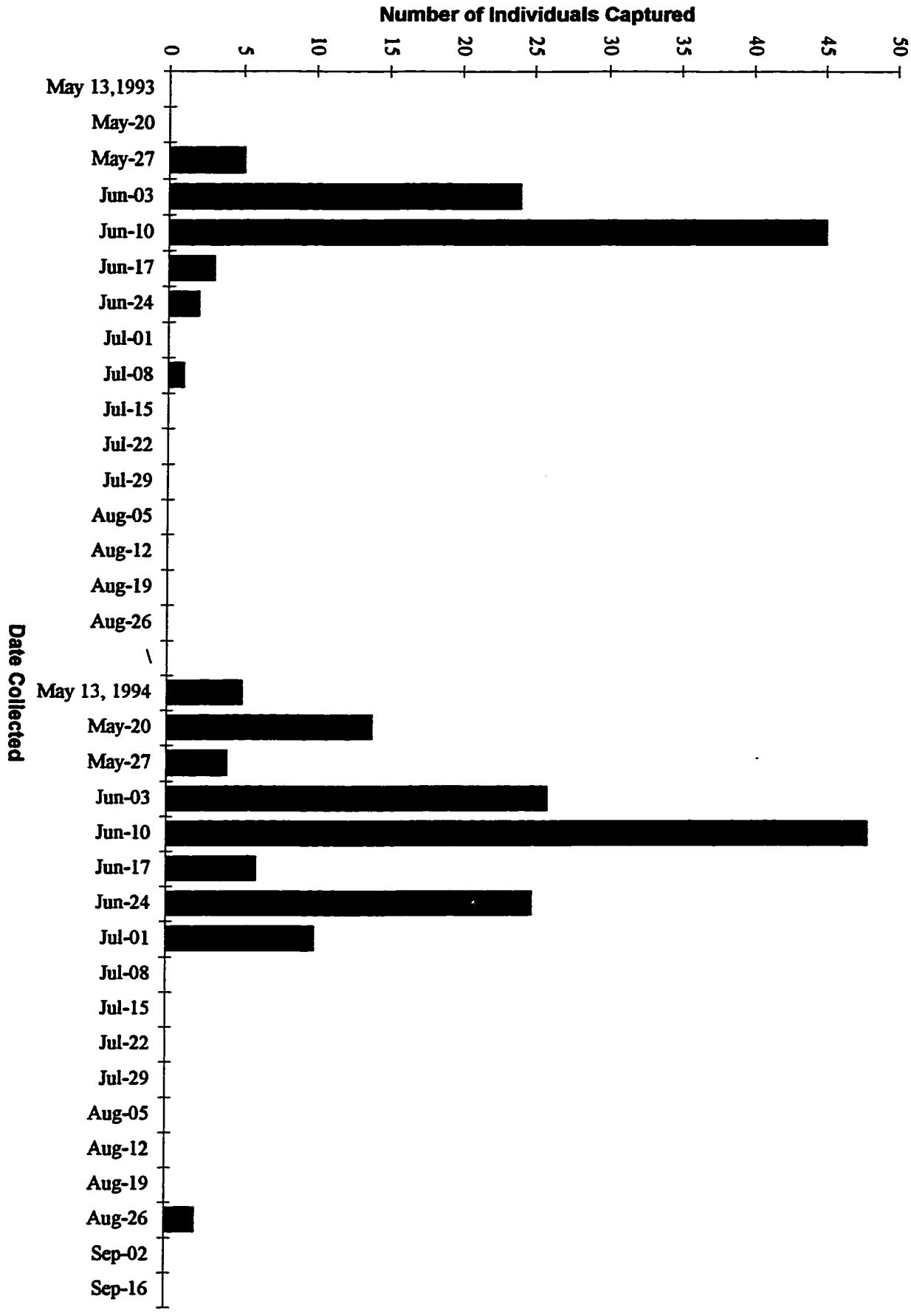
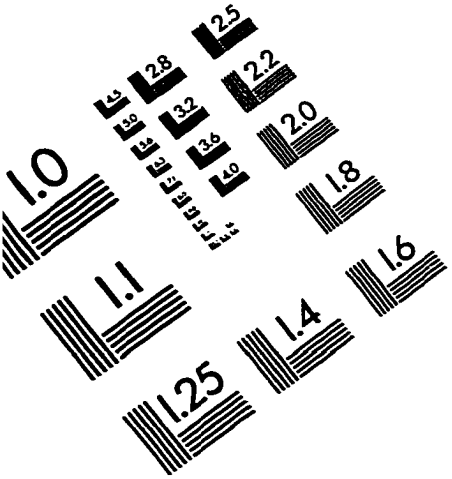
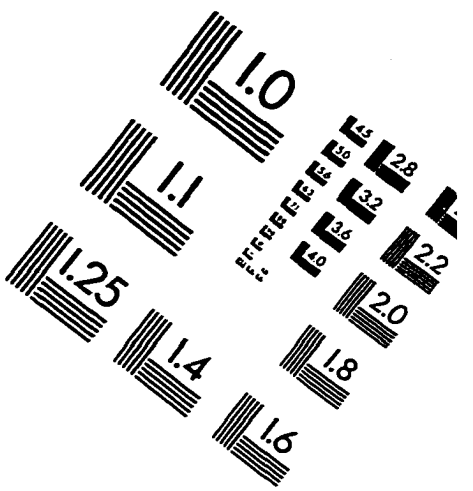
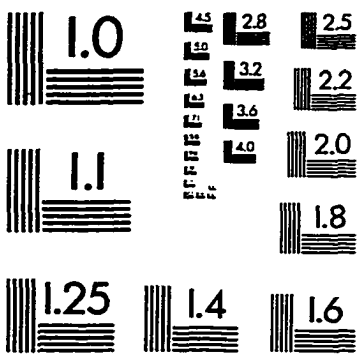
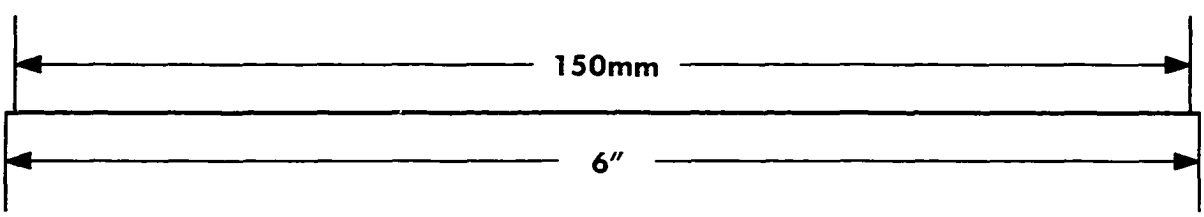


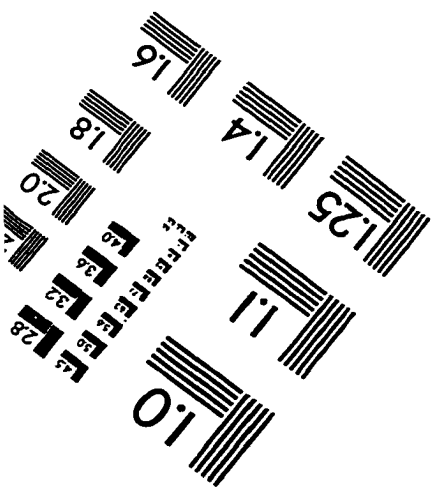
IMAGE EVALUATION TEST TARGET (QA-3)

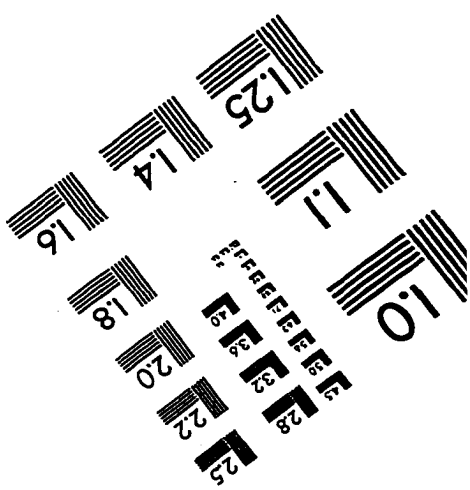












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