NATIONAL RIVERS AUTHORITY THAMES REGION
BIOLOGY
THAMES ESTUARY BENTHIC PROGRAMME

Inferences on the Pollution Status of the Thames Estuary from the Macrobenthic Community Structure

NRA
THAMES REGION

Compiled by Martin Attrill, Biologist
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<u>CONTENTS</u>

SUMMARY

The macrofauna community structure at 28 sites in the Thames Estuary was investigated in order to draw inferences on the pollution status of each site. Species number, diversity, evenness, biomass/abundance relationships (including ABC curves) and indicator organisms were used to assess the pollution status of each site.

The analysis suggested that the most polluted sites were in the reach from Woolwich to Purfleet, particularly at Beckton and Crossness where the outfalls from the two main sewage works discharge into the estuary. In addition, the communities at Kew, Southend intertidal and Allhallows were pinpointed as being influenced by organic enrichment.

The least polluted sites in the Thames estuary appear to be the outer estuary subtidal sites (particularly Chapman Buoy and Southend subtidal) and Teddington under full flow conditions. The detrimental effect of low flows on the community structure at Teddington was apparent.

Full summaries of the inferred pollution status of each site are provided.

The use of indicator organisms was appraised. It was suggested that the NRA proposed species should be used with great caution until full research on each species has evaluated their relationship with both the variable estuarine environment and pollution influences.

A community scoring system was suggested, utilizing the full range of community parameters to create a single index. This is applied to the Thames estuary sites and displayed using a proposed zone map.

1. INTRODUCTION

1.1 The aim of this report is to use the macrofauna community structure of sites in the Thames Estuary to make inferences on the pollution status of these sites and/or the Thames Estuary as a whole. This will be undertaken by utilising a variety of statistical and analytical techniques that can be applied in order to detect stresses within a community. However, many natural stresses occur in an estuarine environment and these have to be taken into account and excluded before any effect of pollution can be determined.

1.2 This report provides analysis of the data presented in the companion site report (Attrill, 1990a), resulting from quarterly samples taken from 28 sites along the length of the Thames Estuary. Details of these sites (Table 1 and Figure 1) are included in this report for reference.

1.3 The report will be structured to deal separately with the available methods of community analysis, appraising the value of each technique in relation to the aims of the report, and suggesting a possible community scoring system generated from the separate parameters. The resulting structure is as follows:

- **Community Statistics.** Species number, afaunal samples, diversity, evenness, abundance/biomass relationships.

- **Indicator Organisms.** Oligochaete abundance, % biomass of organisms indicative of organic enrichment, NRA suggested indicator organisms.

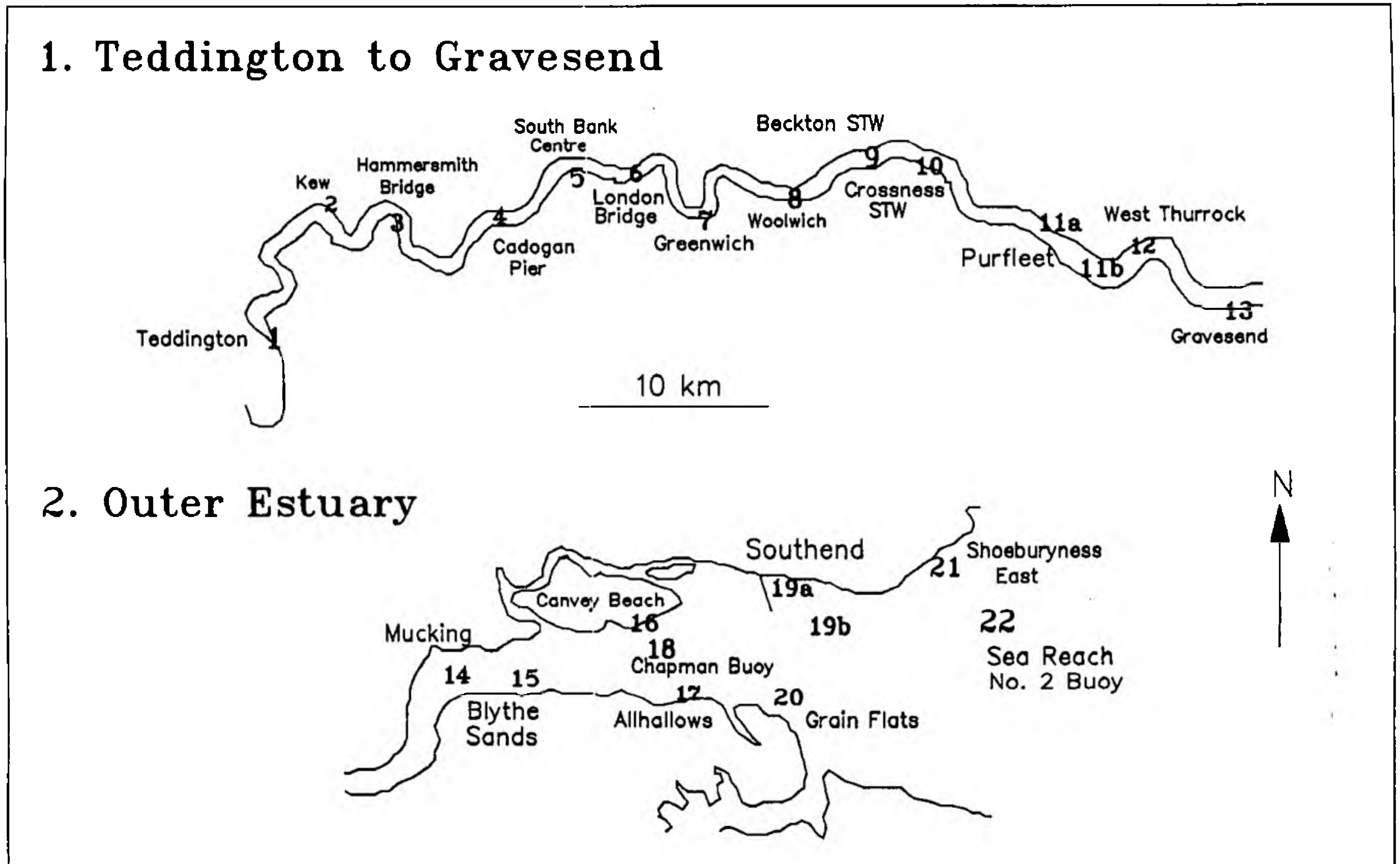
- **Community Score.** Development of CS, scoring system, relation to a "prediction", map display.

- **Site Summaries.** Brief summaries on the pollution status of each site from the previous analyses.

Table 1
Thames Estuary Benthic Programme Sample Sites

Site	Abbrv.	Site Name	NGR	Type	Km from LB
1.	T	Teddington	TQ 168 715	Subtidal Kick	-30.5
2.	K	Kew	TQ 191 779	Subtidal Kick	-23.6
3.	HB	Hammersmith Bridge	TQ 230 780	Intertidal	-14.8
4.	CP	Cadogan Pier	TQ 274 776	Subtidal Kick	- 7.4
5.	SBC	South Bank Centre	TQ 308 803	Intertidal	- 2.3
6.	LB	London Bridge	TQ 327 805	Subtidal Kick	- 0.2
7.	GW	Greenwich	TQ 383 780	Intertidal	7.7
8i.	WWi	Woolwich	TQ 427 793	Intertidal	14.5
8s.	WWs	Woolwich	TQ 429 794	Subtidal Grab	15.0
9.	BK	Beckton	TQ 456 815	Subtidal Grab	18.3
10i.	XNi	Crossness	TQ 492 809	Intertidal	22.5
10s.	XNs	Crossness	TQ 494 809	Subtidal Grab	22.7
11i.	Pi	Purfleet	TQ 548 786	Intertidal	30.8
11s.	Ps	Purfleet	TQ 580 761	Subtidal Grab	34.7
12i.	WTi	West Thurrock	TQ 592 770	Intertidal	36.0
12s.	WTs	West Thurrock	TQ 593 770	Subtidal Grab	36.1
13i.	GVi	Gravesend	TQ 648 745	Intertidal	42.5
13s.	GVs	Gravesend	TQ 649 746	Subtidal Grab	42.6
14.	MK	Mucking	TQ 707 808	Subtidal Grab	52.4
15.	BS	Blythe Sands	TQ 757 805	Subtidal Grab	56.3
16.	CB	Canvey Beach	TQ 800 824	Intertidal	61.1
17.	AH	Allhallows	TQ 838 792	Intertidal	64.5
18.	CHB	Chapman Buoy	TQ 809 813	Subtidal Grab	62.5
19i.	SEi	Southend	TQ 888 844	Intertidal	69.5
19s.	SEs	Southend	TQ 901 828	Subtidal Grab	71.8
20.	GF	Grain Flats	TQ 877 795	Subtidal Grab	69.0
21.	SNE	Shoeburyness East	TQ 949 850	Intertidal	75.2
22.	SR2	Sea Reach No.2 Buoy	TQ 955 810	Subtidal Grab	77.6

Figure 1.



Position of Thames Estuary Benthic Programme Sample Sites

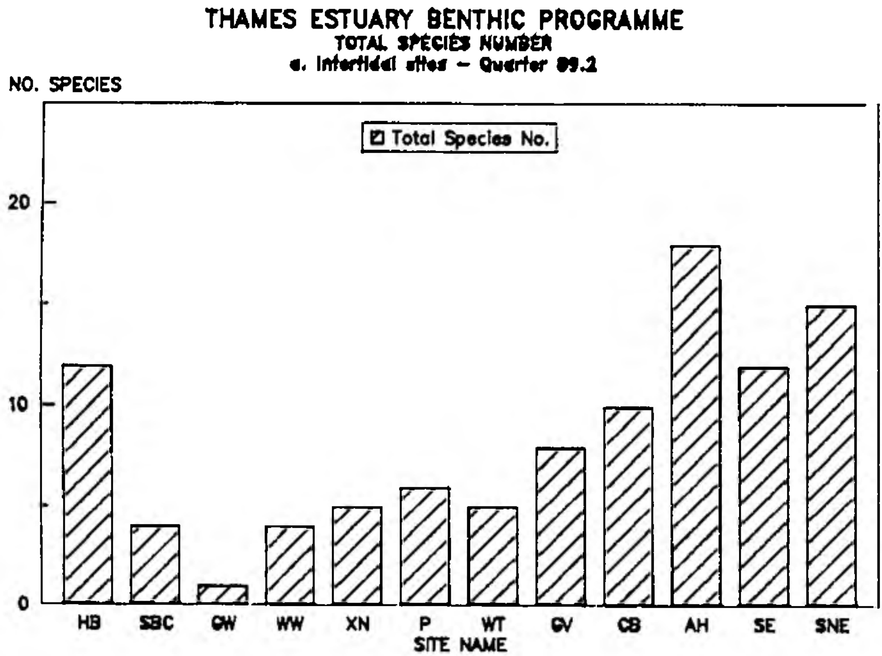
2 COMMUNITY STATISTICS

2.1 Species Number (n).

2.1.1 Species number is defined as the total number of species recorded at each site during each sample visit. In certain cases, identification to species level was regarded as unnecessary or was particularly difficult (e.g. chironomid larvae, ostracods). These were therefore regarded as one species for the purposes of analysis.

2.1.2 Species number can be regarded as a primary indicator, with several other parameters depending wholly or partly on the number of species present. It can give a useful basic indication of the richness of a community, with clean, stable, low-stress environments generally recording high species numbers. However, the value obtained takes account of neither the abundance of each species nor the actual composition of the species present, so omitting valuable data. In addition, natural stress will reduce the range of species that the environment can potentially support, so a lower species number would be expected in the middle of an estuary than at each end.

2.1.3 The change in conditions along an estuary is gradual, so in theory the species number curve should reflect this gradualness. Any deviation from such a curve may be indicative of stresses additional to those naturally encountered. Figs 2 & 3 illustrate the recorded species numbers for each site over four consecutive quarters. Intertidal sites (Fig 2) show a similar number of species for sites above West Thurrock, with an increase in species present towards the sea. The subtidal curves (Fig 3) demonstrate a dramatic dip in mid-estuary, with several sites (notably Beckton) registering below the general trend. The upper estuary values have been depressed in quarter 89.4 (Fig 3c) due to the influence of low freshwater flow (Attrill, 1990b).


THAMES ESTUARY BENTHIC PROGRAMME
TOTAL SPECIES NUMBER
a. Intertidal sites – Quarter 89.2
NO. SPECIES
Total Species No.
20
10
0
HB
SBC
GW
WW
XN
P
WT
GV
CB
AH
SE
SNE
SITE NAME

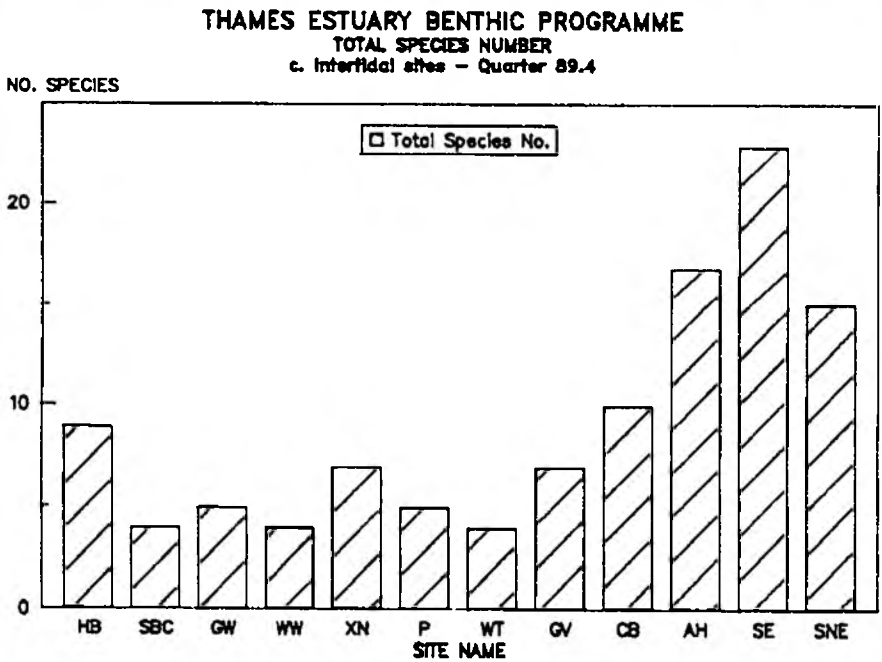
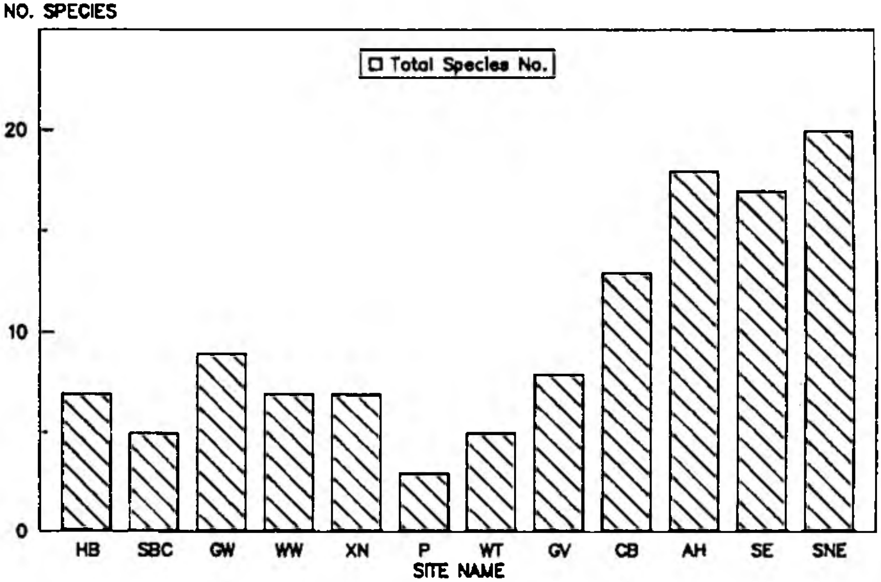
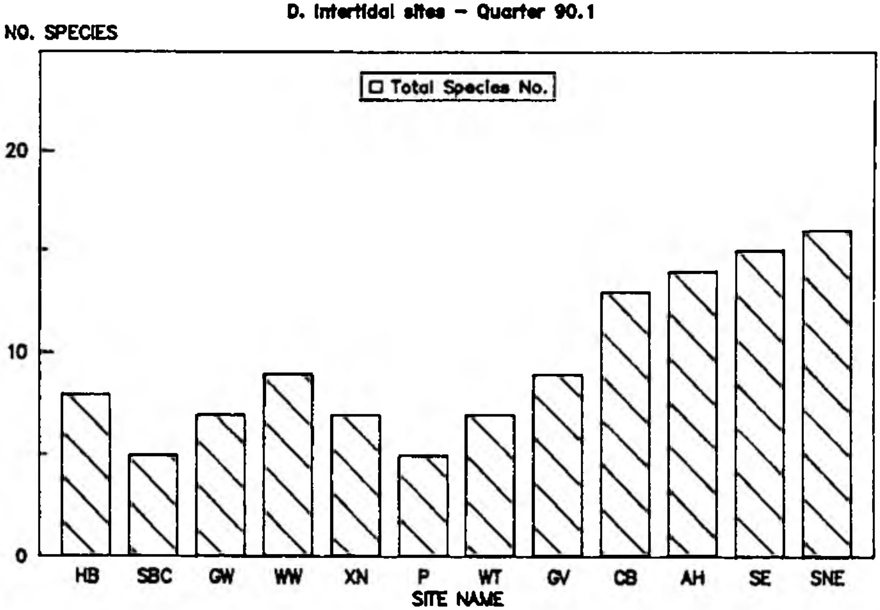

THAMES ESTUARY BENTHIC PROGRAMME
TOTAL SPECIES NUMBER
c. Intertidal sites – Quarter 89.4
NO. SPECIES
Total Species No.
20
10
0
HB
SBC
GW
WW
XN
P
WT
GV
CB
AH
SE
SNE
SITE NAME

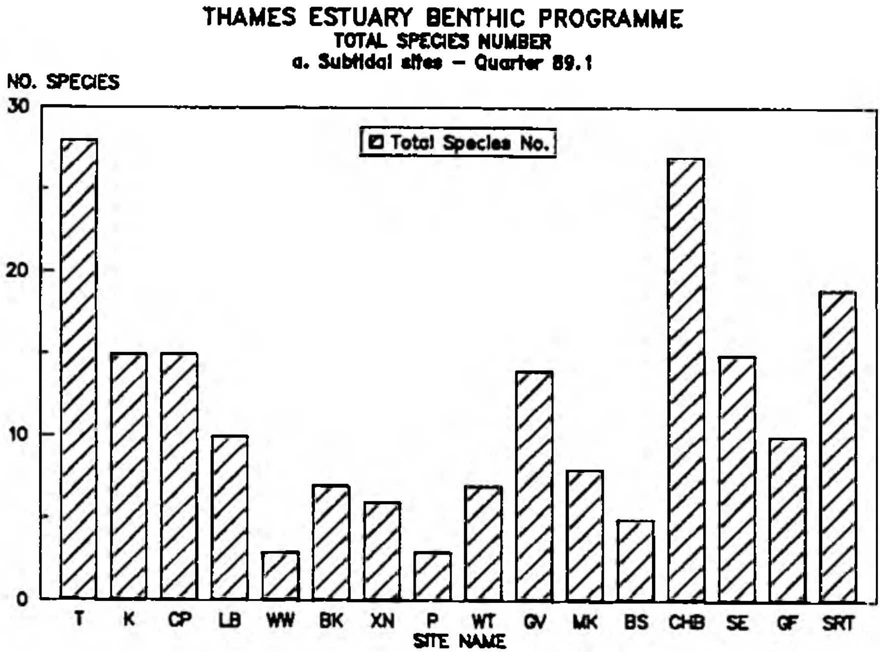
Fig.2

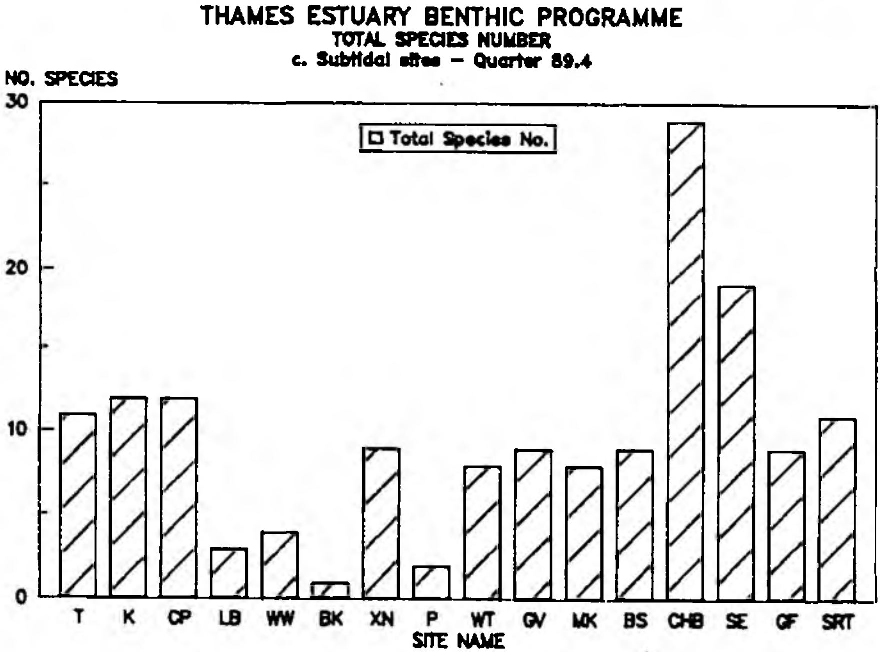
THAMES ESTUARY BENTHIC PROGRAMME
TOTAL SPECIES NUMBER
b. Intertidal sites – Quarter 89.3



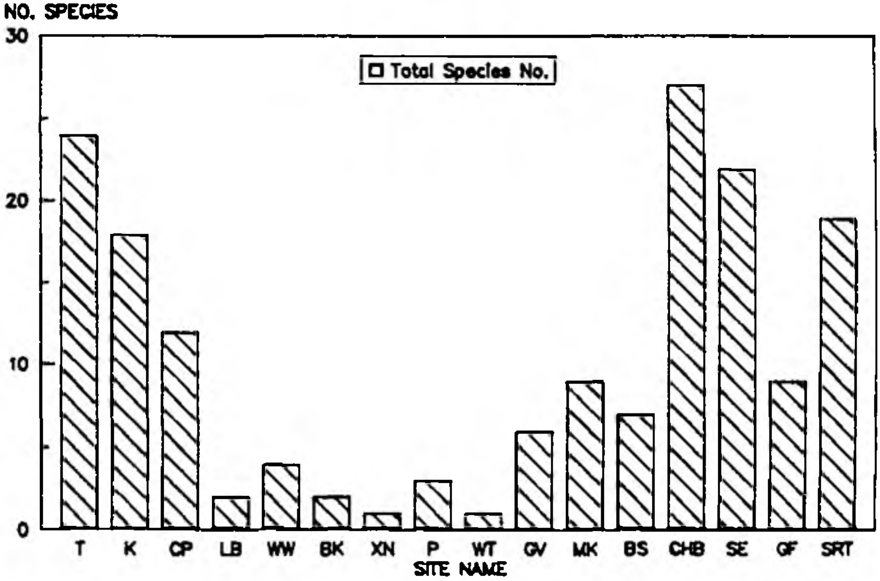
THAMES ESTUARY BENTHIC PROGRAMME
TOTAL SPECIES NUMBER
D. Intertidal sites – Quarter 90.1



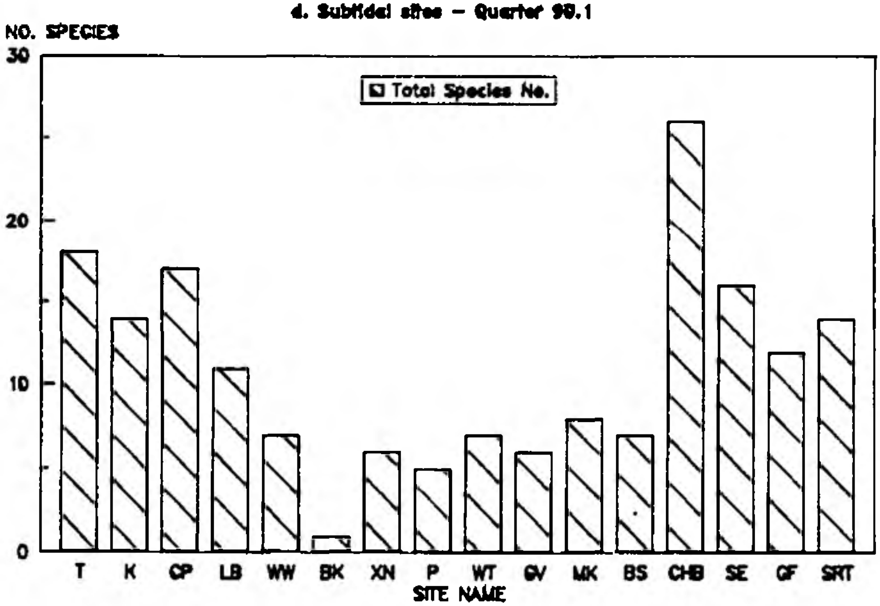

THAMES ESTUARY BENTHIC PROGRAMME
TOTAL SPECIES NUMBER
a. Subtidal sites – Quarter 89.1
NO. SPECIES
30
20
10
0
Total Species No.
T
K
CP
LB
WW
BK
XN
P
WT
GV
MK
BS
CHB
SE
GF
SRT
SITE NAME


THAMES ESTUARY BENTHIC PROGRAMME
TOTAL SPECIES NUMBER
c. Subtidal sites – Quarter 89.4
NO. SPECIES
30
20
10
0
Total Species No.
T
K
CP
LB
WW
BK
XN
P
WT
GV
MK
BS
CHB
SE
GF
SRT
SITE NAME

THAMES ESTUARY BENTHIC PROGRAMME
TOTAL SPECIES NUMBER
b. Subtidal sites – Quarter 89.3



THAMES ESTUARY BENTHIC PROGRAMME
TOTAL SPECIES NUMBER
d. Subtidal sites – Quarter 90.1



2.2 Afaunal Samples.

2.2.1 The worse scenario at a macrofauna site is to have no species present at all. The sample analysed for each site is composed of 4 replicate sub-samples, so recording the number of afaunal sub-samples from each site can give information on the most stressful habitats. It is unusual to record no macrofauna life under natural conditions.

2.2.2 Figure 4 illustrates the sites where afaunal samples have been recorded, with Beckton registering seven lifeless samples since 1/4/89. Purfleet intertidal is the only intertidal site to have recorded afaunal samples.

2.3 Diversity (H'e).

2.3.1 Diversity indices are used to summarise relatively complex species data into a single descriptive value by integrating the two components of the diversity of a community, i.e. species number and the relative abundance of the species. The Shannon-Wiener index is generally regarded to be one of the best measures of community diversity, providing a useful method for inter-station comparison within a survey. By their very nature, however, all such diversity indices simplify a multi-dimensional community structure and should be used in conjunction with other parameters.

2.3.2 The Shannon-Wiener diversity index used in the TEBP is calculated as follows:

$$H'e = - \Sigma\, p_i \log_e p_i$$

where p_i = proportion of the total abundance represented by the ith species.

2.3.3 As the diversity index uses the two community components detailed above, a low diversity can result from either a low species number or a numerical dominance by one or two species. Figures 5 and 6

Fig.4

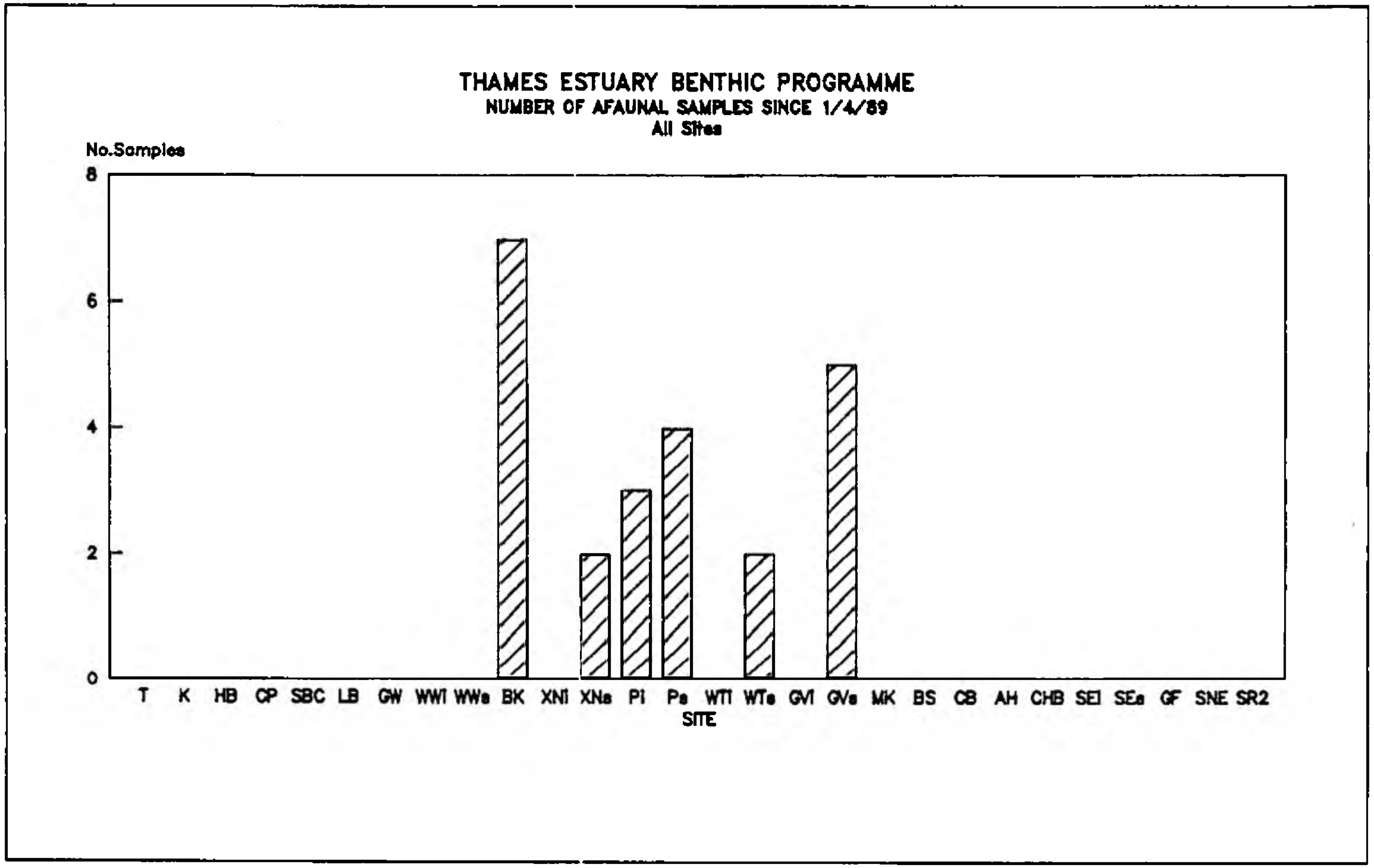
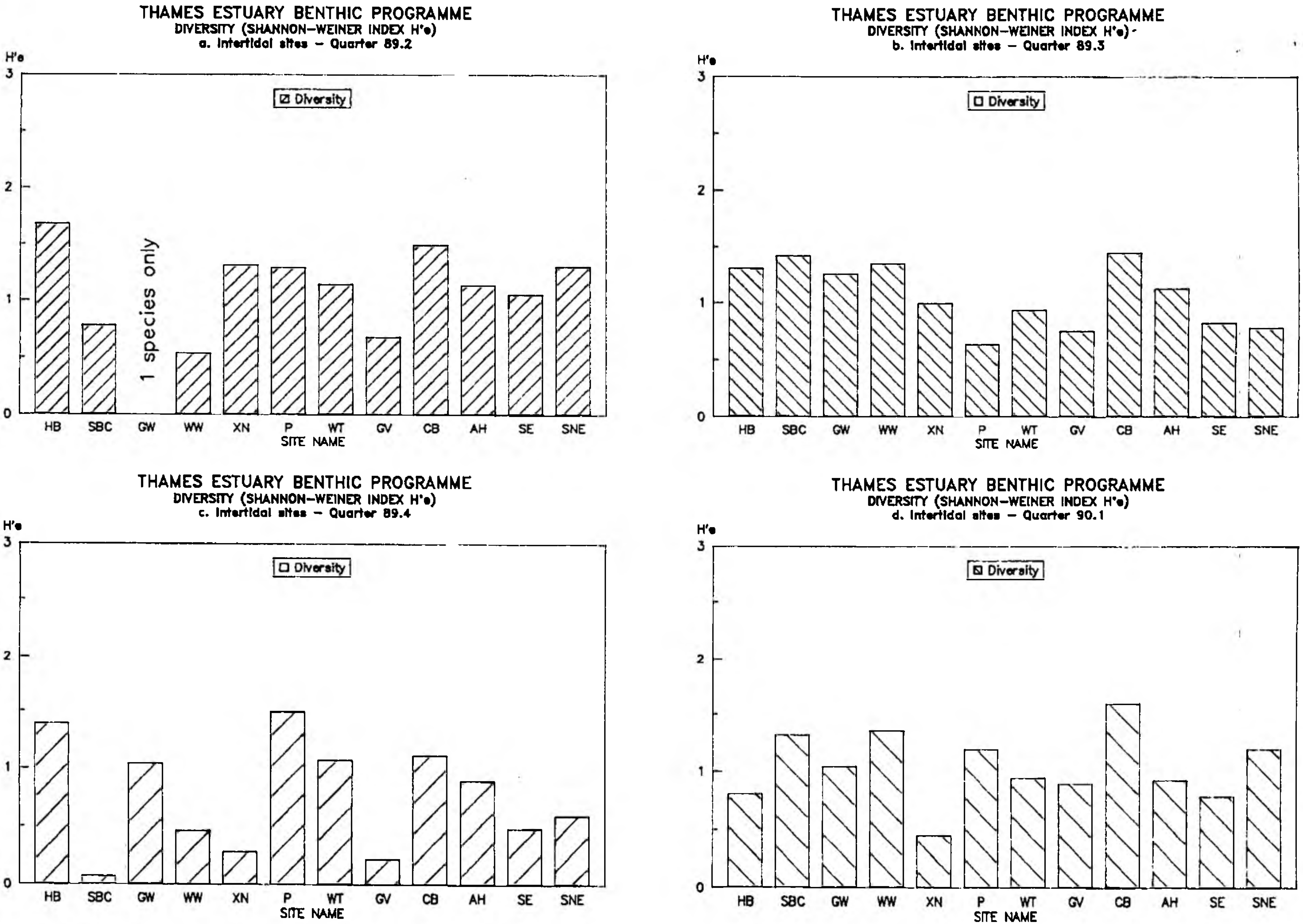
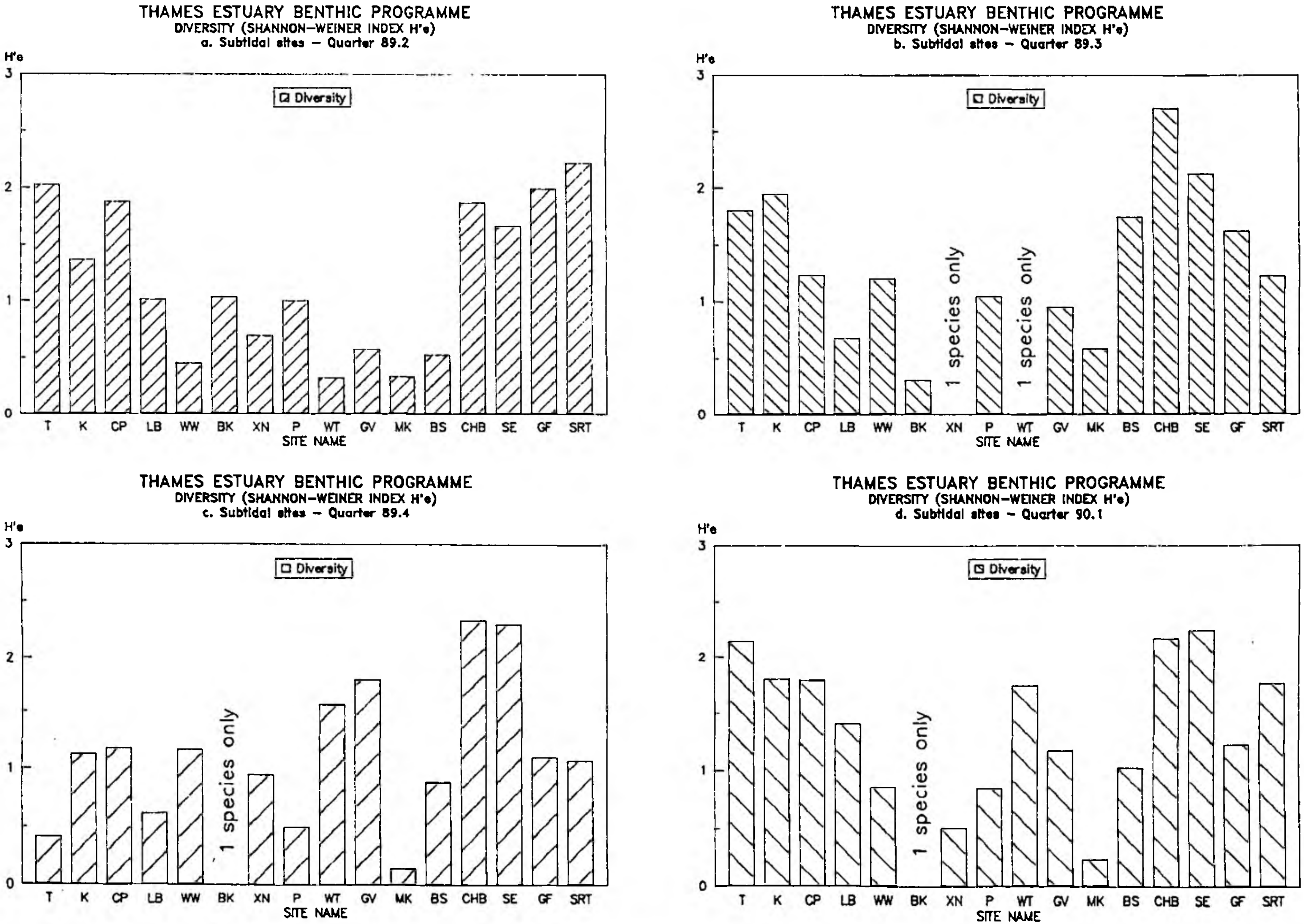

THAMES ESTUARY BENTHIC PROGRAMME
NUMBER OF AFAUNAL SAMPLES SINCE 1/4/89
All Sites
No.Samples
8
6
4
2
0
T K HB CP SBC LB GW WWI WWe BK XNI XNe PI Pe WTI WTe GVI GVe MK BS CB AH CHB SEI SEe GF SNE SR2
SITE

Fig.5



THAMES ESTUARY BENTHIC PROGRAMME
DIVERSITY (SHANNON-WEINER INDEX H'e)
a. Intertidal sites - Quarter 89.2
H'e
Diversity
1 species only
HB SBC GW WW XN P WT GV CB AH SE SNE
SITE NAME
THAMES ESTUARY BENTHIC PROGRAMME
DIVERSITY (SHANNON-WEINER INDEX H'e)
b. Intertidal sites - Quarter 89.3
H'e
Diversity
HB SBC GW WW XN P WT GV CB AH SE SNE
SITE NAME
THAMES ESTUARY BENTHIC PROGRAMME
DIVERSITY (SHANNON-WEINER INDEX H'e)
c. Intertidal sites - Quarter 89.4
H'e
Diversity
HB SBC GW WW XN P WT GV CB AH SE SNE
SITE NAME
THAMES ESTUARY BENTHIC PROGRAMME
DIVERSITY (SHANNON-WEINER INDEX H'e)
d. Intertidal sites - Quarter 90.1
H'e
Diversity
HB SBC GW WW XN P WT GV CB AH SE SNE
SITE NAME

Fig.6



THAMES ESTUARY BENTHIC PROGRAMME
DIVERSITY (SHANNON-WEINER INDEX H'e)
a. Subtidal sites – Quarter 89.2
b. Subtidal sites – Quarter 89.3
c. Subtidal sites – Quarter 89.4
d. Subtidal sites – Quarter 90.1
H'e
Diversity
1 species only
T K CP LB WW BK XN P WT GV MK BS CHB SE GF SRT
SITE NAME

illustrate the diversities recorded for each site over four quarters.

2.3.4 The intertidal sites demonstrate similar values, all comparatively low. The diversities at sites in the outer estuary tend to be depressed by large numbers of small annelids, whereas low species number affects sites in the mid-estuary. Occasionally, high numbers of oligochaetes depress the scores further, as in the cases of Crossness (Figs.5c & d) and Gravesend (Fig.5c). The extremely low diversity at South Bank Centre (Fig.5c) was due to an influx of large numbers of the gastropod Potamopyrgus jenkinsi. The sites were influenced by low freshwater flows during this quarter (4.89).

2.3.5 The subtidal sites show less overall similarity, with increases in diversity at each end of the estuary. Notable troughs include the sites where only one species was recorded (so registering a diversity of zero), i.e. Beckton & West Thurrock, Mucking (high numbers of small annelids) and Teddington during the low flow period of quarter 4.89 (Fig.6c).

2.4 Evenness (J).

2.4.1 To investigate whether diversities are influenced by either abundances or species number, an evenness value can be calculated to indicate the degree of dominance in a community. This value measures the evenness with which individuals are distributed amongst the species, and is derived by dividing the observed value of the Shannon-Wiener index by its theoretical maximum value:

$$J = \frac{H'e}{H\ max}$$

where $H\ max = \log_e S$ (S is the total number of species recorded).

2.4.2 A low evenness value will be indicative of dominance in the community, with stressed environments often being dominated by small ephemeral organisms that are able to exploit the conditions.

A low diversity coupled with a high evenness, however, may indicate that other factors (e.g. substrate instability) are reducing the species number of the site, particularly when total abundances are low.

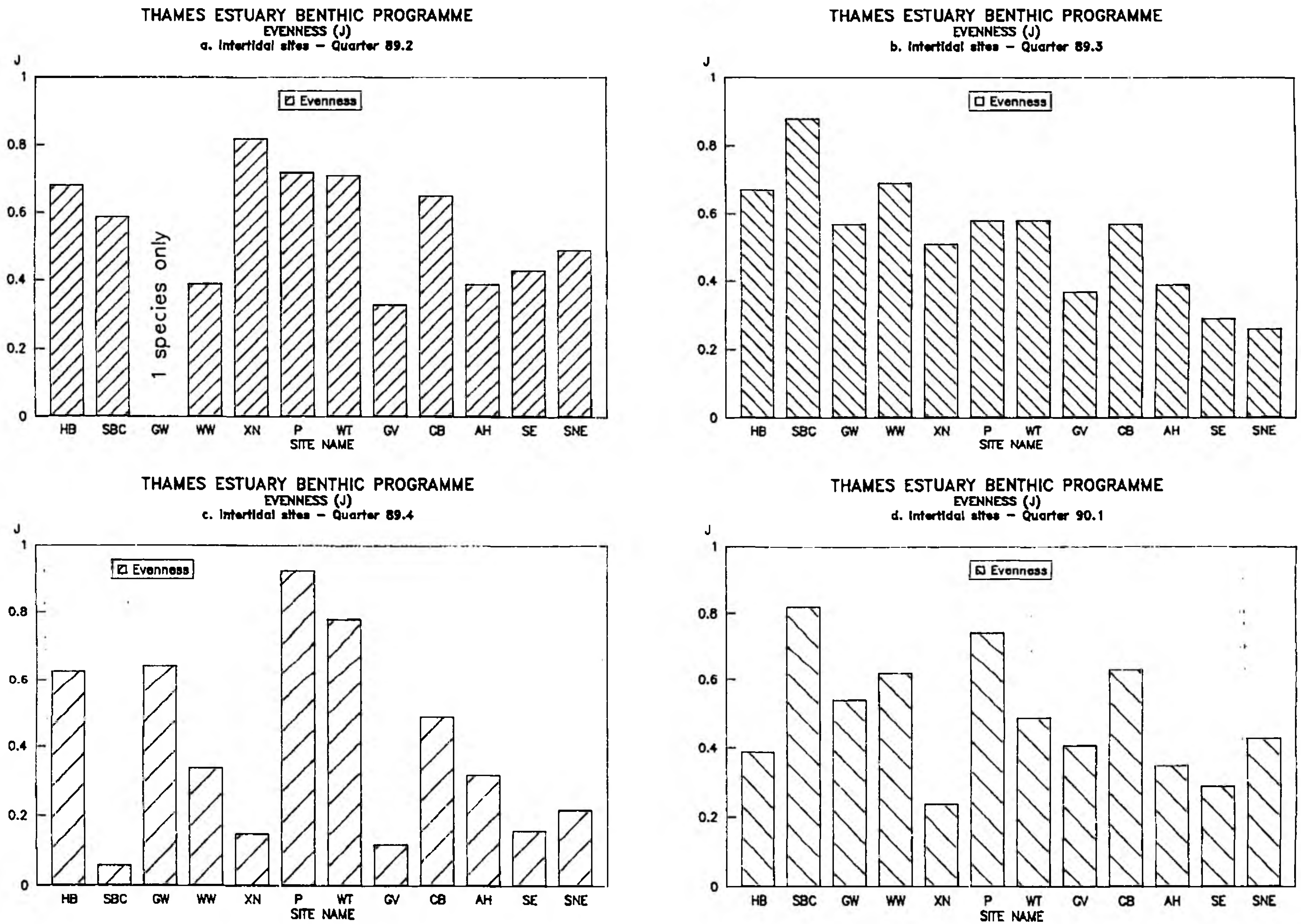
2.4.3 Figures 7 & 8 display the evenness values recorded for all sites over a four quarter period. Notable decreases in evenness are obvious for the intertidal sites of South Bank Centre, Crossness and Gravesend during the low flows of 4.89 (Fig.7c), confirming the low diversities were due to dominance and a possible variation in water quality. Other sites (e.g. Purfleet) have higher evenness values, suggesting perhaps stability is the greater factor. Outer estuary sites show low evenness, these sites being dominated by small annelids.

2.4.4 The subtidal sites (Fig.8) show more variation. Many mid estuary sites (e.g. Purfleet, Gravesend, Woolwich) show high evenness to couple with their low diversities. It is probable, therefore, that sediment instability is a major factor in this area. Other sites (Beckton, Crossness) have lower evenness. In the outer estuary, Chapman Buoy and Southend couple high diversity with consistently high evenness, indicating stable healthy communities, whereas Mucking shows a low value (high dominance of small annelids). The site at West Thurrock showed a dramatic change over the year, which is highlighted by these data. A community dominated by Corophium disappeared during quarter 89.2, probably due to mobile sediment. The evenness values display this, with a low value for quarter 89.2 and higher values for the last two quarters when the sediment appeared more unstable.

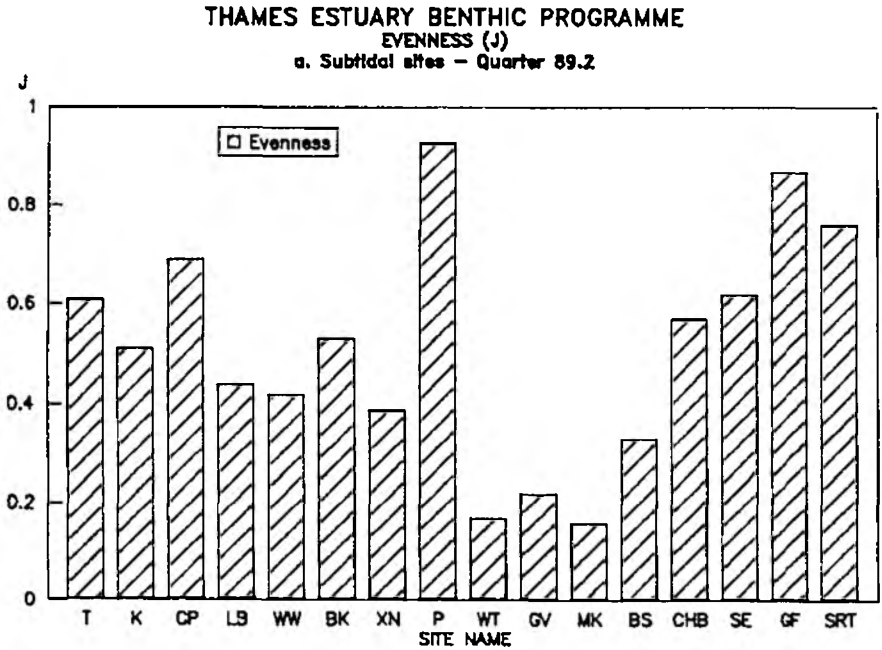
2.5 Abundance/biomass relationships.

2.5.1 The relationships between abundance and biomass within a community are probably the most sensitive methods of analysis available as they deal with a greater range of data than previous parameters.

Fig.7



THAMES ESTUARY BENTHIC PROGRAMME
EVENNESS (J)
a. Intertidal sites – Quarter 89.2
J
1
0.8
0.6
0.4
0.2
0
Evenness
1 species only
HB SBC GW WW XN P WT GV CB AH SE SNE
SITE NAME
THAMES ESTUARY BENTHIC PROGRAMME
EVENNESS (J)
b. Intertidal sites – Quarter 89.3
Evenness
SITE NAME
THAMES ESTUARY BENTHIC PROGRAMME
EVENNESS (J)
c. Intertidal sites – Quarter 89.4
Evenness
SITE NAME
THAMES ESTUARY BENTHIC PROGRAMME
EVENNESS (J)
d. Intertidal sites – Quarter 90.1
Evenness
SITE NAME


THAMES ESTUARY BENTHIC PROGRAMME
EVENNESS (J)
a. Subtidal sites – Quarter 89.2
J
1
0.8
0.6
0.4
0.2
0
Evenness
T
K
CP
LB
WW
BK
XN
P
WT
GV
MK
BS
CHB
SE
GF
SRT
SITE NAME

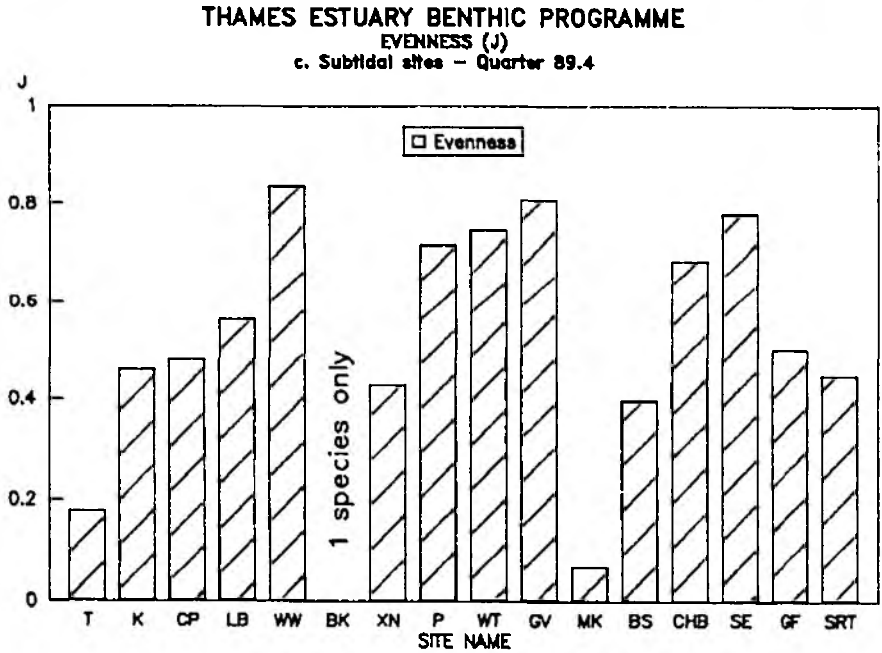
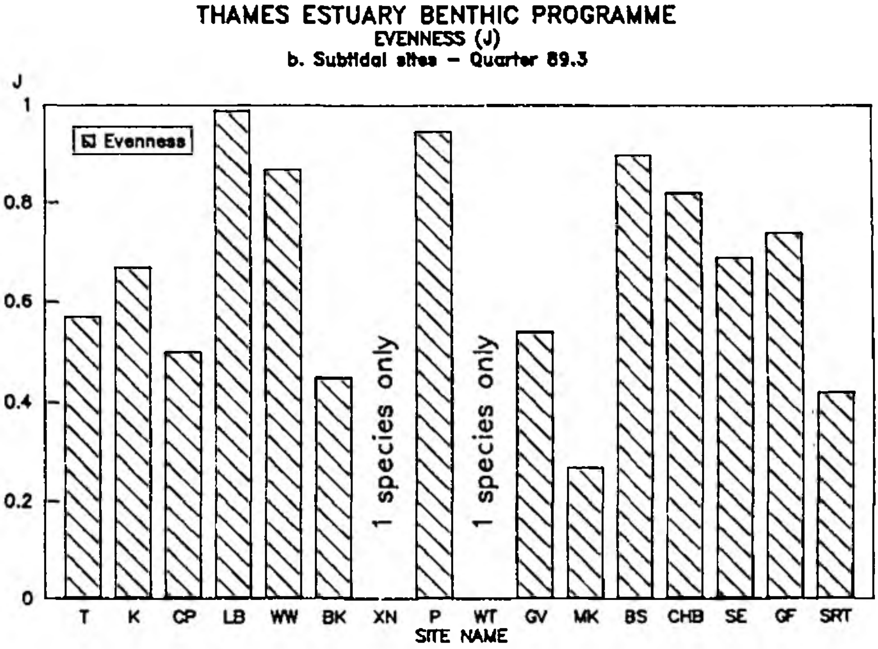
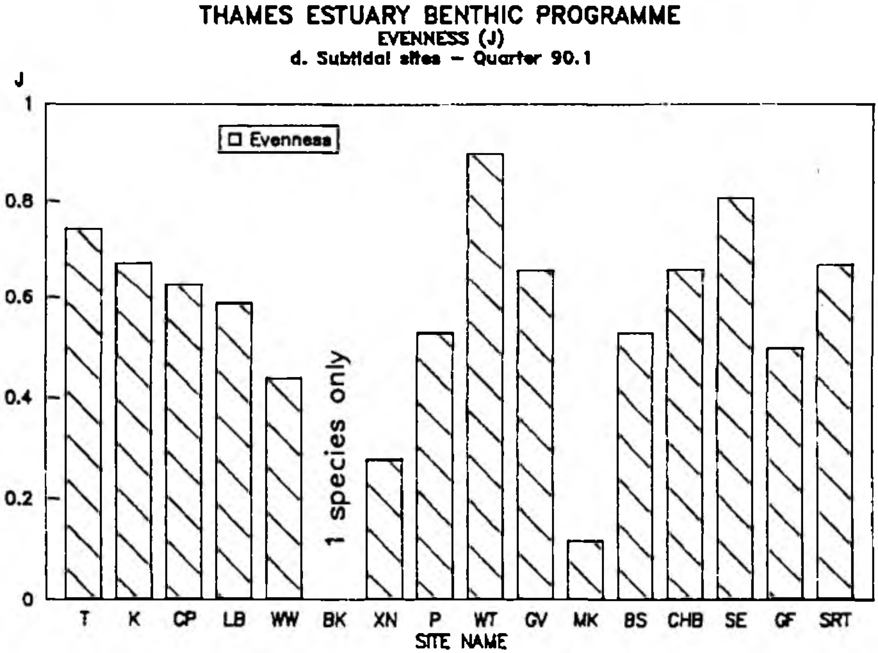

THAMES ESTUARY BENTHIC PROGRAMME
EVENNESS (J)
c. Subtidal sites – Quarter 89.4
J
1
0.8
0.6
0.4
0.2
0
Evenness
1 species only
T
K
CP
LB
WW
BK
XN
P
WT
GV
MK
BS
CHB
SE
GF
SRT
SITE NAME

Fig.8


THAMES ESTUARY BENTHIC PROGRAMME
EVENNESS (J)
b. Subtidal sites – Quarter 89.3
J
1
0.8
0.6
0.4
0.2
0
Evenness
1 species only
1 species only
T
K
CP
LB
WW
BK
XN
P
WT
GV
MK
BS
CHB
SE
GF
SRT
SITE NAME


THAMES ESTUARY BENTHIC PROGRAMME
EVENNESS (J)
d. Subtidal sites – Quarter 90.1
J
1
0.8
0.6
0.4
0.2
0
Evenness
1 species only
T
K
CP
LB
WW
BK
XN
P
WT
GV
MK
BS
CHB
SE
GF
SRT
SITE NAME

2.5.2 Under stable, unpolluted conditions, the biomass of the community tends to be dominated by one or a few large species, each represented by few individuals (Warwick, 1987). These conservative species are characterised by large body size and long lifespan, so requiring the stability to develop a population. Under these stable conditions, there will also be a number of smaller often opportunistic species which will be the numerical dominants. However, the distribution of numbers of individuals among the species should be more even than the relative distribution of biomass. As disturbance (e.g. pollution) increases, the large conservative species are the first casualties, while the opportunistic species become more favoured. This may initially cause an increase in diversity, but with further disturbance the opportunistics often become the "biomass dominants" (Warwick, 1987) as well as the numerical dominants, the number of intolerant species is reduced and diversity falls.

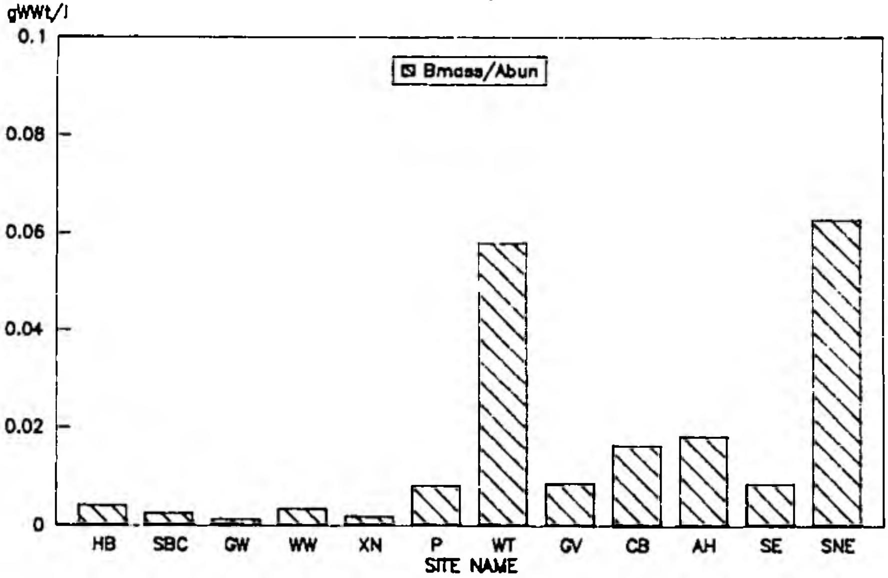
2.5.3 The consequence of disturbance is a change in the abundance/biomass relationship, from a stable community of a few biomass dominants and an even spread of numbers over all species to a state of more even biomass distribution with numerical dominance of smaller organisms.

2.5.4 A very basic method of investigating this relationship is to calculate the average weight per individual for each site, achieved simply by dividing the total observed biomass by the total abundance. This gives an indication of sites that have a high proportion of larger animals in respect to their total abundances. Figures 9 & 10 illustrate these data for the TEBP sites, with several sites registering high ratios (WTi, CHB, SRT, CB, SEs), suggesting stability. However, it is more difficult to draw conclusions from sites at the other end of the scale - a more sensitive method is required.

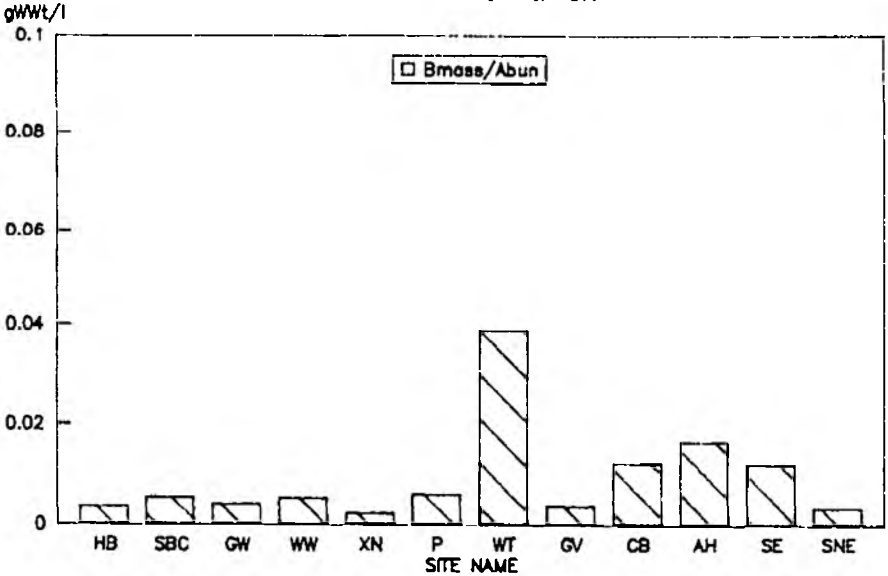
2.5.5 Warwick (1986, 1987) has devised a method of illustrating the relationship between the distributions of biomass and abundance within a single community, by constructing curves in which the species are ranked in order of importance on the x-axis (log scale)

Fig

THAMES ESTUARY BENTHIC PROGRAMME
BIOMASS/ABUNDANCE – MEAN WWT PER INDIVIDUAL
A. Intertidal sites – Quarter 89.2

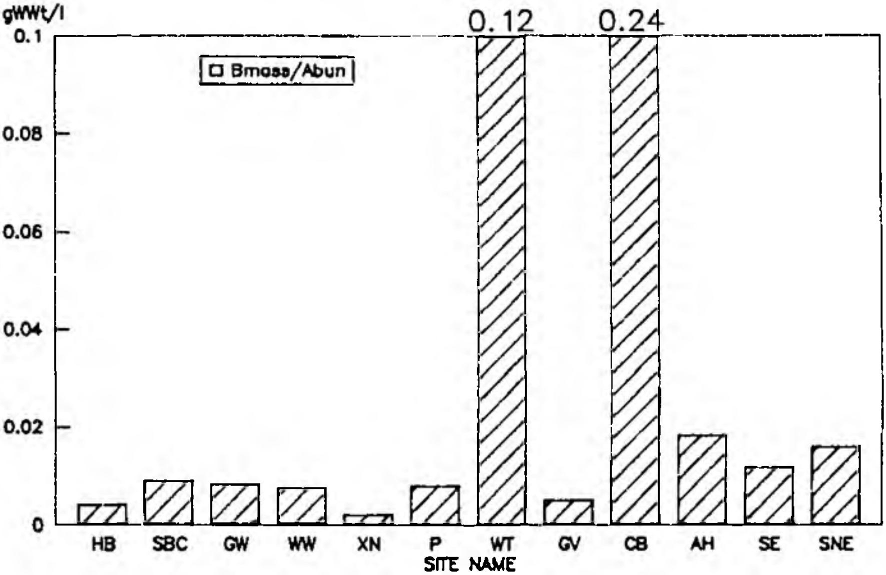


THAMES ESTUARY BENTHIC PROGRAMME
BIOMASS/ABUNDANCE – MEAN WWT PER INDIVIDUAL
C. Intertidal sites – Quarter 89.4



.9

THAMES ESTUARY BENTHIC PROGRAMME
BIOMASS/ABUNDANCE – MEAN WWT PER INDIVIDUAL
B. Intertidal sites – Quarter 89.3



THAMES ESTUARY BENTHIC PROGRAMME
BIOMASS/ABUNDANCE – MEAN WWT PER INDIVIDUAL
D. Intertidal sites – Quarter 90.1

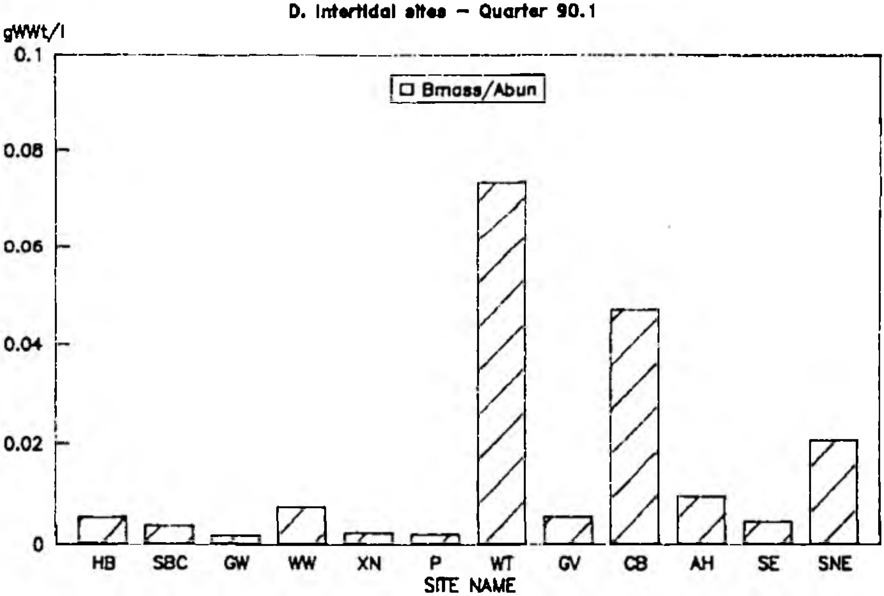
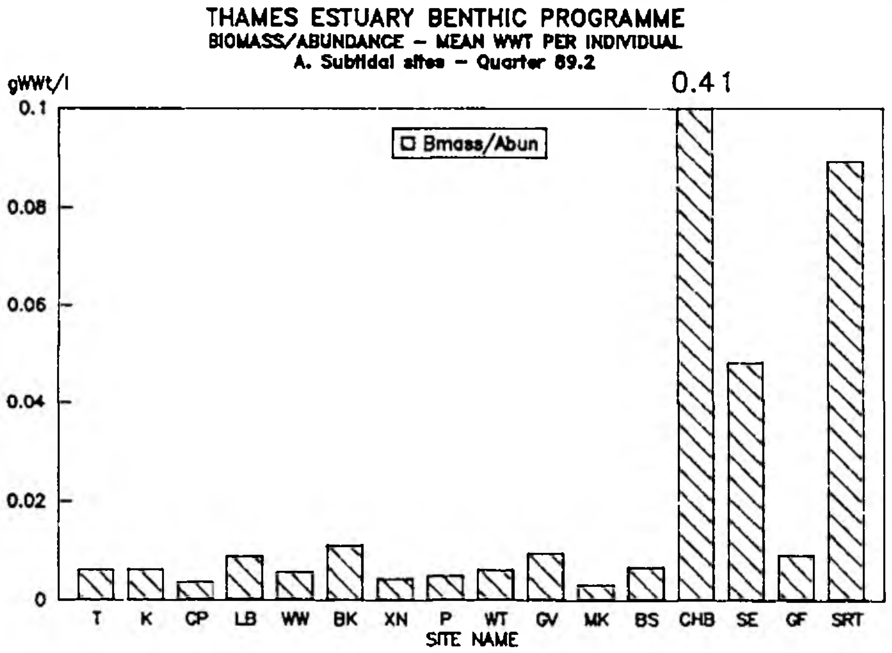
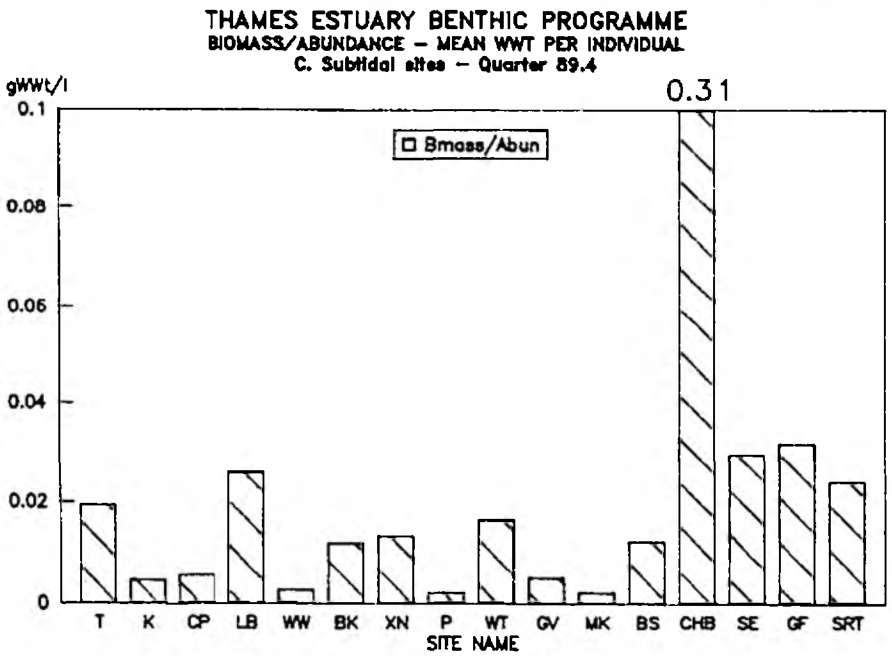


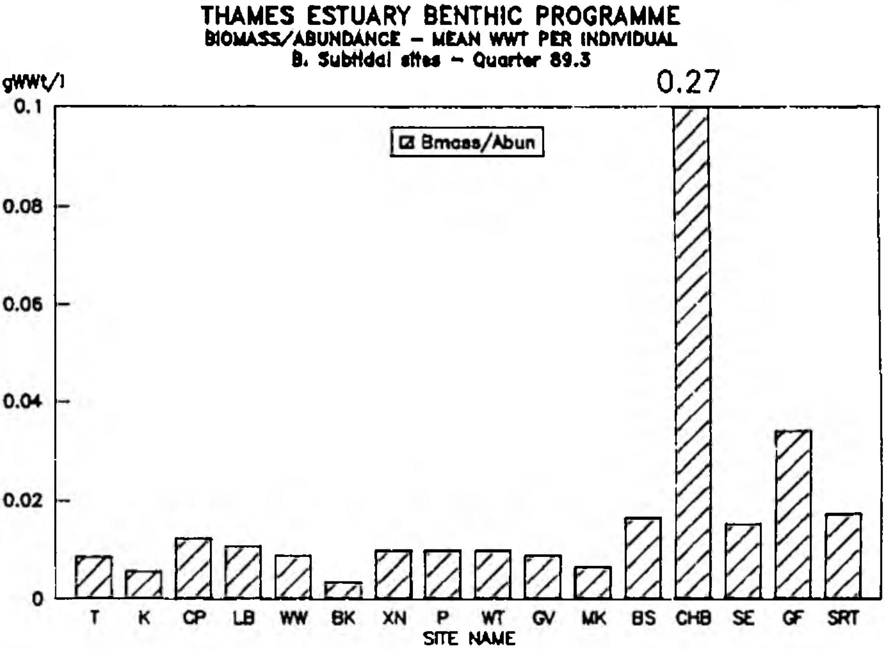
Fig.

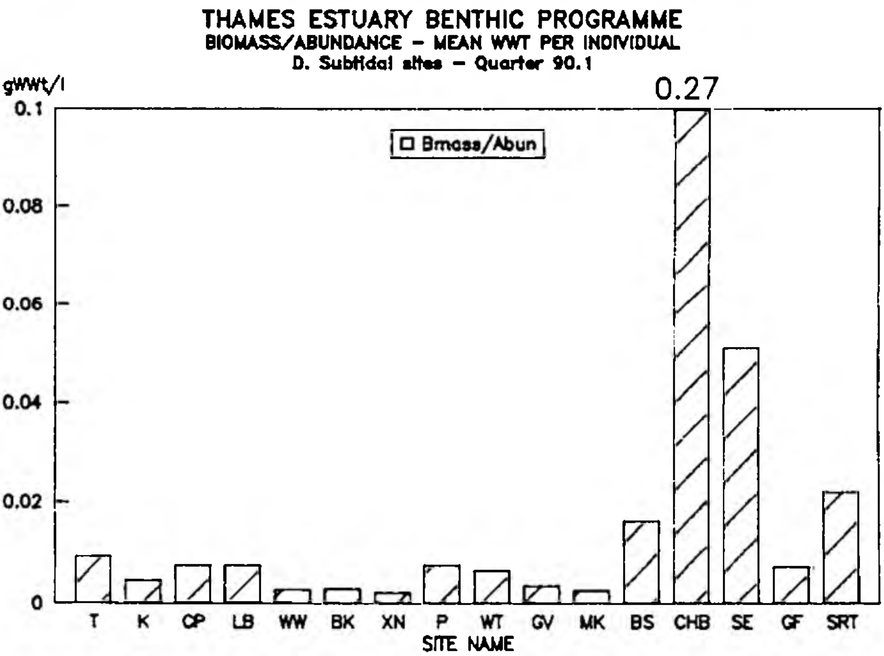


THAMES ESTUARY BENTHIC PROGRAMME
BIOMASS/ABUNDANCE – MEAN WWT PER INDIVIDUAL
A. Subtidal sites – Quarter 89.2
gWWt/I
0.41
Bmass/Abun
0.1
0.08
0.06
0.04
0.02
0
T
K
CP
LB
WW
BK
XN
P
WT
GV
MK
BS
CHB
SE
GF
SRT
SITE NAME



THAMES ESTUARY BENTHIC PROGRAMME
BIOMASS/ABUNDANCE – MEAN WWT PER INDIVIDUAL
C. Subtidal sites – Quarter 89.4
gWWt/I
0.31
Bmass/Abun
0.1
0.08
0.06
0.04
0.02
0
T
K
CP
LB
WW
BK
XN
P
WT
GV
MK
BS
CHB
SE
GF
SRT
SITE NAME


THAMES ESTUARY BENTHIC PROGRAMME
BIOMASS/ABUNDANCE - MEAN WWT PER INDIVIDUAL
B. Subtidal sites - Quarter 89.3
gWWt/I
0.27
0.1
0.08
0.06
0.04
0.02
0
Bmass/Abun
T
K
CP
LB
WW
BK
XN
P
WT
GV
MK
BS
CHB
SE
GF
SRT
SITE NAME


THAMES ESTUARY BENTHIC PROGRAMME
BIOMASS/ABUNDANCE - MEAN WWT PER INDIVIDUAL
D. Subtidal sites - Quarter 90.1
gWWt/I
0.27
0.1
0.08
0.06
0.04
0.02
0
Bmass/Abun
T
K
CP
LB
WW
BK
XN
P
WT
GV
MK
BS
CHB
SE
GF
SRT
SITE NAME

with percentage dominance on the y-axis (cumulative scale). These graphs are termed ABC plots (Abundance Biomass Comparison). This method has been tested on a wide range of community data from polluted and unpolluted sites, with both spatial and temporal comparisons, resulting in models for unpolluted, moderately polluted and grossly polluted conditions (Appendix 1, Figure A). Expected curves for an unpolluted/undisturbed site (Fig.Ai) show the biomass curve to be above the abundance curve for all its length. Conversely under grossly polluted/disturbed conditions, the abundance curve will be above the biomass curve for all its length (Fig.Aiii), with a transitional graph for a moderately polluted situation (Fig.Aii).

2.5.6 The great benefit of this technique is that each condition should be recognisable in a community without the need for reference to control samples. A possible drawback exists, however, in unpolluted conditions. The low abundance of the biomass dominants will be liable to higher sampling error than numerical dominants, thus possibly influencing the biomass curve. The result may be the indication of moderate pollution where none exists. However, no cases have yet been found where the unpolluted condition has been indicated in situations of known pollution (Warwick, 1987). The technique identifies disturbance, of which pollution is a main example. However, it will also identify other severe disruptive influences such as sediment instability that have a more sudden effect (acute effect) than long term pollution levels (chronic effect). Sites that exhibit variations in ABC curves from one sample to the next may be influenced by these acute effects.

2.5.7 ABC plots have been constructed for all TEBP sites at each quarter (where sufficient species number exists), these graphs forming Appendix 1. Table 2 summarises each site visit into each class (e.g. GVi2.89 = Gravesend intertidal, 2nd quarter of 1989). The following site visits had a species number too low for ABC curve construction: LB3.89, GW2.89, BK3.89 4.89 1.90, XNs3.89, Ps4.89, WTs3.89.

TABLE 2: POLLUTION STATUS AS DEFINED BY ABC PLOTS

UNPOLLUTED	MODERATELY POLLUTED	GROSSLY POLLUTED
T1.90	T2.89 T3.89 T4.89	
	K4.89 K1.90	K2.89 K3.89
	HB All Quarters	
	CP All Quarters	
	SBC3.89 SBC1.90	SBC2.89 SBC4.89
LB1.90	LB2.89 LB4.89	
	GW3.89	GW4.89 1.90
WWi1.90	WWi3.89 WWi4.89	WWi2.89
WWs3.89	WWs4.89	WWs2.89 WWs1.90
	BK2.89	
	XNi2.89	XNi3.89 XNi4.89 XNi1.90
	XNs4.89	XNs2.89 XNs1.90
	Pi4.89	Pi2.89 Pi3.89 Pi1.90
Ps3.89	Ps2.89 Ps1.90	
WTi All Quarters		
WTs4.89	WTs2.89	WTs1.90
	GVi2.89 GVi1.90	GVi3.89 GVi4.89
	GVs3.89 GVs4.89	GVs2.89 GVs1.90
		MK All Quarters
BS3.89	BS4.89 BS1.90	BS2.89
CB2.89 CB1.90	CB3.89 CB4.89	
		AH All Quarters
CHB All Quarters		
	SEi2.89	SEi3.89 SEi4.89 SEi1.90
SEs2.89 4.89 1.90	SEs3.89	
GF2.89 3.89 4.89	GF1.90	
	SNE2.89 SNE1.90	SNE3.89 SNE4.89
SR22.89 SR21.90		SR23.89 SR24.89

2.5.8 This technique was originally tested on intertidal and subtidal sites from marine and estuarine environments, so results from equivalent areas in the Thames Estuary can be regarded as valid. Results from freshwater/upper estuarine sites have not been tested in the original model, but have been included here for completeness and comparison.

2.5.9 The ABC technique appears to identify the following reaches (overlaid by individual site characteristics):

- Teddington - moderately polluted; unpolluted under full flow.
- Kew-Cadogan Pier - moderately polluted.
- South Bank Centre-Woolwich - moderately polluted with probable sediment instability.
- Beckton-Purfleet - grossly/moderately polluted regardless of instability.
- West Thurrock intertidal - stable unpolluted.
- West Thurrock subtidal-Blythe Sands - moderately/grossly polluted with sediment instability.
- Canvey Beach - unpolluted/moderately polluted.
- Outer estuary subtidal - unpolluted.
- Outer estuary intertidal - grossly/moderately polluted.

2.5.10 There is an obvious difference in the pollution status of the intertidal and subtidal sites in the outer estuary. It is possible that the large sand/mud flats (areas of sedimentation) each side of the estuary are acting as sinks for organic particles from upstream, particularly the sewage works, resulting in the large numbers of small annelids present at these sites. In contrast, the deep subtidal sites (e.g. Chapman Buoy, Southend) may not come into contact with the river water and so reflect a clean marine environment. Shallower subtidal sites (e.g. Mucking, Blythe Sands) appear to show a different pattern - perhaps these sites are more highly influenced by the Thames.

2.5.11 Section 5 summarises each site in more detail, amalgamating the results from the various techniques investigated.

3 INDICATOR ORGANISMS

3.1 NRA suggested indicator organisms.

3.1.1 As part of the NRA classification scheme for estuaries, a list of organisms was drawn up that were considered indicative of both organic enrichment and normal conditions (Table 3). It was suggested that where there is substantial organic enrichment, more than 50% of individuals biomass will be of species indicative of organic enrichment, the listed organisms being regarded as closely associated with organic pollution and so increase in numbers upon an increase in pollution load, often at the expense of more tolerant organisms.

3.1.2 Figures 11 & 12 illustrate the results of plotting the % biomass of the listed organisms for each site. The sites that exceeded the 50% threshold were:

K4.89, HB1.90, CP1.90, SBC2.89 1.90, GW2.89, WWi2.89, WWs1.90, BK3.89 4.89 1.90, XNi2.89 3.89 4.89 1.90, XNs2.89 3.89 1.90, Pi3.89 4.89 1.90, Ps4.89, GVi4.89, MK2.89.

58% of sites exceeding the 50% value fall in the relatively short stretch (15.5 km) between Beckton and Purfleet subtidal, the area dominated by the inputs from the major sewage works.

3.1.3 This percentage figure provides a useful indication of the proportion of these organisms in the community in terms of biomass, but it does not take into account the absolute numbers present, i.e. whether for example the percentage is of a total of 6 organisms or 6000. This extra data can give valuable information on some underlying characteristics of the community, particularly the relationship between organic enrichment and sediment stability. Opportunistic organisms are able to form vast populations in stable substrates, where other organisms should also thrive if no pollution is apparent. In unstable conditions, the community may be

Table 3
Proposed Indicator Organisms

Part of suggested NRA classification scheme for estuaries

Indicative of Normal Conditions

Polychaeta

* Neanthes diversicolor
* Nephtys hombergii
* Scoloplos armiger
* Eteone longa
* Arenicola marina
+ Ampharete balthica
* Neanthes virens
+ Pholoe inornata
(*) Anaitides mucosa
(*) A. maculata

Mollusca

* Hydrobia ulvae
* Macoma balthica
* Scrobicularia plana
* Cerastoderma edule
* Mya arenaria
* Abra alba

Crustacea

* Corophium volutator
* Carcinus maenas
Marinogammarus sp.
+ Diastylis rathkei
* Crangon crangon

Indicative of organic enrichment

Polychaeta

Steblospio shrubsolii
* Polydora spp.
Malacoceros fuliginosus
* Pygospio elegans
* Capitella capitata
Mediomastus fragilis

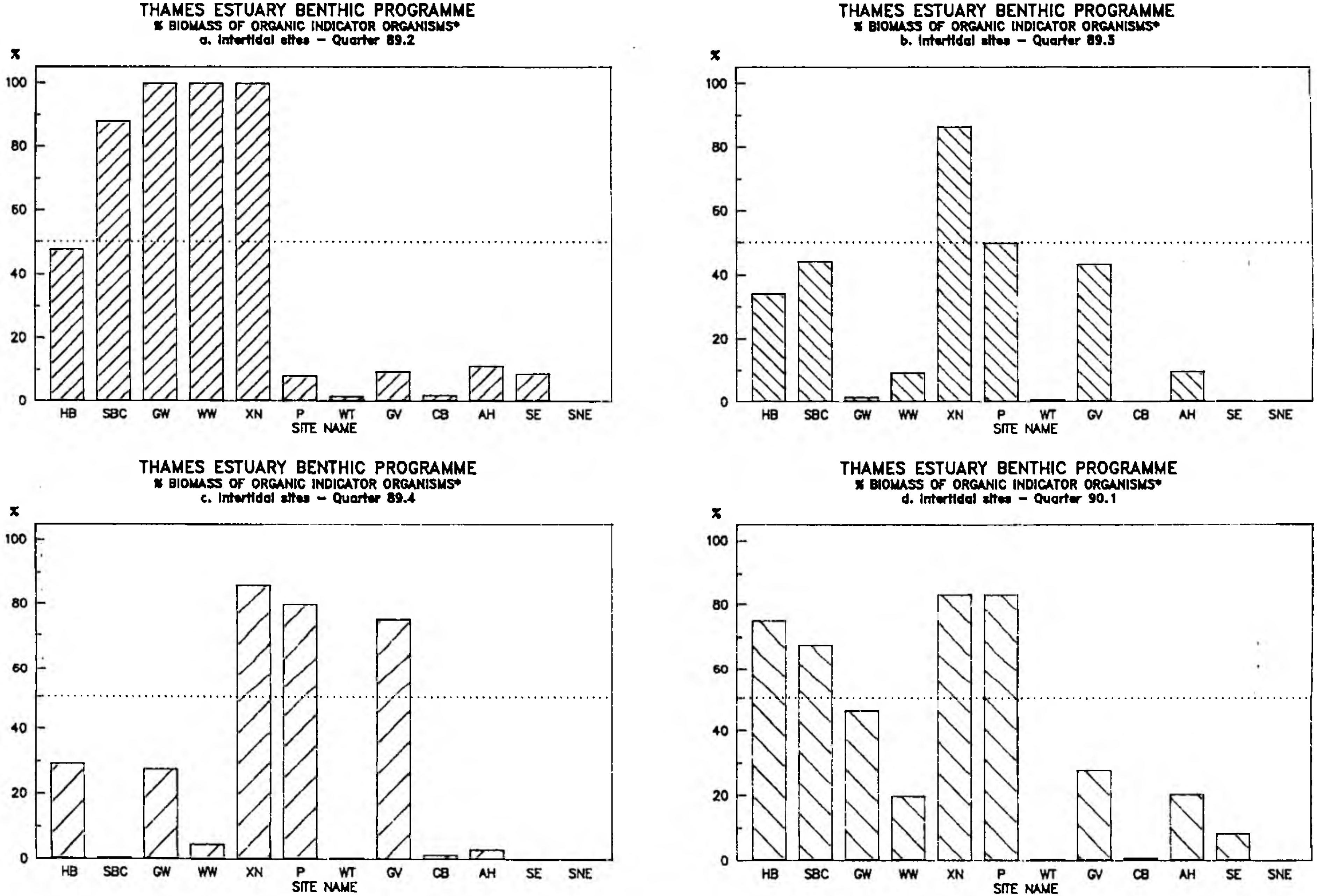
Oligochaeta

* Tubificidae
* Naididae
* Enchytraeidae

* = recorded in Thames Estuary during TEBP

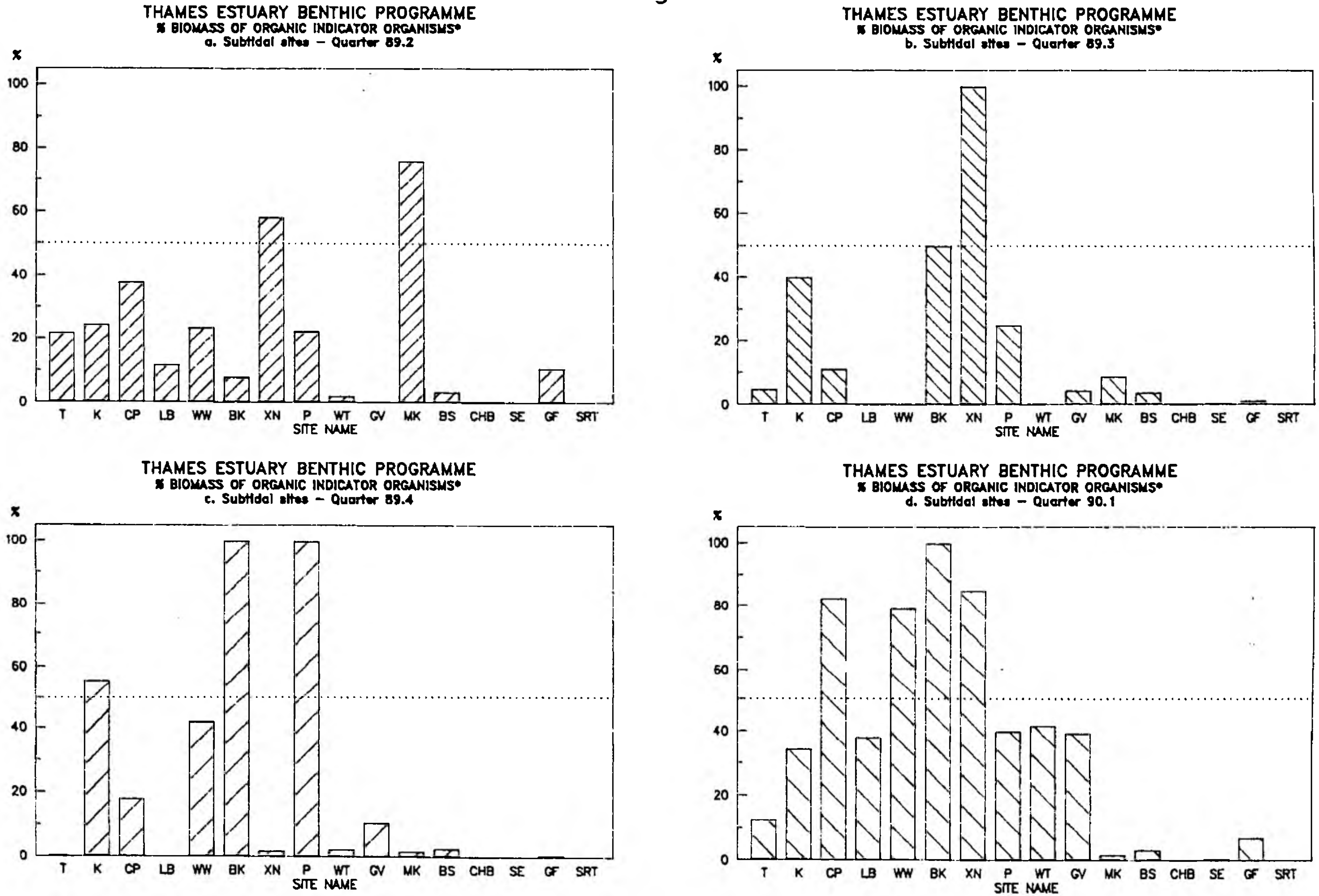
+ = related species recorded

Fig. 11



* oligochaetes, Polydora spp., Pygospio elegans

Fig. 12



* oligochaetes, Polydora spp., Pygospio elegans

represented by a few organisms, the composition of which can vastly influence the % biomass figure.

3.2 Absolute abundance of oligochaetes.

3.2.1 Figures 13 & 14 illustrate the absolute abundances of tubificid oligochaetes at the TEBP sites. Oligochaetes are a group of organisms that have representatives along the whole length of the estuary and are known to form vast populations under conditions of organic enrichment.

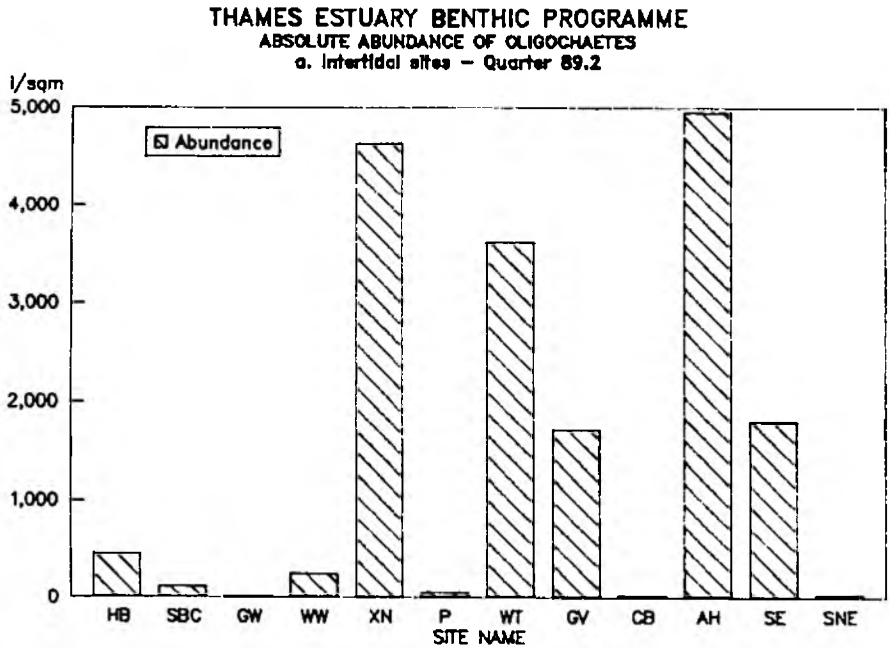
3.2.2 Several intertidal sites have consistently high numbers of oligochaetes: Crossness, West Thurrock (see also below under problems of indicator organisms), Gravesend, Allhallows and Southend. Crossness and Gravesend were also highlighted by the % biomass figures, but the others were not pinpointed, having additional populations of larger organisms. It is possible, therefore, that these sites have a moderate organic enrichment, enabling the increase in oligochaete numbers without as yet affecting the larger organisms.

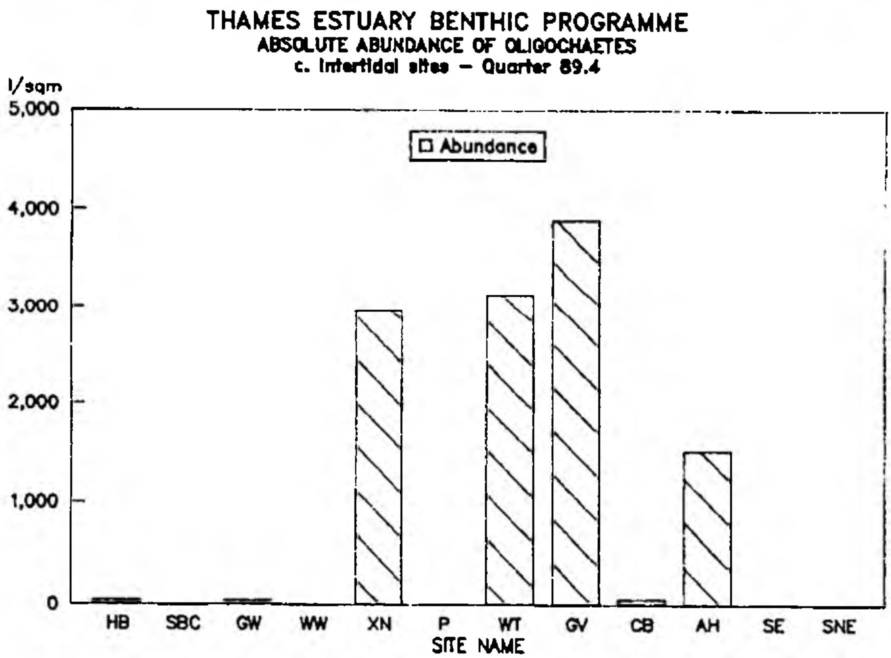
3.2.3 Few subtidal sites have high absolute values of oligochaetes, perhaps indicating the less stable conditions in the mid-estuary and the relatively unpolluted state of the outer estuary sites. The samples from above London Bridge have higher levels, particularly Kew and Cadogan Pier - both sites being pinpointed by the % biomass calculation.

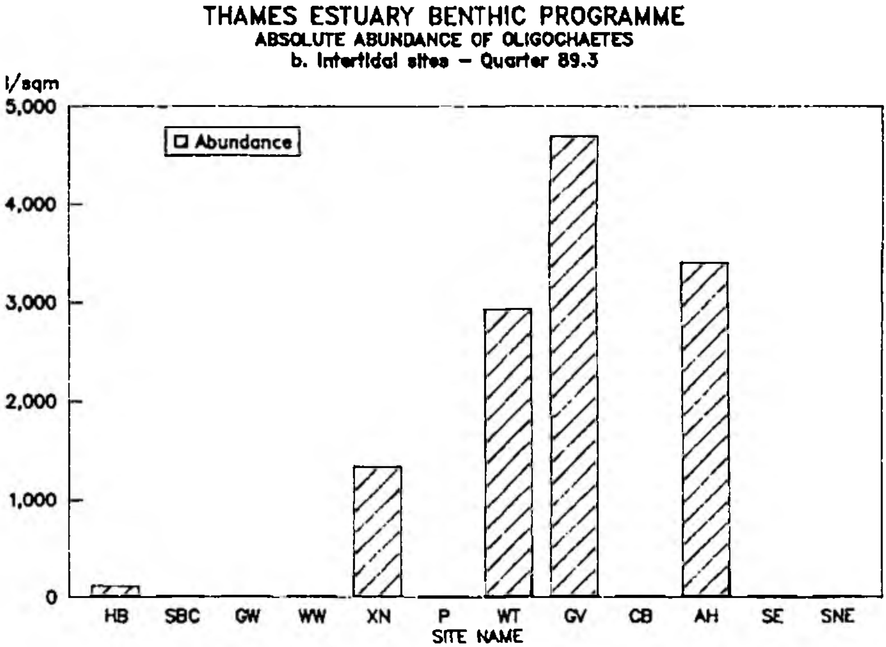
3.3 Relative % dominance of biomass by listed indicator organisms.

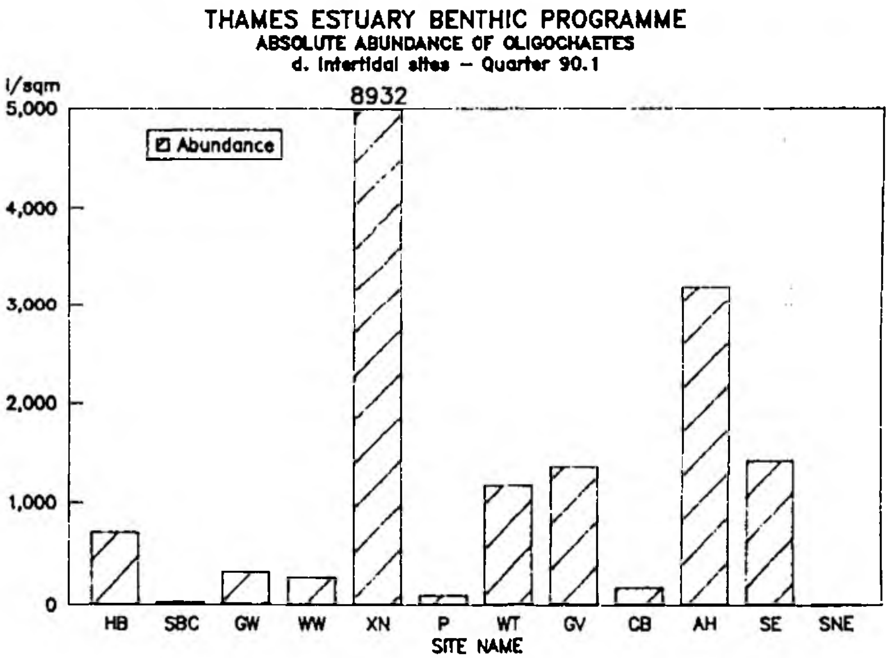
3.3.1 A further investigation that can be undertaken involves the calculation of a percentage dominance using the two lists provided in the NRA estuarine classification document (Table 3). This compares the relative biomass represented by each class of organism ("normal" and "organic enrichment"), resulting in either a positive or negative figure depending on which group is dominant. In this

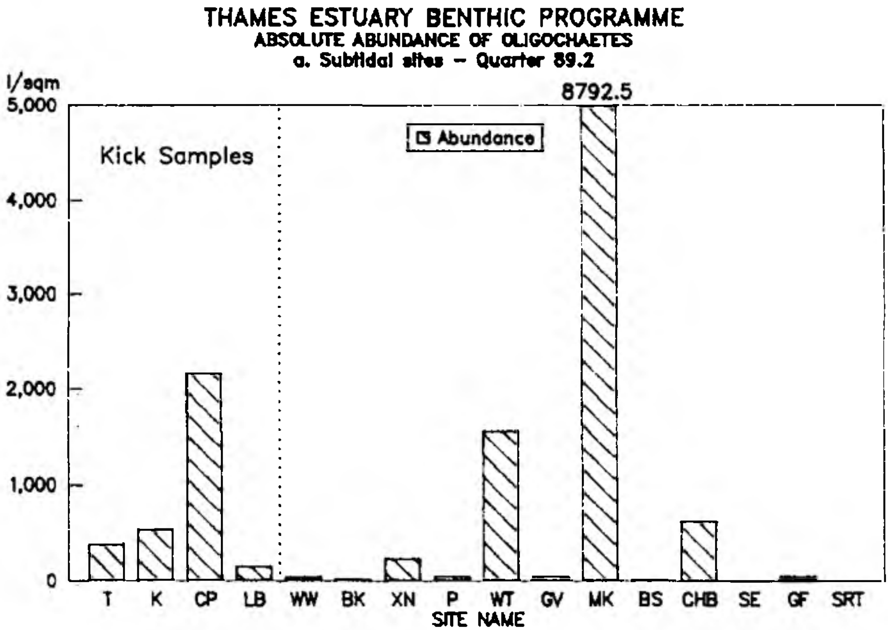
Fig.

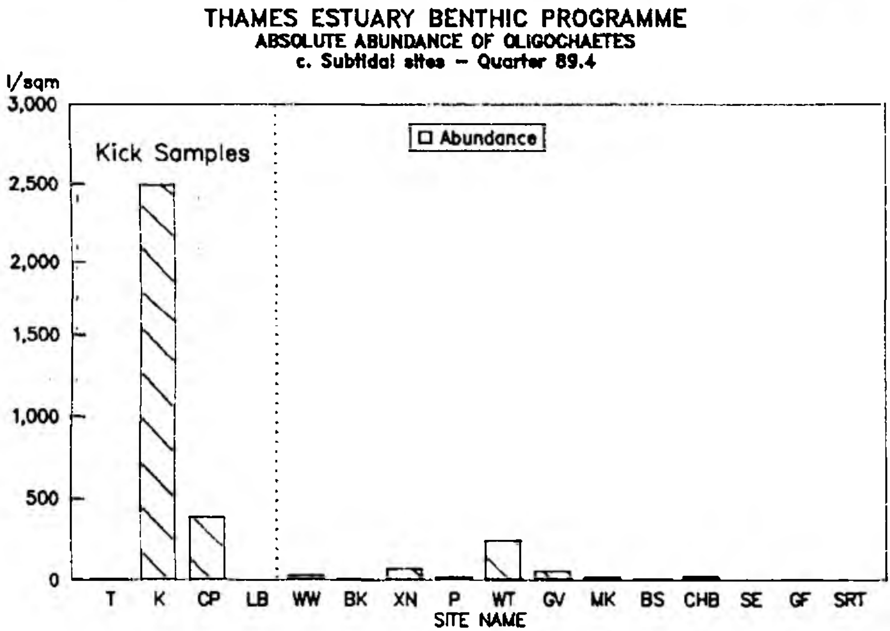

THAMES ESTUARY BENTHIC PROGRAMME
ABSOLUTE ABUNDANCE OF OLIGOCHAETES
a. Intertidal sites – Quarter 89.2
l/sqm
5,000
4,000
3,000
2,000
1,000
0
Abundance
HB
SBC
GW
WW
XN
P
WT
GV
CB
AH
SE
SNE
SITE NAME


THAMES ESTUARY BENTHIC PROGRAMME
ABSOLUTE ABUNDANCE OF OLIGOCHAETES
c. Intertidal sites – Quarter 89.4
l/sqm
5,000
4,000
3,000
2,000
1,000
0
Abundance
HB
SBC
GW
WW
XN
P
WT
GV
CB
AH
SE
SNE
SITE NAME


THAMES ESTUARY BENTHIC PROGRAMME
ABSOLUTE ABUNDANCE OF OLIGOCHAETES
b. Intertidal sites – Quarter 89.3
I/sqm
5,000
4,000
3,000
2,000
1,000
0
Abundance
HB
SBC
GW
WW
XN
P
WT
GV
CB
AH
SE
SNE
SITE NAME

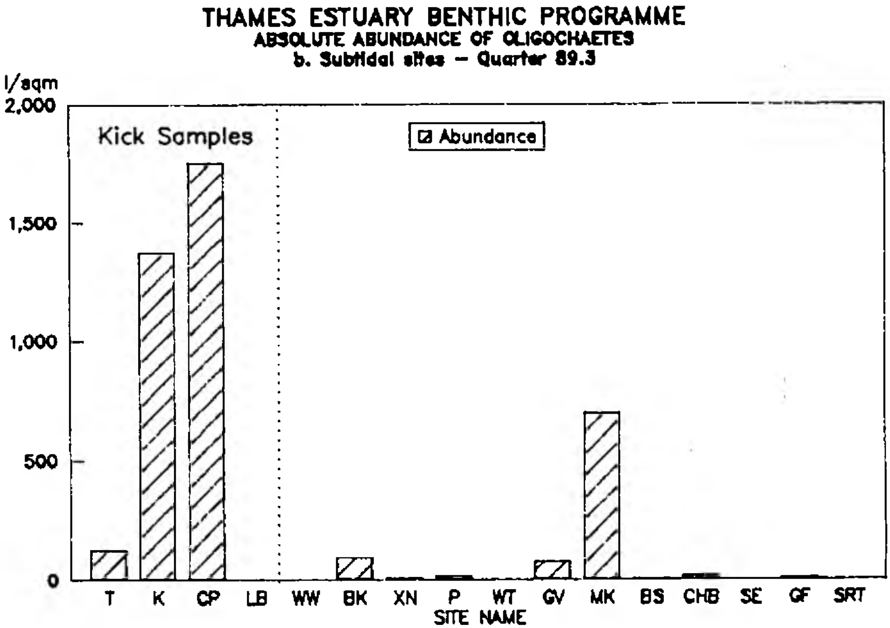

THAMES ESTUARY BENTHIC PROGRAMME
ABSOLUTE ABUNDANCE OF OLIGOCHAETES
d. Intertidal sites – Quarter 90.1
I/sqm
8932
5,000
4,000
3,000
2,000
1,000
0
Abundance
HB
SBC
GW
WW
XN
P
WT
GV
CB
AH
SE
SNE
SITE NAME

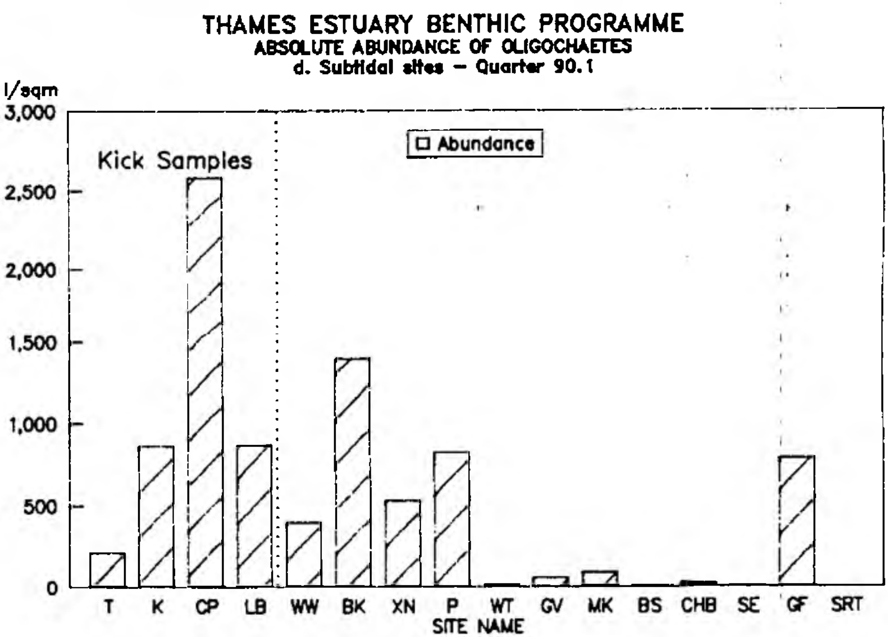




Kick sample values =

Fig. 14





/3min kick. Approximates to 1 sqm

way, sites can be identified that have a majority of "normal conditions" organisms as well as those indicative of organic enrichment. It also indicates sites with a similar proportion of each.

3.3.2 Figures 15-18 illustrate this technique applied to the TEBP sites. Most of the sites with negative scores have previously been highlighted using other methods. These graphs do, however, illustrate some of the pitfalls apparent when using the indicator species, particularly those for "normal" conditions.

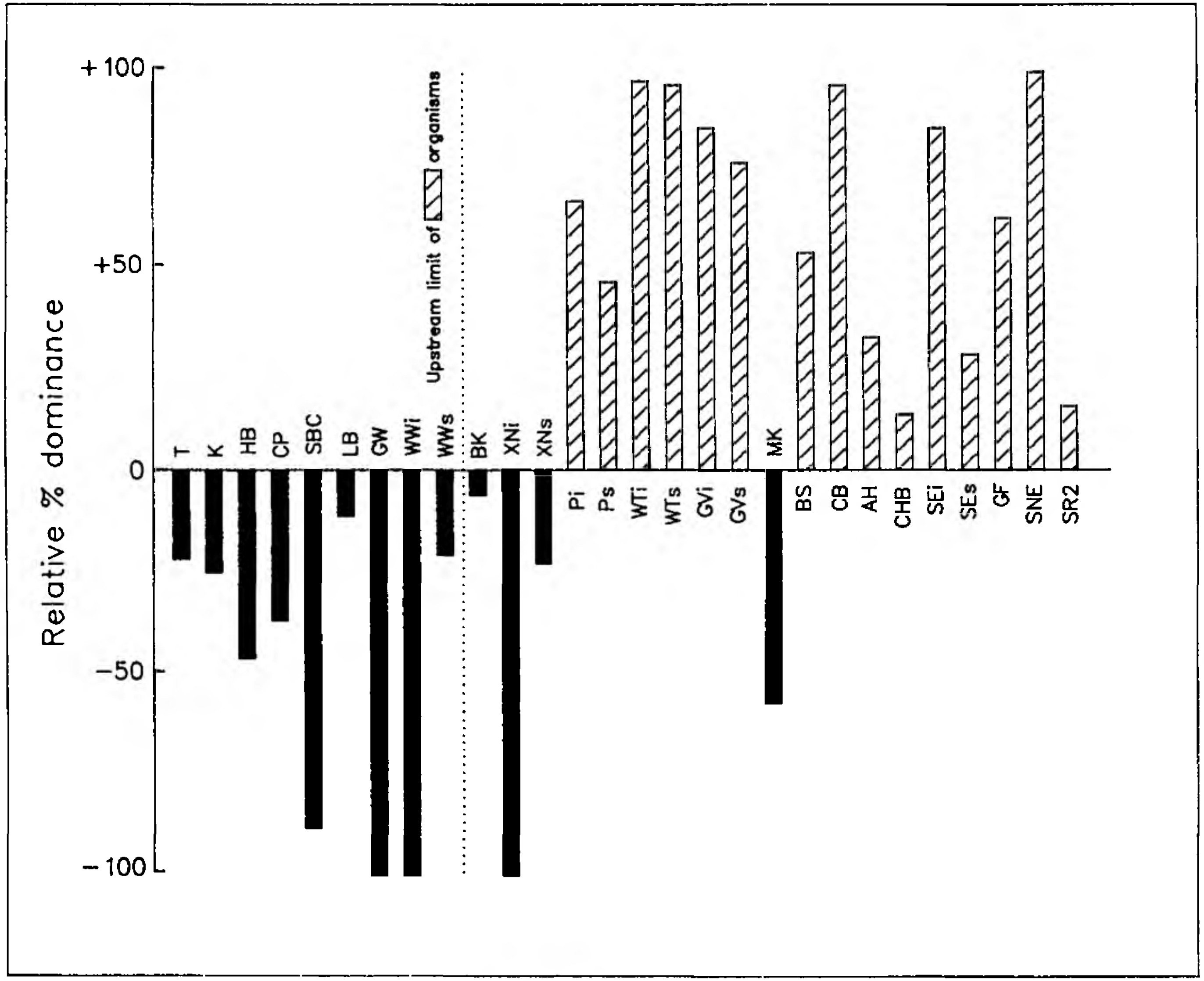
3.4 The limitations of the listed indicator organisms.

3.4.1 The theory behind the use of indicator organisms is sound, particularly when the relationship between the species in question and pollution has been well investigated and understood. The list in use, however, has to be exhaustive to be of value. Several sites in the outer estuary are dominated numerically by a small cerratulid polychaete (<u>Caulleriella</u> sp.) that has all the hallmarks of an organism that responds to organic enrichment, but is not on the NRA list. If it was included in the % biomass calculations, several of the outer estuary sites may have exceeded the 50% threshold. The dynamics of all such organisms has to be assessed to produce a full list of indicator organisms.

3.4.2 The list for organisms indicative of normal conditions appears to be even more limited, with some spurious organisms listed. One obvious limitation is the spatial cover of these organisms (Figs 15-18); none of the listed organisms would be found consistently in the natural conditions of the upper estuary (i.e. above Crossness). Another limitation is apparent at the other end of the estuary, many marine organisms are present in sites such as Chapman Buoy and Southend subtidal that are not listed, but are generally found in clean conditions (e.g. <u>Sabella</u>, many amphipods, sea spiders & bivalves).

Fig. 15

Relative % dominance of biomass by listed indicator organisms
Quarter 2.89



Relative % dominance = (Biomass organisms − Biomass organisms) × 100 / Total sample biomass

Indicative of Normal Conditions

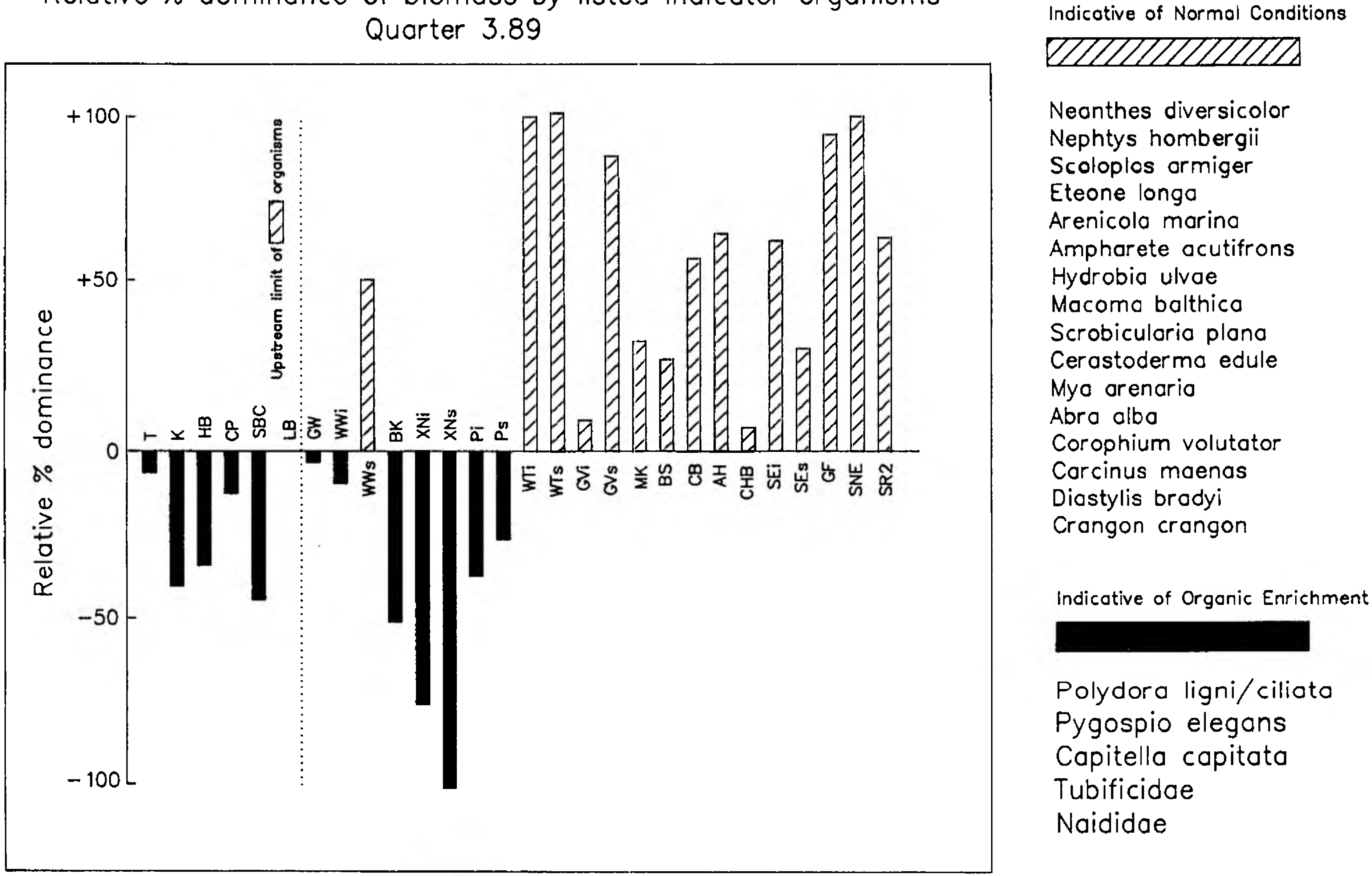
Neanthes diversicolor
Nephtys hombergii
Scoloplos armiger
Eteone longa
Arenicola marina
Ampharete acutifrons
Hydrobia ulvae
Macoma balthica
Scrobicularia plana
Cerastoderma edule
Mya arenaria
Abra alba
Corophium volutator
Carcinus maenas
Diastylis bradyi
Crangon crangon

Indicative of Organic Enrichment

Polydora ligni/ciliata
Pygospio elegans
Capitella capitata
Tubificidae
Naididae

Fig. 16

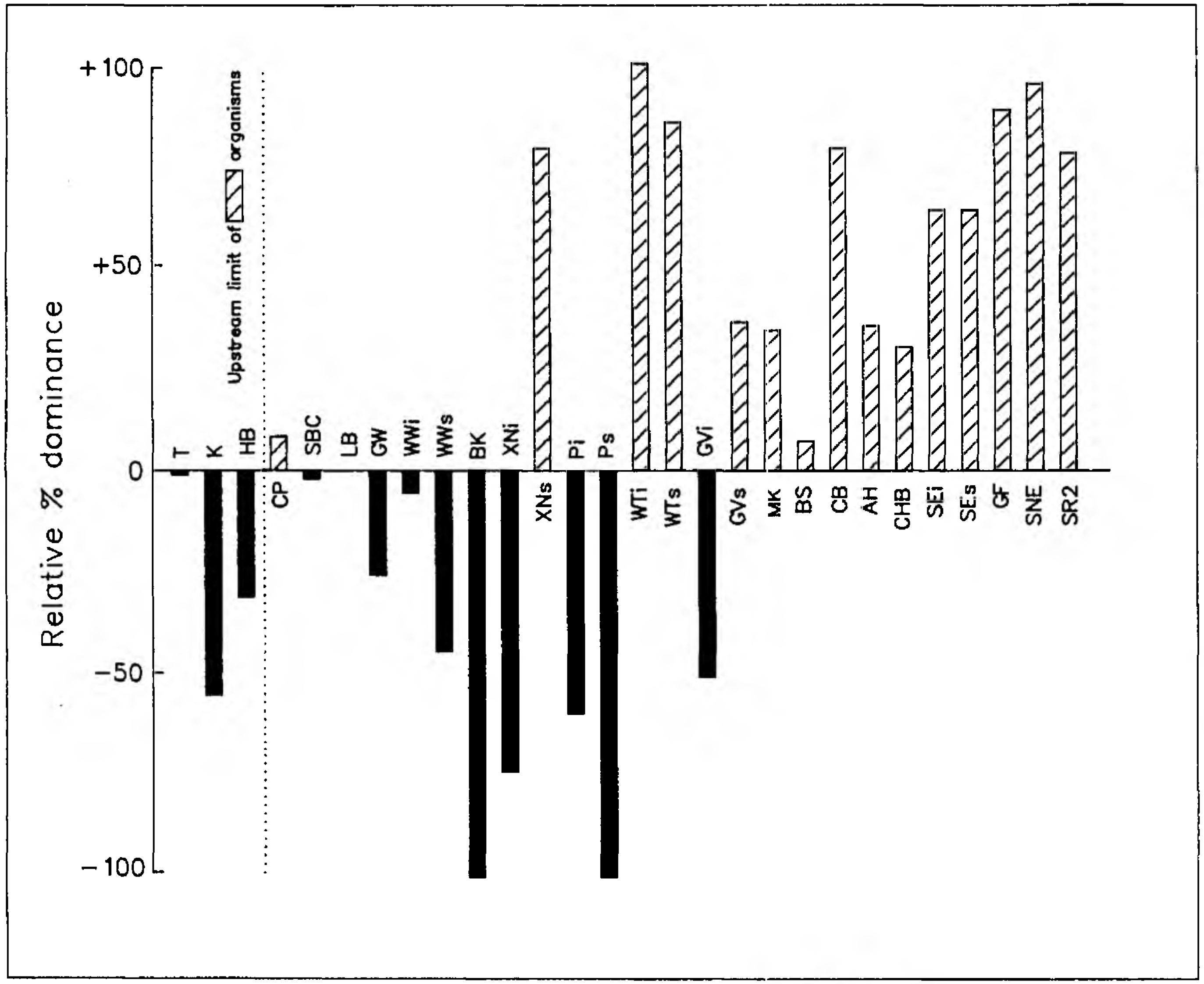
Relative % dominance of biomass by listed indicator organisms
Quarter 3.89



Relative % dominance = (Biomass ▨ organisms − Biomass ■ organisms) × 100 / Total sample biomass

Fig. 17

Relative % dominance of biomass by listed indicator organisms
Quarter 4.89



Relative % dominance = (Biomass ▨ organisms − Biomass ■ organisms) / Total sample biomass × 100

Indicative of Normal Conditions

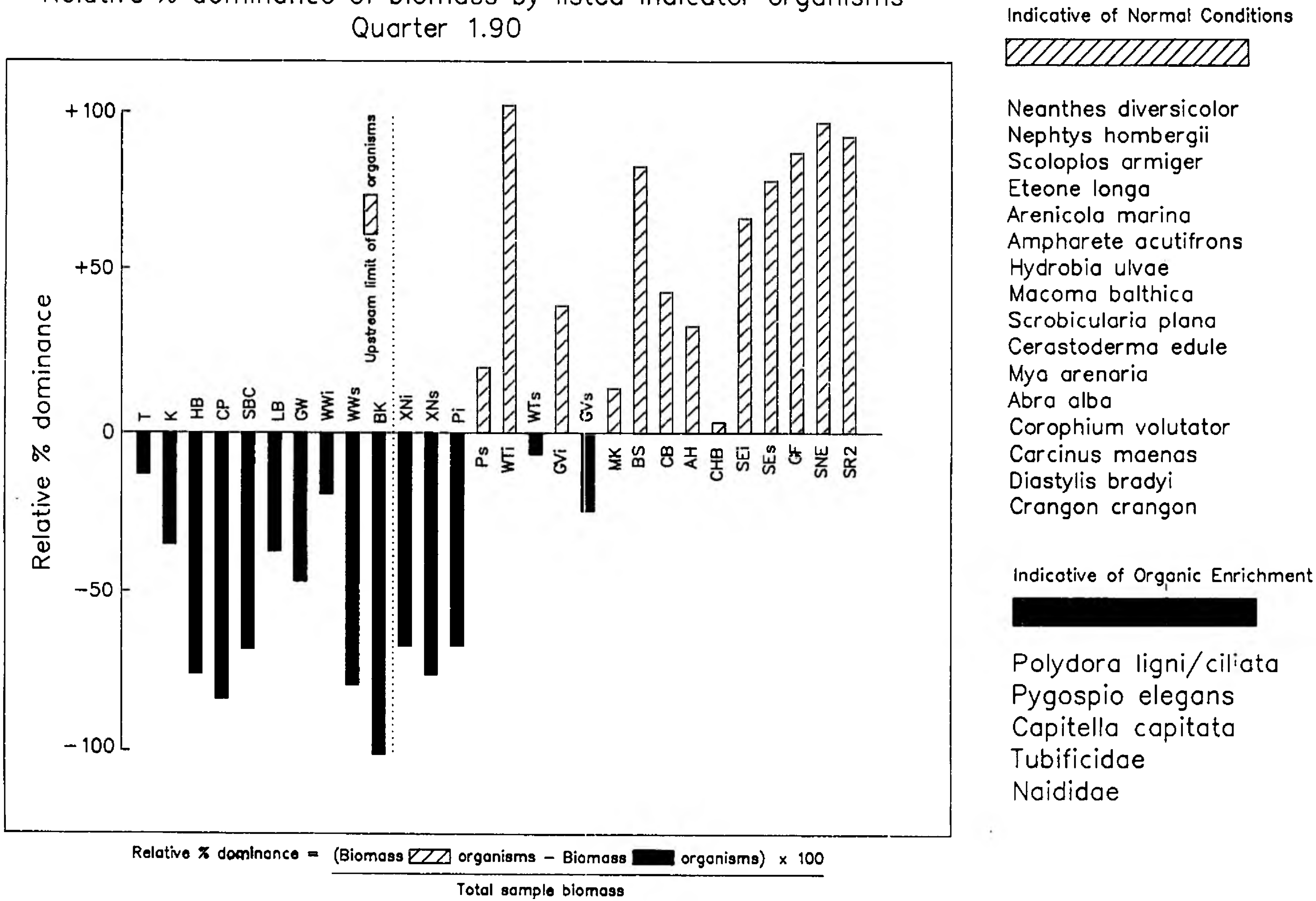
Neanthes diversicolor
Nephtys hombergii
Scoloplos armiger
Eteone longa
Arenicola marina
Ampharete acutifrons
Hydrobia ulvae
Macoma balthica
Scrobicularia plana
Cerastoderma edule
Mya arenaria
Abra alba
Corophium volutator
Carcinus maenas
Diastylis bradyi
Crangon crangon

Indicative of Organic Enrichment

Polydora ligni/ciliata
Pygospio elegans
Capitella capitata
Tubificidae
Naididae

Fig. 18

Relative % dominance of biomass by listed indicator organisms
Quarter 1.90



3.4.3 Probably the greatest limitation of the species list is the actual choice of species itself. Any list of indicator organisms has to be compiled following knowledge of the animal's response to change in condition, pollution or otherwise. Several of the species listed (e.g. Neanthes diversicolor, Hydrobia ulvae) are likely to be found under natural conditions in estuaries, but also respond to increased organic enrichment. An indicator species of value to monitor "normal" conditions should either be related to its biomass and/or abundance or be adversely affected by increased levels of pollution.

3.4.4 It is interesting to compare the list in Table 3 with that constructed by Anger (1977) following a survey of the fauna along a gradient of organic enrichment caused by sewage outfalls from Kiel.

Indicators for organic pollution	**Indicators for slight organic pollution**	**Adverse indicators**
Capitella capitata	Corophium insidiosum	Bathyporeia sarsi
Neanthes diversicolor	Mytilus edulis	Copidognathus fabriciusi
Polydora ligni	Pygospio elegans	Pholoe minuta
	Hydrobia ulvae	Nephtys caeca
	Gammarus salinus	Protodrilus chaetifer
	Polydora ciliata	Mysella bidentata
	Neanthes succinea	
	Idotea balthica	
	Microdeutopus gryllotalpa	
	Anaitides mucosa	

3.4.5 It is notable that Anger lists N.diversicolor as a main indicator for organic pollution along with Capitella, whereas the NRA list classes it as indicative of normal conditions. If this species was also included in the % biomass calculations, then sites like West Thurrock intertidal would shift dramatically to an area dominated by organisms indicative of organic enrichment. It is apparent that much work is needed on the community dynamics of certain species, both in relation to the natural physico-chemical variation within an estuary and the additional effects of pollution, before indicator organisms can be used without caution. They do, however, have the potential to be an extremely useful tool in determining pollution status and a precursor to a full scoring system relating to the distribution and abundance of the organisms themselves.

4 A COMMUNITY SCORE - INITIAL SUGGESTIONS

4.1 The ultimate estuarine quality scoring system would be related to the expected distribution and abundance of a wide range of organisms over the particular set of physico-chemical parameters at each site under investigation. This development is a long way off, requiring a large scale co-ordinated survey of many major UK and north European estuaries coupled with a fuller understanding of the response of estuarine organisms to both natural and anthropogenic variation. In the absence of such a system, the community structure within an estuary has to be used for any pollution inference (as detailed in earlier sections), but it would be useful to be able to amalgamate all these data into a single value to give a rough indication of the status of the site in question. This would act as a summary of the various community parameters rather than an alternative.

4.2 **Initial scoring system.**

4.2.1 It is possible to allocate a sliding scale of scores to each valuable community parameter previously investigated, a higher score relating to the values expected within an unpolluted, stable community. For example, high species number will score more than a low species number, whereas a high % biomass represented by the organisms indicative of organic enrichment would be allocated a lower score than a site where few of these organisms are present.

4.2.2 Table 4 details the series of scores allocated to the parameters species number, diversity, evenness, % biomass represented by taxa indicative of organic enrichment, total oligochaete abundance and ABC curves. In addition, nematode species number is used from data in a companion report on the meiofauna of the TEBP sites (Trett & Feil, 1990). Scores are summed to give a Community Score (CS).

4.2.3 It has to be stressed that, in accordance with many scoring systems like the freshwater BMWP score, the scores allocated are arbitrary, relating only to the value of each parameter in determining

Table 4

Community Score Allocation.

Species Number

Value	Score
0	0
1-5	2
6-10	4
11-15	6
16-20	8
>20	10

Evenness (J)

Value	Score
0	0
0.01-0.2	1
0.21-0.4	2
0.41-0.6	3
0.61-0.8	4
>0.8	5

Diversity (H'e)

Value	Score
0	0
0-0.5	1
0.51-1.0	2
1.01-1.5	3
1.51-2.0	4
>2.0	5

% Biomass represented by taxa indicative of organic enrichment

Value	Score
<20	10
20-39.99	8
40-59.99	6
60-79.99	4
80-99.99	2
100	0

Total oligochaete abundance

Value	Score
0-10	5
11-100	4
101-1000	3
1001-5000	2
5001-10000	1
>10000	0

Abundance/Biomass Curves

Value	Score
Bmass>>Abun	10
Bmass>Abun	7
Bmass=Abun	5
Abun>Bmass	2
Abun>>Bmass	0

Number nematode species

Value	Score
0	0
1-5	2
6-10	4
11-20	6
21-30	8
>30	10

pollution disturbance. The scores do not necessarily relate to each other, i.e. 6-10 species present are as valuable as an evenness of 0.61-0.8. Primary indicators (i.e. species number) are given extra weighting, together with the two developed methods for determining pollution levels (% biomass indicator species and ABC plots). Overall, however, the scores should reflect the environment as a whole, with poor sites recording low scores and clean sites recording high scores.

4.2.4 It also has to be stressed that the whole score allocation and score classes within each category are provisional and subject to much development when necessary.

4.3 Score results from the TEBP sites.

4.3.1 Table 5 (columns 3-6) and Figure 19 display the accumulated scores for each site in each quarter.

4.3.2 Peaks and troughs can be detected, such as low values for Beckton, Crossness and Purfleet in most quarters and constant high values for Chapman Buoy and Southend subtidal. The score at Teddington is seen to drop during the low flow conditions of quarter 4.89 and recover on resumption of full flow conditions (Quarter 1.90). The scores also reflect the variability of sites in the mid-estuary.

4.3.3 It would appear that the community score pinpoints poor and good sites and is sensitive, responding to known variations (low flows). It also allows sites to be compared, as the same system is used over the full range of the estuary.

4.4 Maximum possible score and % Maximum (%M).

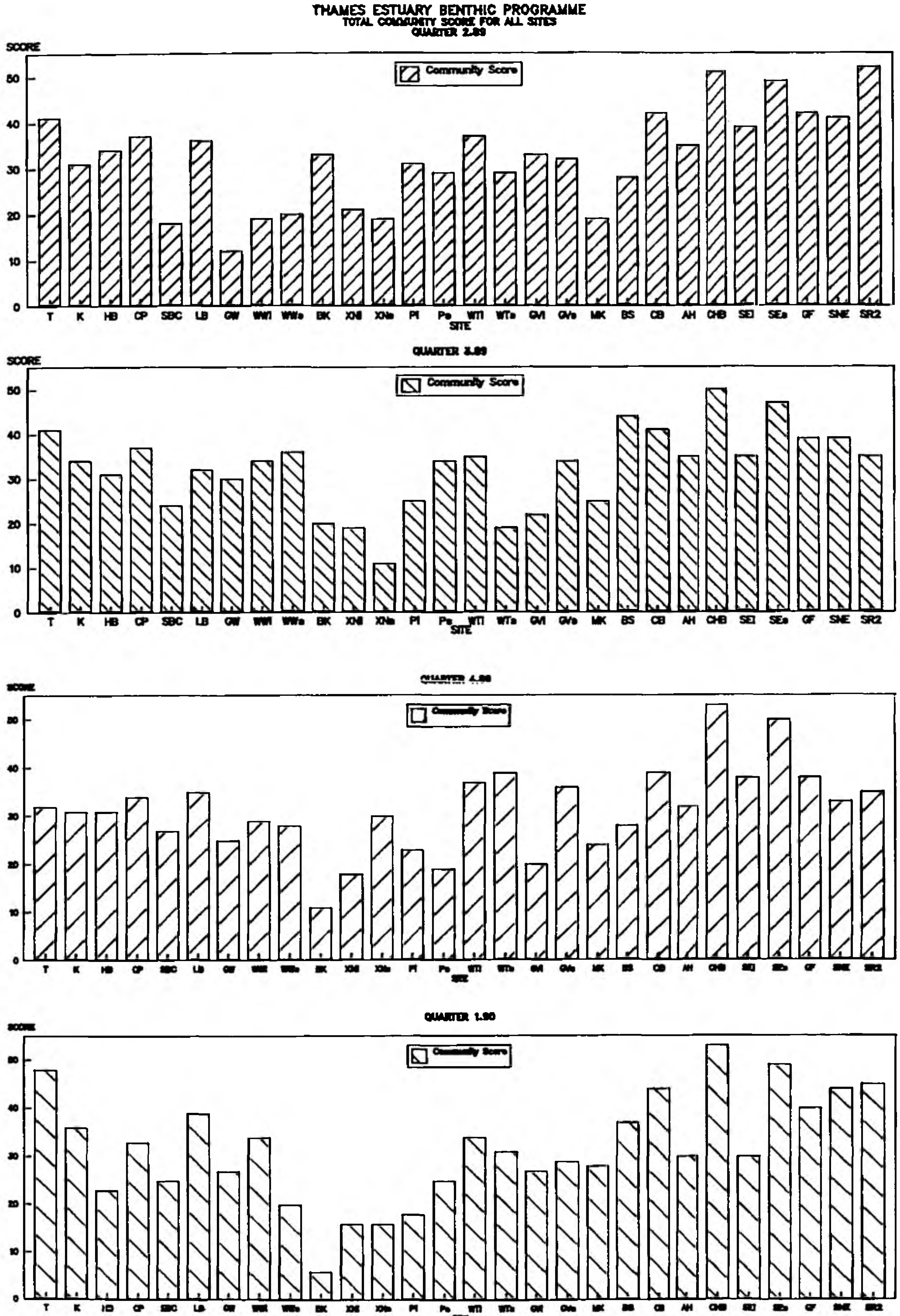
4.4.1 As discussed earlier, the most naturally stressful area in the estuary is in the middle reaches where variations are greatest. As a result the potential pool of species is smaller here than at each end of the estuary. This will influence the community score, the

Table 5

COMMUNITY SCORE DATA, APRIL 1989-MARCH 1990

Site	Max Score	Observed Score 2.89	3.89	4.89	1.90	% Max Score 2.89	3.89	4.89	1.90
1. T	55	41	41	32	48	74.5	74.5	58.2	87.3
2. K	55	31	34	31	36	56.4	61.8	56.4	65.5
3. HB	51	34	31	31	23	66.7	60.8	60.8	45.1
4. CP	55	37	37	34	33	67.3	67.3	61.8	60.0
5. SBC	49	18	24	27	25	36.7	48.9	55.1	51.0
6. LB	53	36	32	35	39	67.9	60.4	66.0	73.6
7. GW	49	12	30	25	27	24.5	61.2	51.0	55.1
8i.WWi	51	19	34	29	34	37.3	66.6	56.9	66.7
8s.WWs	45	20	36	28	20	44.4	80.0	62.2	44.4
9. BK	44	33	20	11	6	75.0	45.5	25.0	13.6
10i.XNi	49	21	19	18	16	42.9	38.8	36.7	32.7
10s.XNs	47	19	11	30	16	40.4	23.4	63.8	34.0
11i.Pi	47	31	25	23	18	65.9	53.2	48.9	38.3
11s.Ps	46	29	34	19	25	63.0	73.9	41.3	54.3
12i.WTi	49	37	35	37	34	75.5	71.4	75.5	69.4
12s.WTs	47	29	19	39	31	61.7	40.4	83.0	66.0
13i.GVi	51	33	22	20	27	64.7	43.1	39.2	52.9
13s.GVs	51	32	34	36	29	62.7	66.6	70.6	56.7
14. MK	51	19	25	24	28	37.3	49.0	47.1	54.9
15. BS	53	28	44	28	37	52.8	83.0	52.8	69.8
16. CB	55	42	41	39	44	76.4	74.5	70.9	80.0
17. AH	55	35	35	32	30	63.6	63.6	58.2	54.5
18. CHB	55	51	50	53	53	92.7	90.9	96.4	96.4
19i.SEi	55	39	35	38	30	70.9	63.6	69.1	54.5
19s.SEs	55	49	47	50	49	89.1	85.4	90.9	89.1
20. GF	55	42	39	38	40	76.4	70.9	69.1	72.7
21. SNE	55	41	39	33	44	74.5	70.9	60.0	80.0
22. SR2	55	52	35	35	45	94.5	63.6	63.6	81.8

Fig. 19


THAMES ESTUARY BENTHIC PROGRAMME
TOTAL COMMUNITY SCORE FOR ALL SITES
QUARTER 2.89
SCORE
Community Score
0
10
20
30
40
50
T
K
HB
CP
SBC
LB
GW
WWl
WWs
BK
XNl
XNs
Pl
Ps
WTl
WTs
GVl
GVs
MK
BS
CB
AH
CHB
SEl
SEs
GF
SNE
SR2
SITE
QUARTER 3.89
QUARTER 1.90

mid estuary would score less under totally natural conditions due to the lower community diversity generally found there. It is therefore necessary to buffer this effect in order to compare sites.

4.4.2 A possibility is to calculate the potential maximum score for each site, calculated from the species recorded there over the year as a whole. The site can potentially support these species, they have been found living there. If this species number is fed into the score allocation and the maximum possible values allocated from then on, the result will be the maximum possible score the site could potentially record (CSmax). Table 5 (column 2) lists the maximum calculated values.

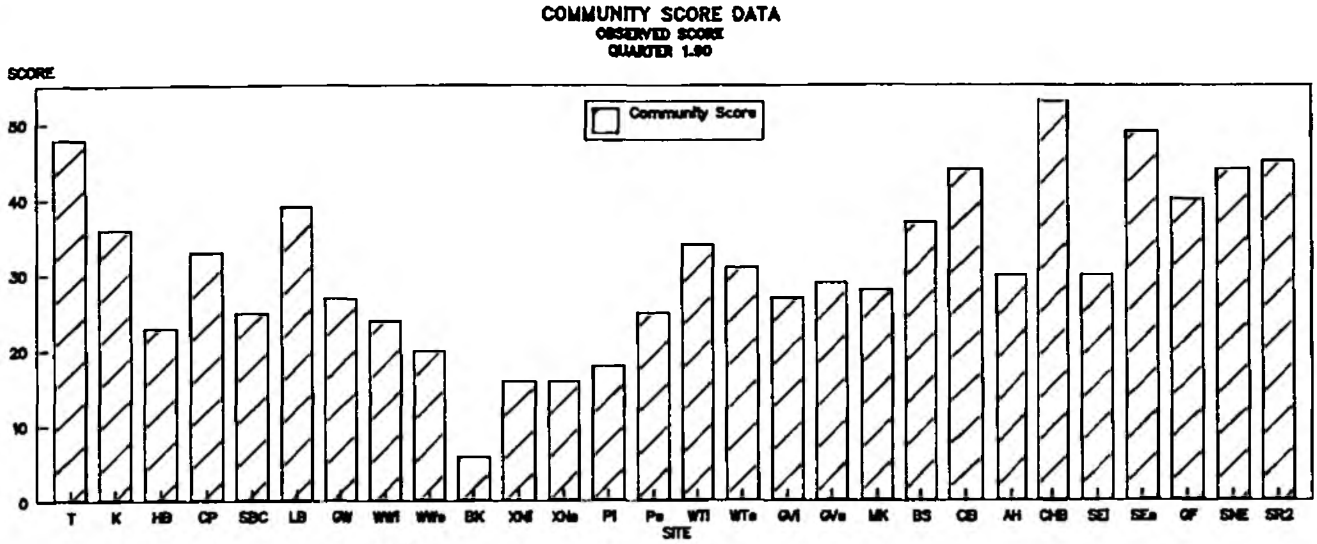
4.4.3 Once calculated, it is therefore possible to relate the observed community score (CS) with the potential maximum score (CSmax) to obtain a percentage of the potential score that the site could record (%M):

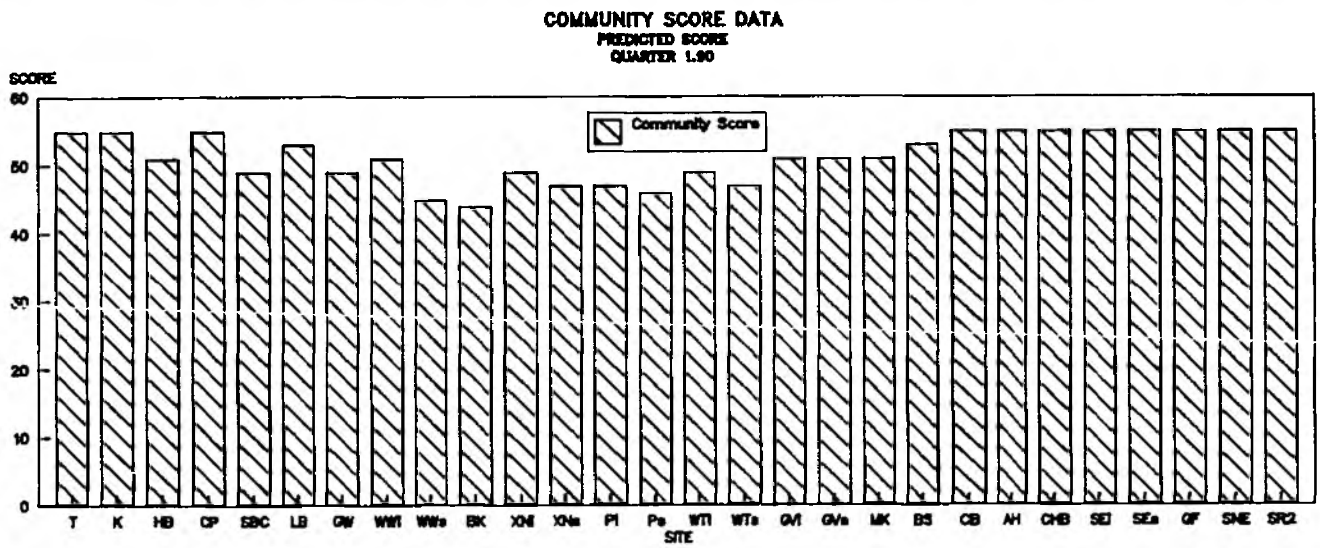
$$\%M = \frac{CS \times 100}{CSmax}$$

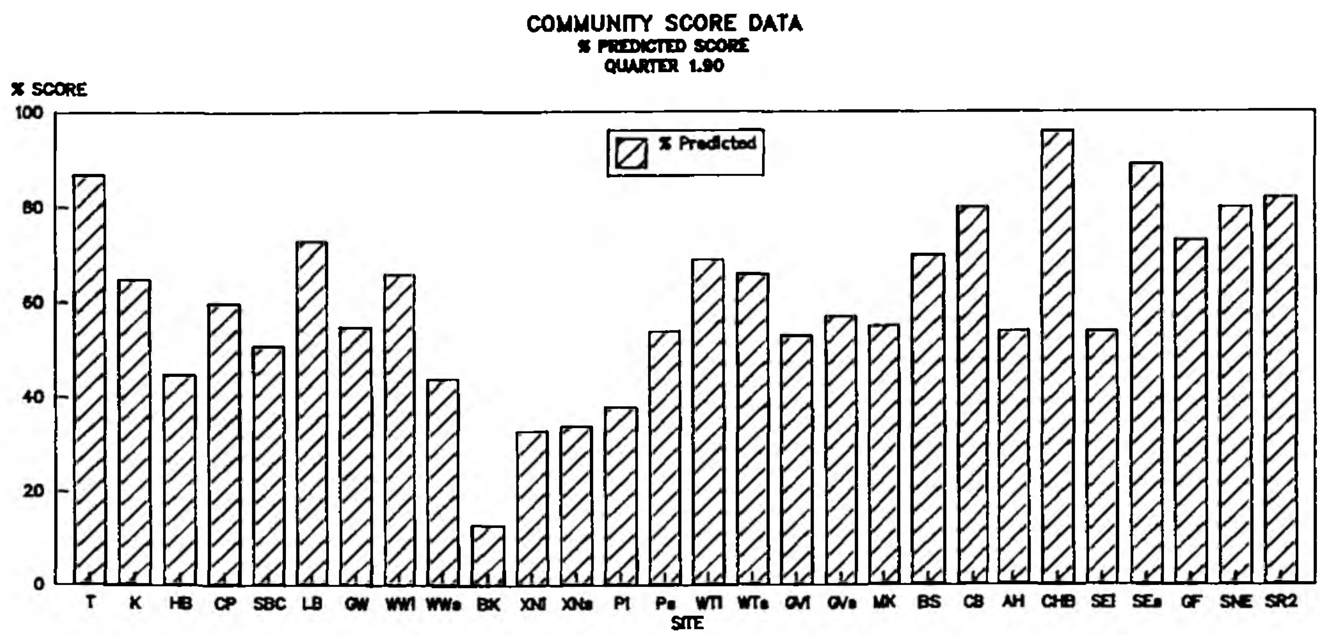
This value can then be used as an indication to the health of the community, lower values perhaps suggesting the community is stressed.

4.4.4 Figure 20 illustrates CS, CSmax and %M for quarter 1.90 as an example. The pattern is similar to CS, though several mid-estuary sites (e.g. WWi, GW) have been elevated as %M is taken into account. This graph also highlights the dramatic drop in scores at Beckton, and a steady recovery from this point. The score system pinpoints the outer estuary intertidal sites of Allhallows and Southend, these scores being considerably lower than the surrounding values.

Fig.20


COMMUNITY SCORE DATA
OBSERVED SCORE
QUARTER 1.90
SCORE
Community Score
0
10
20
30
40
50
T K HB CP SBC LB GW WW1 WWs BK XN1 XNs P1 Ps WT1 WTs GV1 GVs MK BS CB AH CHB SE1 SEs GF SNE SR2
SITE


COMMUNITY SCORE DATA
PREDICTED SCORE
QUARTER 1.90
SCORE
Community Score
0
10
20
30
40
50
60
T K HB CP SBC LB GW WW1 WWs BK XN1 XNs P1 Ps WT1 WTs GV1 GVs MK BS CB AH CHB SE1 SEs GF SNE SR2
SITE


COMMUNITY SCORE DATA
% PREDICTED SCORE
QUARTER 1.90
% SCORE
% Predicted
0
20
40
60
80
100
T K HB CP SBC LB GW WW1 WWs BK XN1 XNs P1 Ps WT1 WTs GV1 GVs MK BS CB AH CHB SE1 SEs GF SNE SR2
SITE

4.5 Thames Estuary Zone Map - alternative data display.

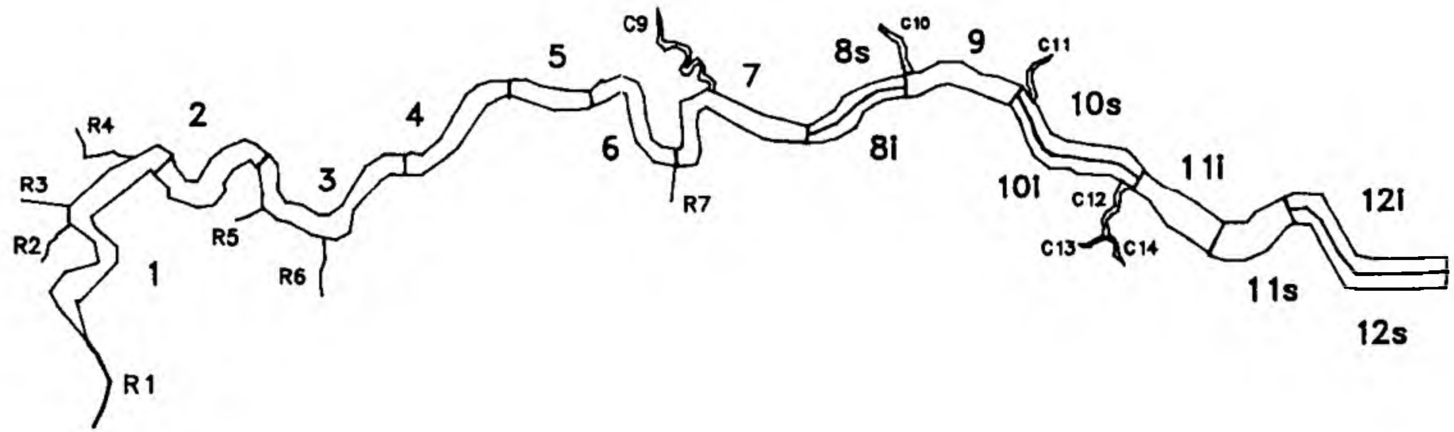
4.5.1 The extensive set of TEBP sites along the Thames Estuary allows the development of zones and corridors - the reach between one site and the next. This can be used as an aid in displaying community data (such as species number, community score) by positioning the actual data at the site where the sample was taken, using a colour coded system.

4.5.2 Figure 21 constructs the Thames Estuary in terms of the zones determined by the position of the TEBP sample sites, the number of each zone relating to the site at its upstream limit (Table 1). In addition, rivers and creeks can be added if required.

4.5.3 Figures 22 and 23 show examples of how the map can be used, illustrating the species number and community score for quarter 1.90. The maps allow the observer to place the sites in their actual space and to pinpoint the areas where scores are low or high.

Fig.21

1. Teddington to Gravesend



2. Outer Estuary

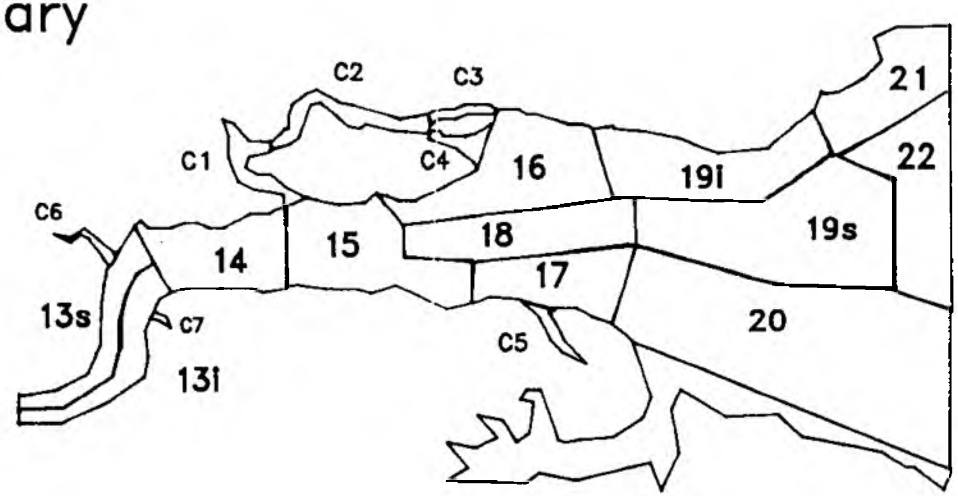


Diagram of the Thames estuary illustrating the position of benthic zones, creeks and other rivers.

Fig.22

1. Teddington to Gravesend

2. Outer Estuary

Quarter 1.90 – Total species number for all sites

Fig.23

1. Teddington to Gravesend

2. Outer Estuary

Quarter 1.90 – Community Score for all sites

5 SITE SUMMARIES IN RELATION TO POLLUTION INFERENCE

5.1 **Teddington** - From the community statistics, Teddington appears to be a relatively unpolluted site, but is highly dependant on the quantity, and obviously the quality, of water coming over the weir from the freshwater Thames. During low flow conditions, the balance of the community is upset, resulting in low diversity and fewer species. This is reflected in the community score, which showed a marked decrease during the low flow period of 4.89.

5.2 **Kew** - This site seems to be influenced by organic enrichment, being pinpointed by the ABC plots and the indicator organism techniques. This could arise from several sources, namely the GUC/Brent, storm drains or most likely Mogden STW, as it is by far the largest discharge entering the Thames in this area.

5.3 **Hammersmith Bridge** - The ABC curves class this site as moderately polluted, though there is less sign of organic enrichment. This may be masked by the relatively unstable sand substrate at this site, resulting in low biomass and abundance. High levels of a variety of contaminants have been detected in the sediment here (Attrill, 1990 c, d).

5.4 **Cadogan Pier** - Again classed as moderately polluted by the ABC method, this site may be influenced by the large number of storm drains in the area, in addition to the quality of water from upstream. Large numbers of oligochaetes suggest organic enrichment.

5.5 **South Bank Centre** - A poor site, with an unstable substrate judging from the low abundances. Most community parameters point to some degree of pollution at this site, two quarters being classed as grossly polluted by the ABC method. This is likely to be aggravated by the unstable, hostile physical conditions, but the community score for this site is lower for each quarter than Cadogan Pier and London Bridge (the immediate upstream and downstream sites).

5.6 **London Bridge** - A harsh, unstable physical environment is present at this site, though it has a comparatively good community score and a low pollution classification using the ABC method. Physico-chemical variations are probably the greatest problem facing organisms at London Bridge.

5.7 **Greenwich** - Twice classed as grossly polluted by the ABC method, only one species (an oligochaete) was recorded here during 2.89. This site represents the upstream limit of permanent, though internally mobile, mudbank, suggesting an area of organic deposition. These mud areas tend to be unstable, however, which will influence the distribution of organisms.

5.8 **Woolwich** - Both sites at Woolwich have similar characteristics, appearing in all three ABC classes during the year. This would suggest major instability here, though it is possible that the sites may be influenced by effluent from Beckton STW on the incoming tide. The community scores are also variable.

5.9 **Beckton** - All indicators point to this site as being the most polluted in the Thames estuary, due to the large amount of STW effluent discharging at this point. Only one species (oligochaete) was recorded here during the second half of the sample period. Apart from the quarter 2.89, when the site indicated what it can potentially support, Beckton has recorded by far the lowest community scores. Variable abundances indicate some instability, though it is quite possible that the unstable sediment is due to the physical effects from the outfall itself.

5.10 **Crossness intertidal** - The relatively stable mudflats here allow this problematic variable to be mostly discounted. The site, however, still appears to be severely polluted, with three quarters being classified as grossly polluted by the ABC method, high % biomass of the organisms indicative of organic enrichment, vast abundances of oligochaetes and relatively low community scores.

5.11 **Crossness subtidal** - This site shows similar characteristics to the intertidal site, but with the added complication of sediment instability. Two quarters were classified as grossly polluted by the ABC method, one quarter had only one species and the community scores tend to be low.

5.12 **Purfleet intertidal** - Low abundances and variable community scores suggest unusual instability at this site, probably due to the river shape at this point. However, many community parameters at this site suggest some pollution, three quarters being classed as grossly polluted by the ABC method together with high % biomass of organic enrichment indicator organisms. Variable community scores indicate the instability.

5.13 **Purfleet subtidal** - As for the intertidal site a highly unstable substrate recording low abundances and variable results from several community parameters. Though no quarters were classed as grossly polluted, 4.89 recorded only two species, both oligochaetes. It is likely that both Purfleet sites are still influenced by the main STW (and possibly other local discharges), though instability is the major problem.

5.14 **West Thurrock intertidal** - As for Crossness, this site possesses a firm, stable substrate recording extremely high abundances. Large numbers of oligochaetes are present in the sediment, indicating some enrichment, but these are dominated by vast numbers of *Neanthes diversicolor*, resulting in generally good scores and unpolluted classification from the ABC method.

5.15 **West Thurrock subtidal** - A dramatically unstable environment, especially when compared to the intertidal site less than 200 m away (see Attrill 1990a for full site details). This instability is reflected in the range of classifications using the ABC method and the variation in community scores. However, it is interesting to note that apart from quarter 3.89 when nearly all life disappeared, the community scores for the subtidal site were similar to the intertidal area.

5.16 **Gravesend** - Both subtidal and intertidal sites recorded two quarters each in the moderately polluted and grossly polluted ABC classes. In a similar way to Crossness and West Thurrock, the subtidal area is inherently less stable than the intertidal site, recording much lower abundances. The intertidal area recorded over 50% biomass of organisms indicative of organic enrichment in quarter 4.89, with constantly high numbers of oligochaetes. Unlike West Thurrock, this is not countered by large numbers of N.diversicolor. As a result, some of the intertidal site's community scores are low.

5.17 **Mucking** - Most community indicators for this site indicate some influence from pollution, the site being dominated by vast numbers of small annelids. This resulted in all four quarters being classed as grossly polluted by the ABC method, complementing low diversities and evenness and low community scores. Quarter 2.89 was dominated by oligochaetes (resulting in >50% biomass of organic enrichment organisms); the other quarters by a small cerratulid polychaete (Caulleriella sp.) not on the NRA list.

5.18 **Blythe Sands** - It would appear that the sand banks at Blythe provide a relatively unstable substrate, with low species number and abundance, variable community score and a wide spread of classification using the ABC method. The site always registered low numbers of oligochaetes, however, and the % biomass of organisms indicative of organic enrichment was consistently small. This would suggest an unstable but relatively unpolluted environment.

5.19 **Canvey Beach** - This site appears to be the least polluted of the outer estuary intertidal sites, with low/moderate pollution classification by the ABC method, a negligible % biomass of organic enrichment organisms, few oligochaetes and a generally good set of community statistics. The community scores are consistently higher than the other outer estuary intertidal sites.

5.20 **Allhallows & Southend intertidal** - These sites possess large stable mudflats with a wide range of species. However, they are numerically dominated by small annelids, both oligochaetes and the polychaete Caulleriella. As a result, they are classified as grossly polluted by the ABC method, have low diversity and evenness and community scores lower than other outer estuary sites. These extensive mud and sand flats may be areas of deposition for material from the Thames estuary and local sewage outfalls, resulting in the organic enrichment that is indicated by community analysis.

5.21 **Chapman Buoy** - This site appears to be wholly unpolluted, with positive results from all the community parameters investigated. As a result it has a consistently high community score. This site is situated deep (20 m) in the outer estuary shipping channel, so it cannot be discounted that the reason the site is so unpolluted is because it rarely, if ever, comes in contact with Thames water. It is possible that the deep channel is generally full of heavier full saline water from the North Sea, the water from the Thames estuary influencing the intertidal and shallower subtidal sites.

5.22 **Southend subtidal** - Apart from Chapman Buoy, this site appears to be the least polluted, which is interesting as it is situated at the end of the Southend sewage outfall pipe. The site consistently scores well on all community parameters, with oligochaetes being rarely found. Three out of four quarters were classified as unpolluted by the ABC method and the community score is always high. It would appear that the outfall has no effect on the benthic environment directly at the end of the pipe. The effluent (mainly freshwater) is discharged through a series of diffusers, so it is likely that most floats to the surface, where is is dispersed over a wider area, i.e. further out to sea and on the outer estuary sand banks.

5.23 **Grain Flats** - This site shares a lot of physical characteristics in common with Blythe Sands, though it tends to have a slightly richer community. The ABC method classes it as generally unpolluted, perhaps a result of its more distant location from the main body of the Thames estuary. However, this site may be influenced by the Medway.

5.24 **Shoeburyness East** - This intertidal area appears to be less polluted than Southend and Allhallows, probably due to its location in the mouth of the estuary. Low diversity, evenness and the ABC classification tends to be due to vast numbers of either <u>Scoloplos armiger</u> or <u>Hydrobia ulvae</u>, both on the NRA list for normal conditions.

It is possible that both respond to moderate levels of organic enrichment, so causing the high abundances.

5.25 **Sea Reach No.2 Buoy** - In theory this site, out on the margins of the estuary, should be the least polluted due to its distal position. However, this was not strictly the case. The site is shallower than both Southend subtidal and Chapman Buoy and may be influenced by the Medway. In addition, many large vessels moor here before journeying into the two estuaries, which may have an effect. The community here is generally good, but appeared to undergo a dramatic deterioration during quarters 3.89 & 4.89, with much lower species numbers, an ABC classification of gross pollution and low community scores. The site has since recovered, but the cause of this deterioration is unknown.

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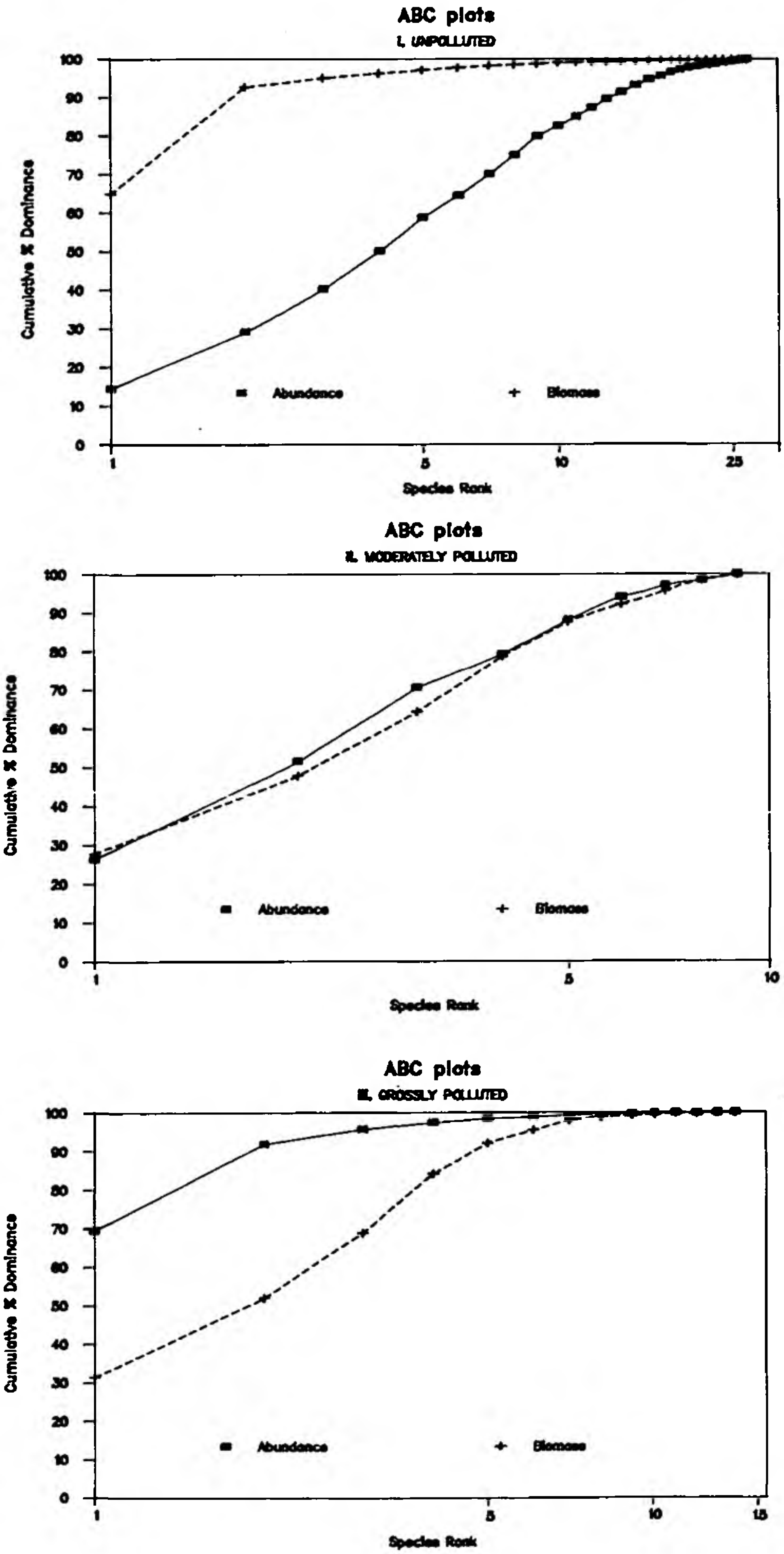
APPENDIX 1

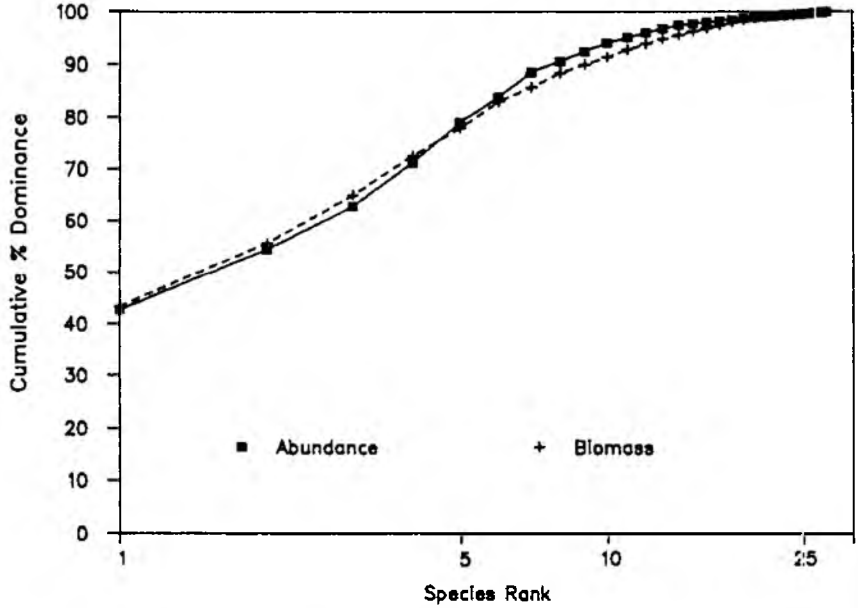
Abundance Biomass Comparison Curves for each TEBP site.
April 1989 - March 1990.

Figure A: Hypothetical ABC plots (after Warwick, 1986)

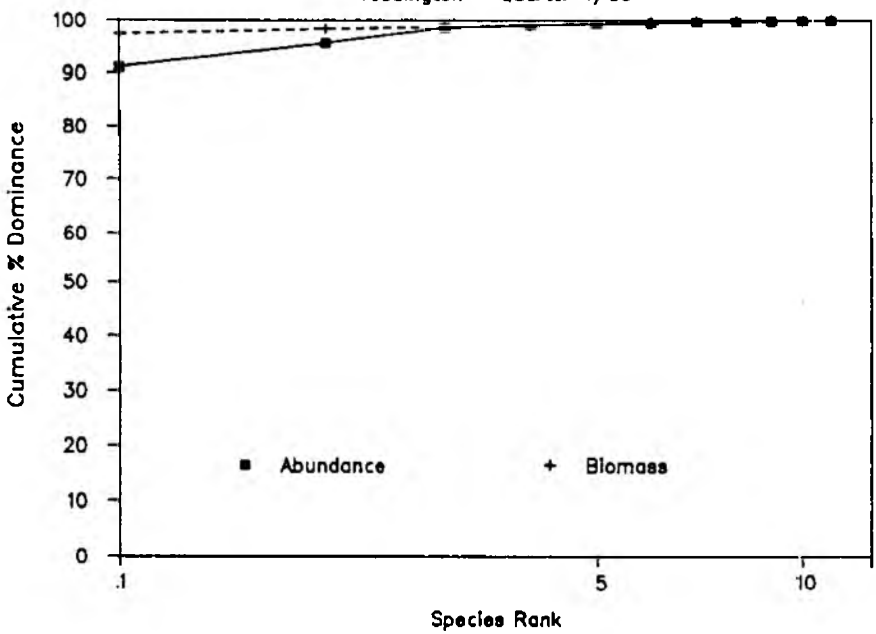


ABC plots

Teddington – Quarter 2/89

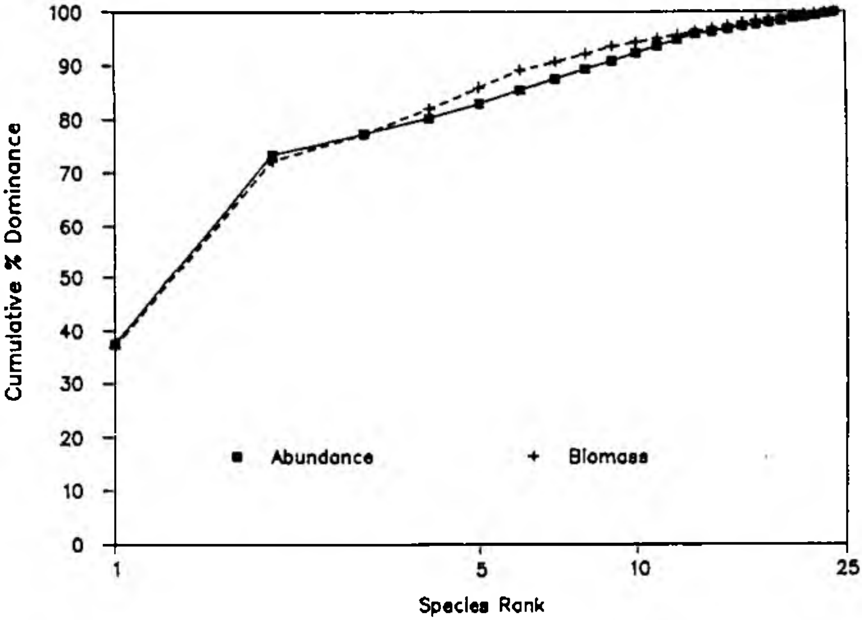


Teddington – Quarter 4/89

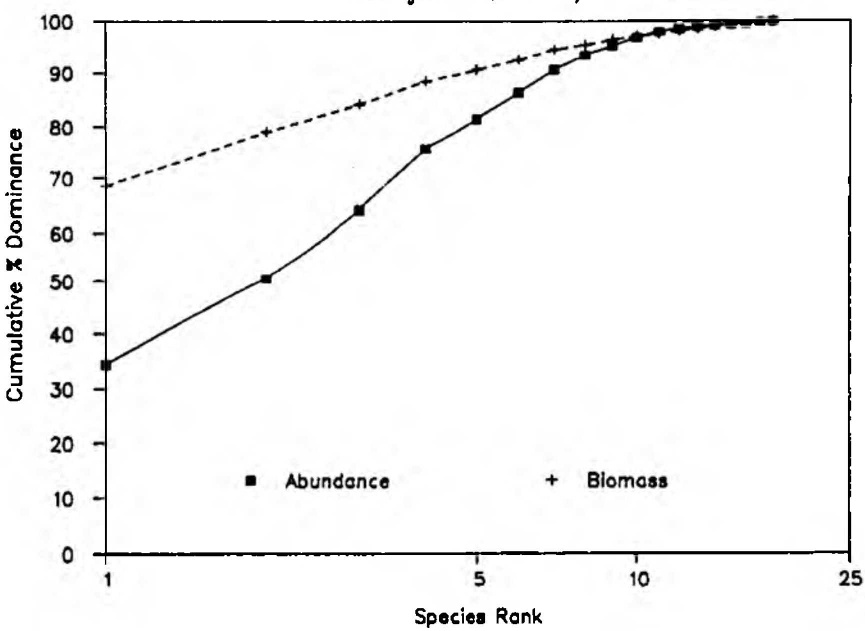


ABC plots

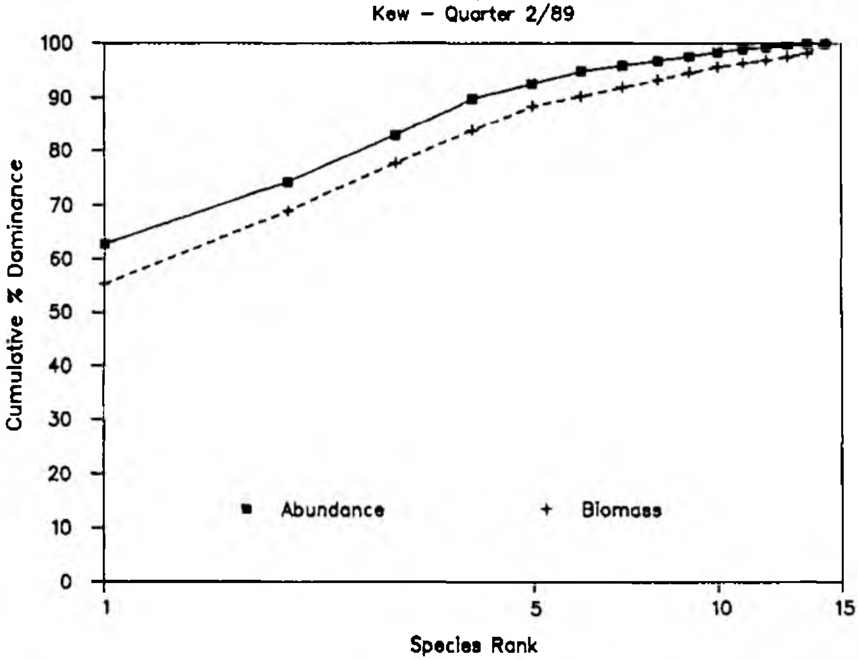
Teddington – Quarter 3/89

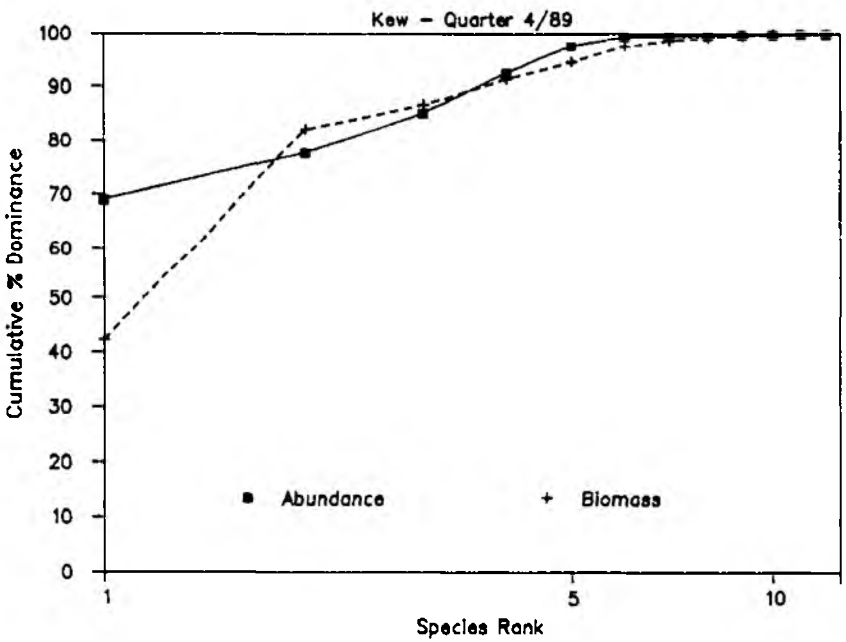


Teddington – Quarter 1/90



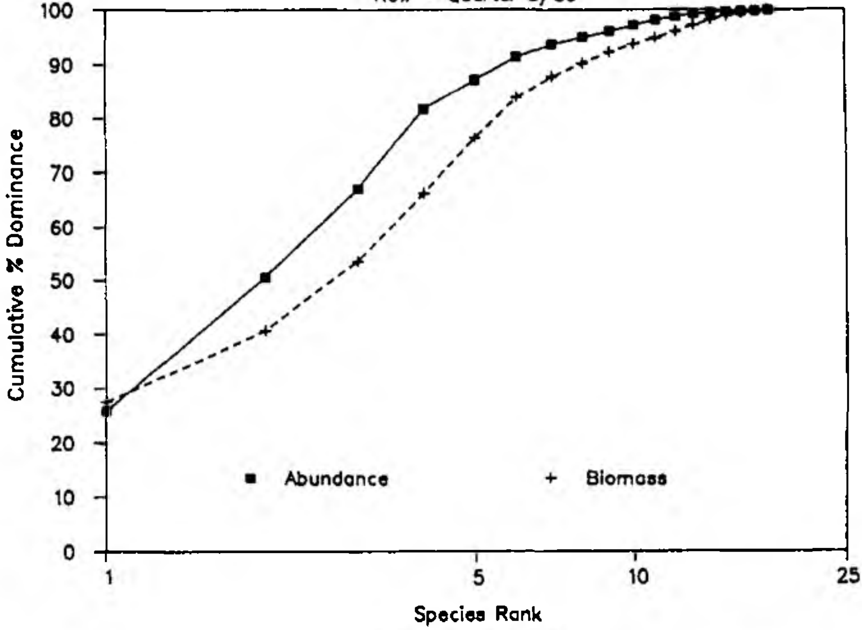
ABC plots


Kew – Quarter 2/89
100
90
80
70
60
50
40
30
20
10
0
Cumulative % Dominance
1
5
10
15
Species Rank
Abundance
Biomass

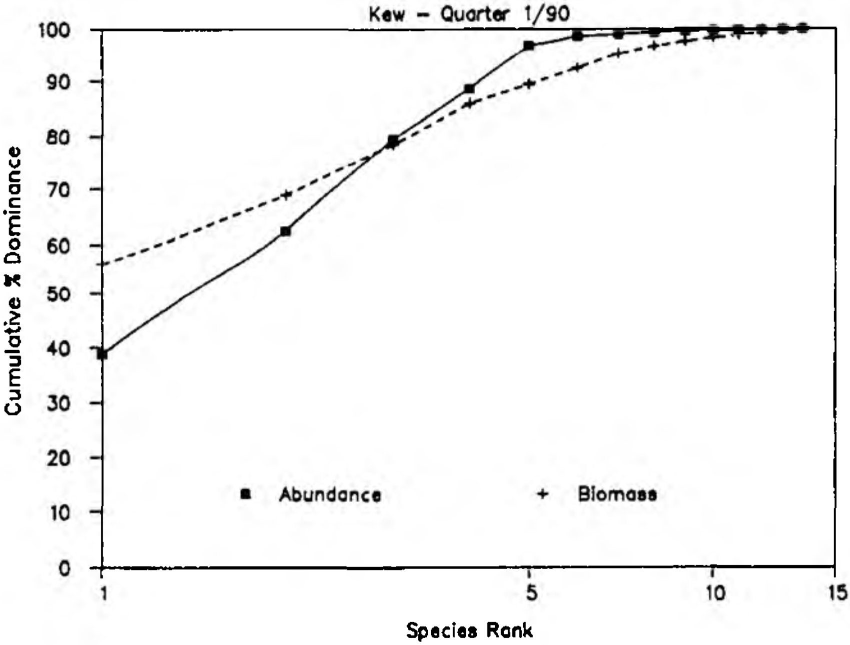

Kew – Quarter 4/89
100
90
80
70
60
50
40
30
20
10
0
Cumulative % Dominance
1
5
10
Species Rank
Abundance
Biomass

ABC plots

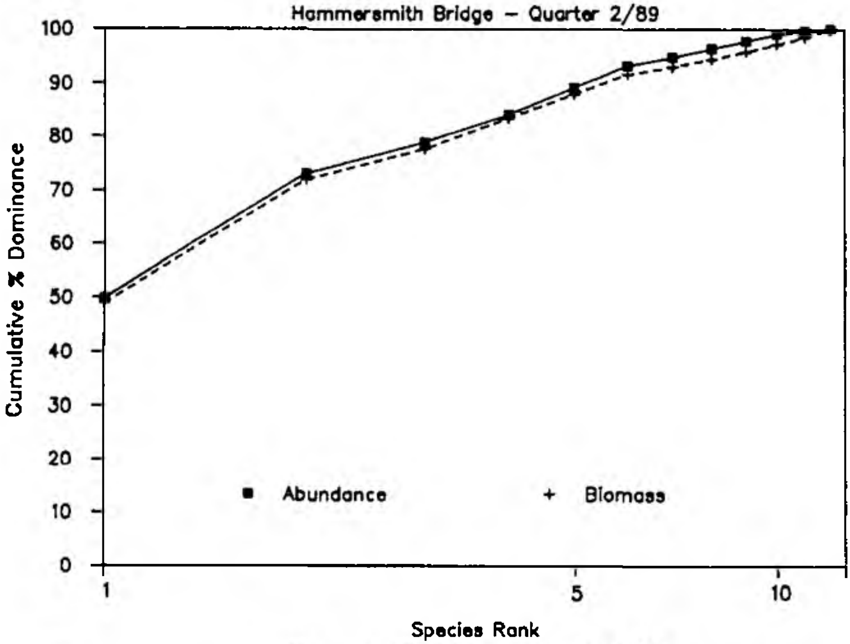
Kew - Quarter 3/89



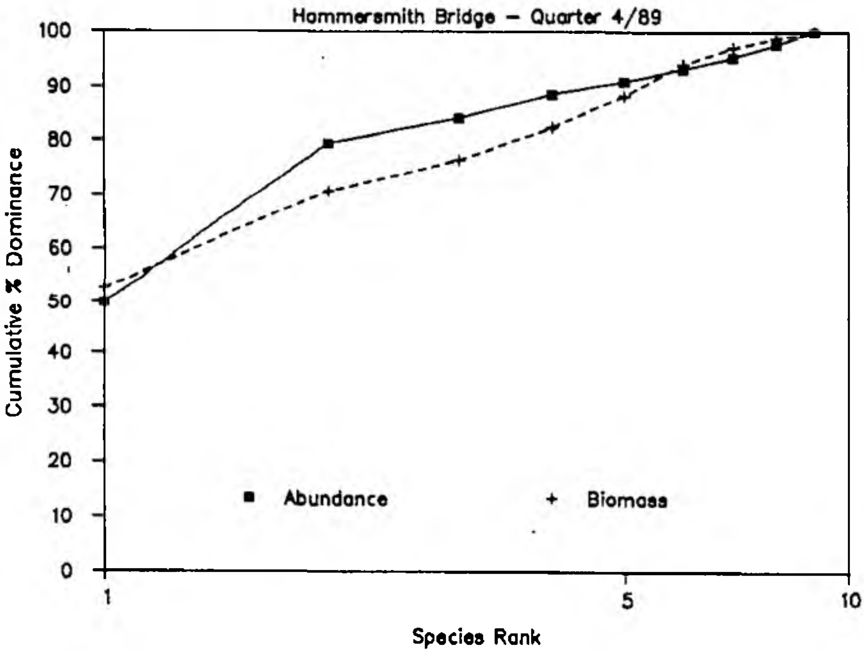
Kew - Quarter 1/90



ABC plots

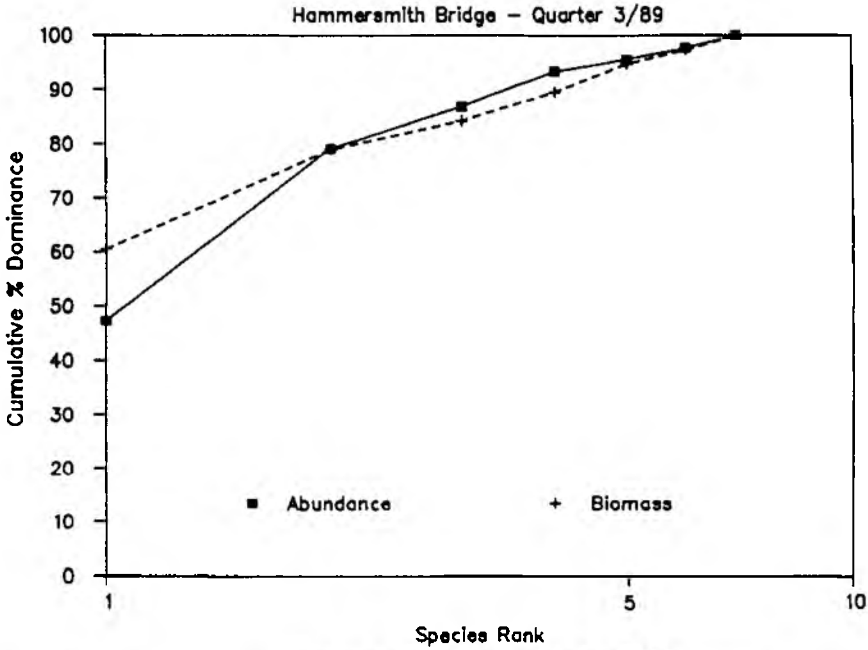


Hammersmith Bridge – Quarter 2/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

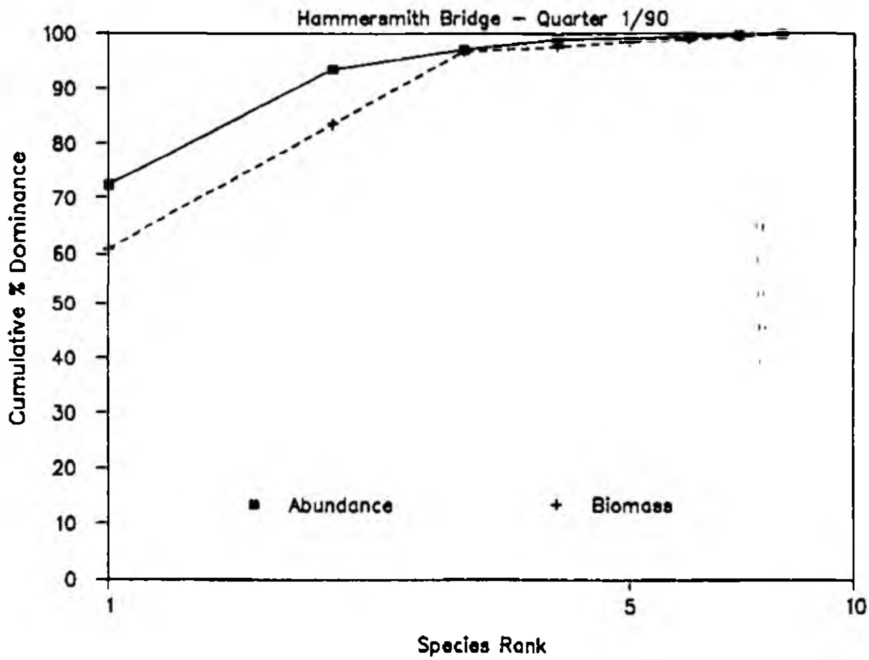


Hammersmith Bridge – Quarter 4/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

ABC plots

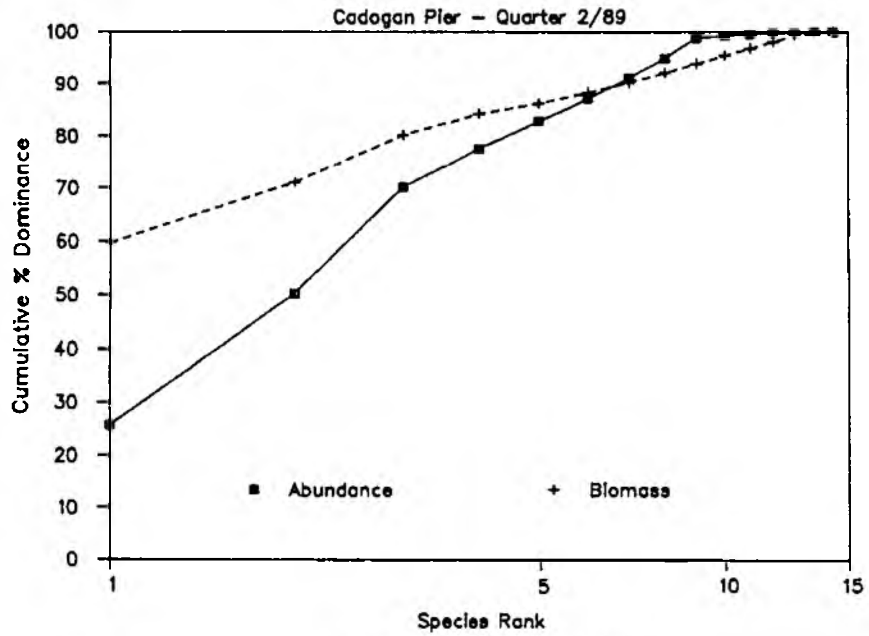


Hammersmith Bridge - Quarter 3/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
1
5
10
Species Rank
Abundance
Biomass

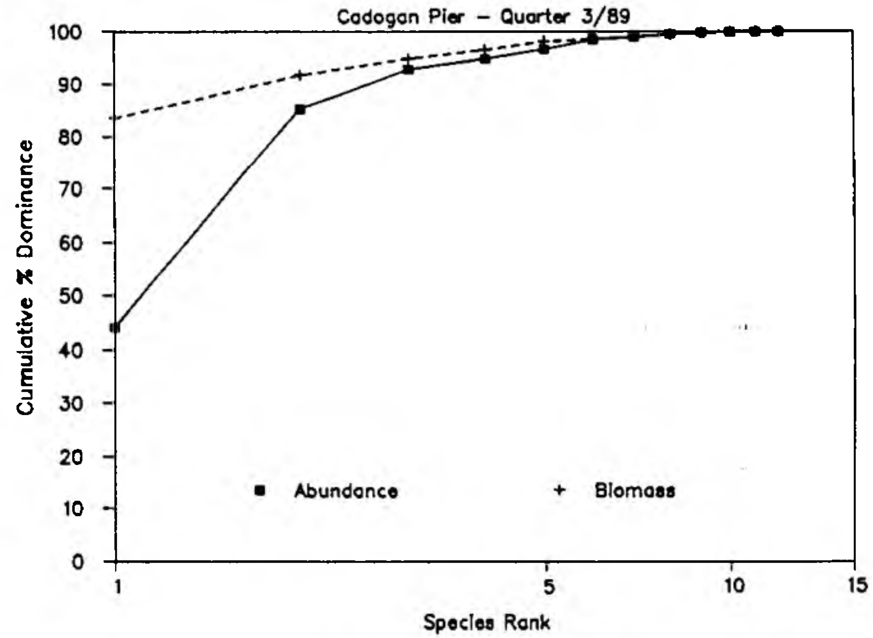


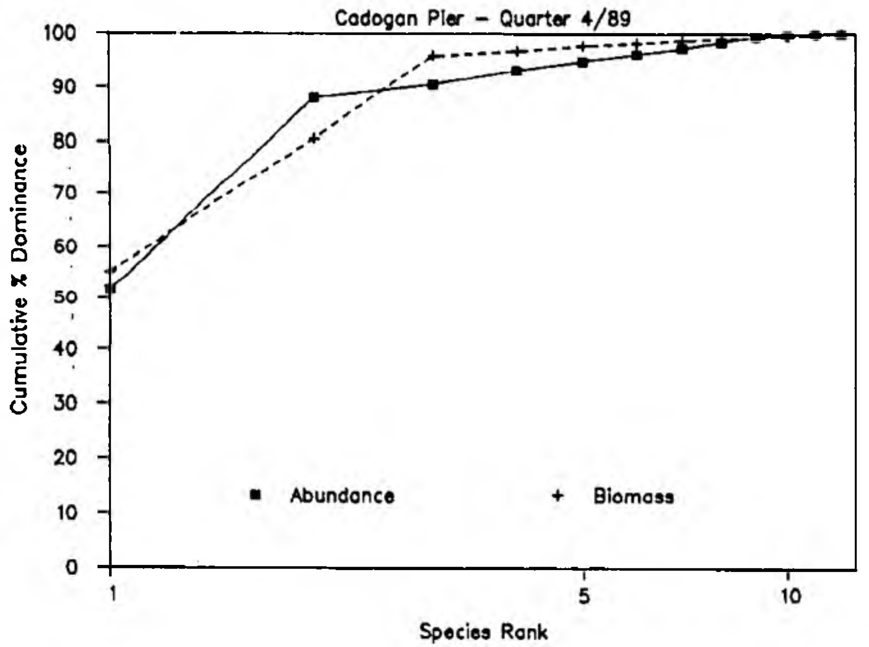
Hammersmith Bridge - Quarter 1/90
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
1
5
10
Species Rank
Abundance
Biomass

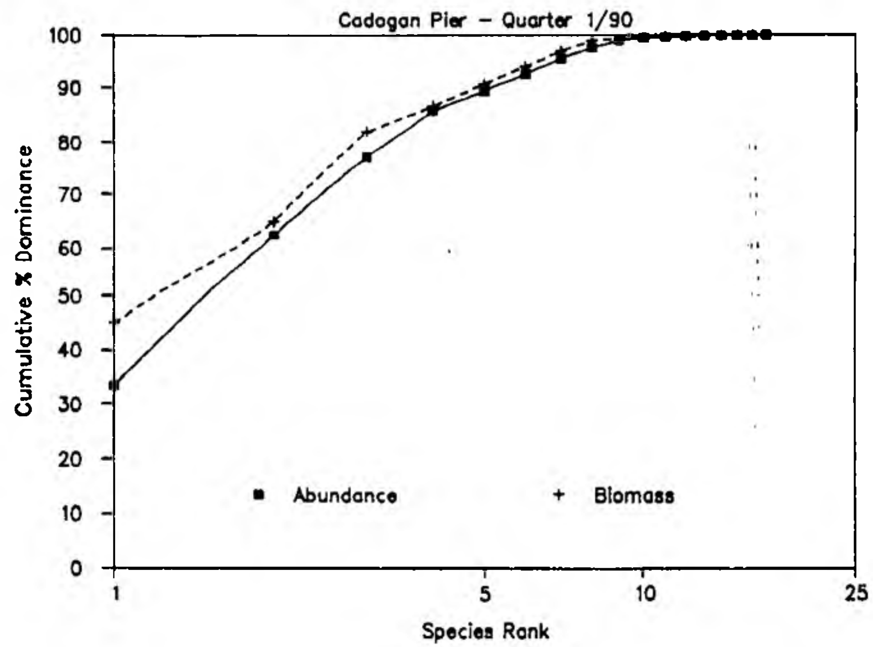
ABC plots



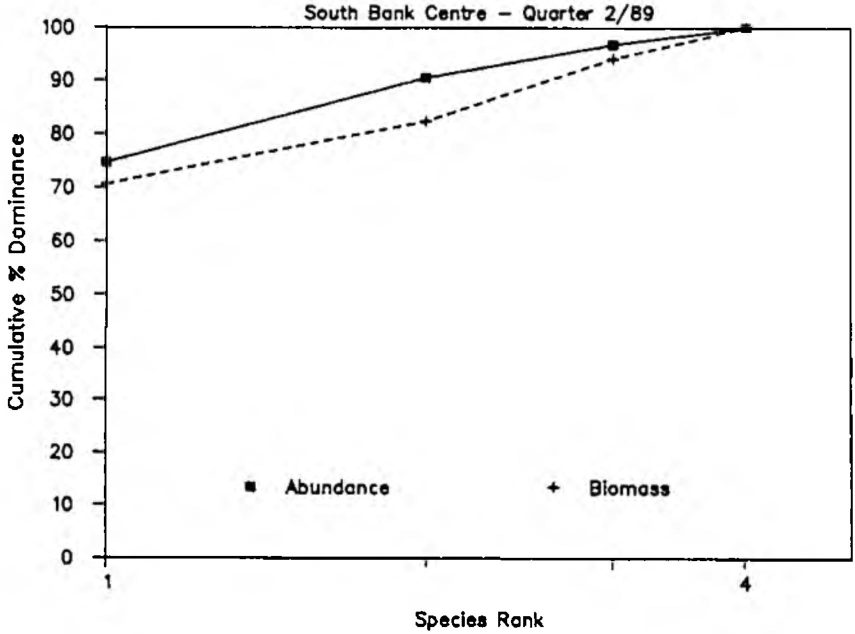
ABC plots

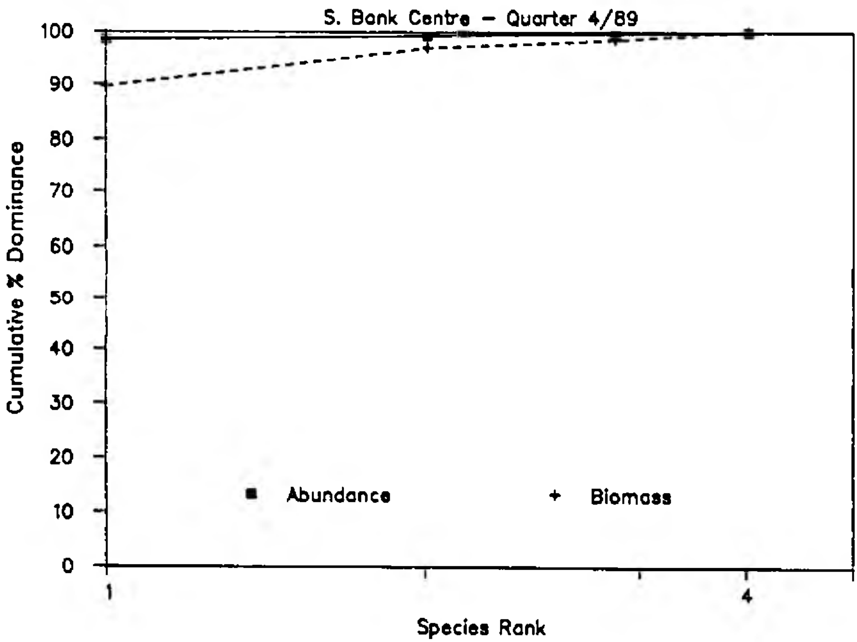




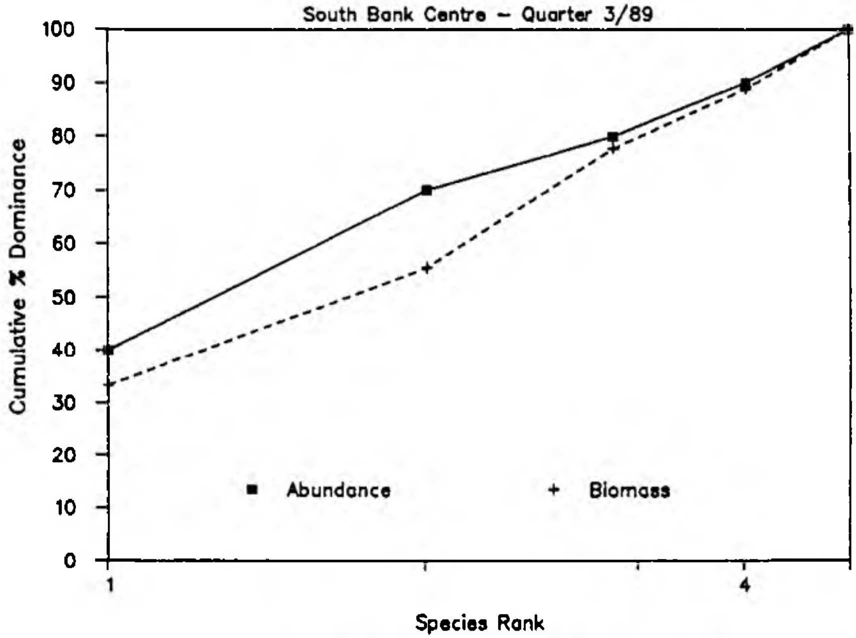


ABC plots

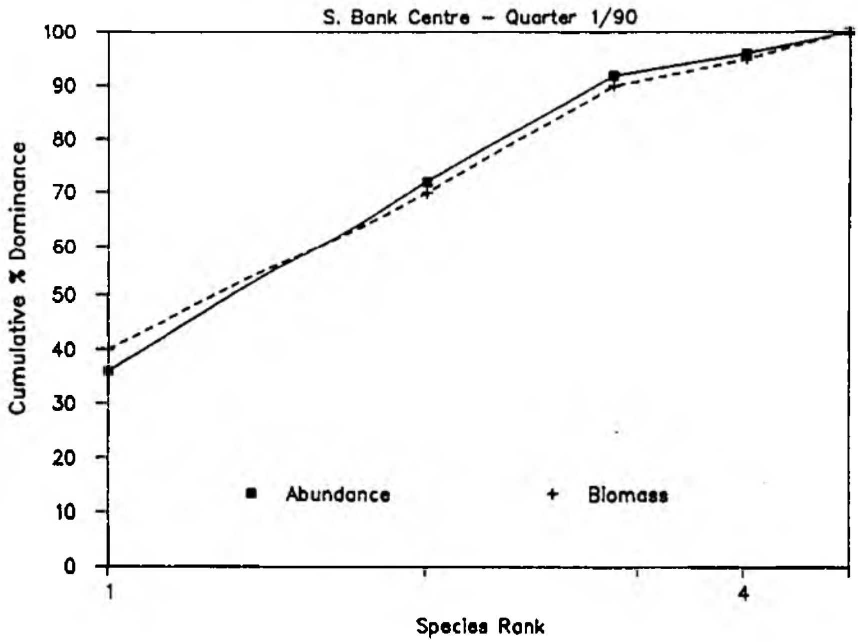

South Bank Centre - Quarter 2/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
4
Species Rank


S. Bank Centre - Quarter 4/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
4
Species Rank

ABC plots

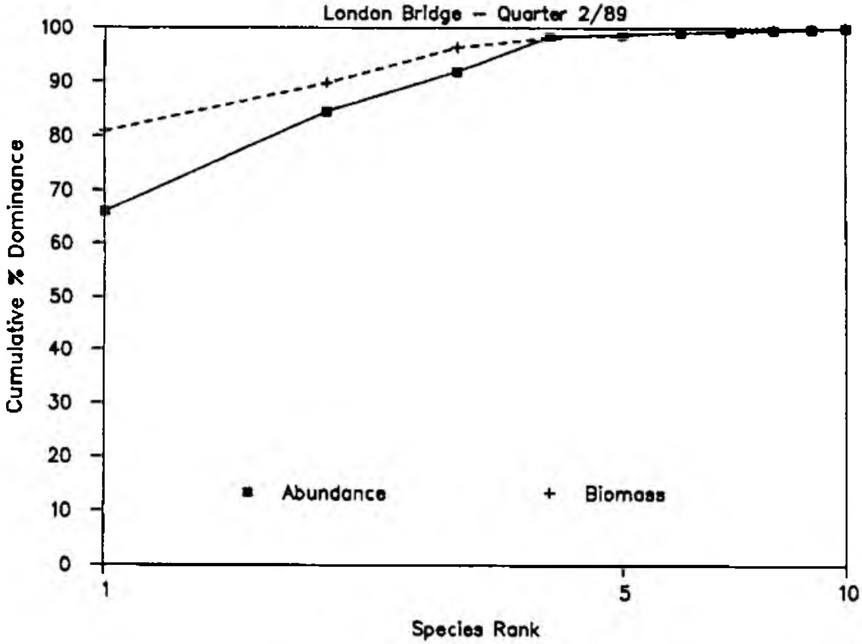


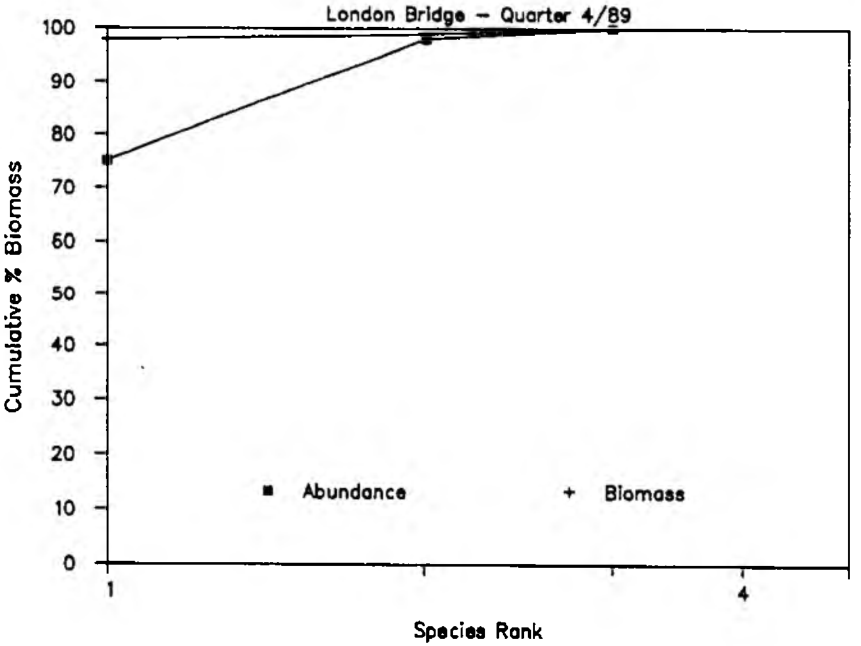
South Bank Centre – Quarter 3/89
100
90
80
70
60
50
40
30
20
10
0
Cumulative % Dominance
Abundance
Biomass
1
4
Species Rank



S. Bank Centre – Quarter 1/90
100
90
80
70
60
50
40
30
20
10
0
Cumulative % Dominance
Abundance
Biomass
1
4
Species Rank

ABC plots


London Bridge – Quarter 2/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
1
5
10
Species Rank
Abundance
Biomass


London Bridge – Quarter 4/89
Cumulative % Biomass
100
90
80
70
60
50
40
30
20
10
0
1
4
Species Rank
Abundance
Biomass

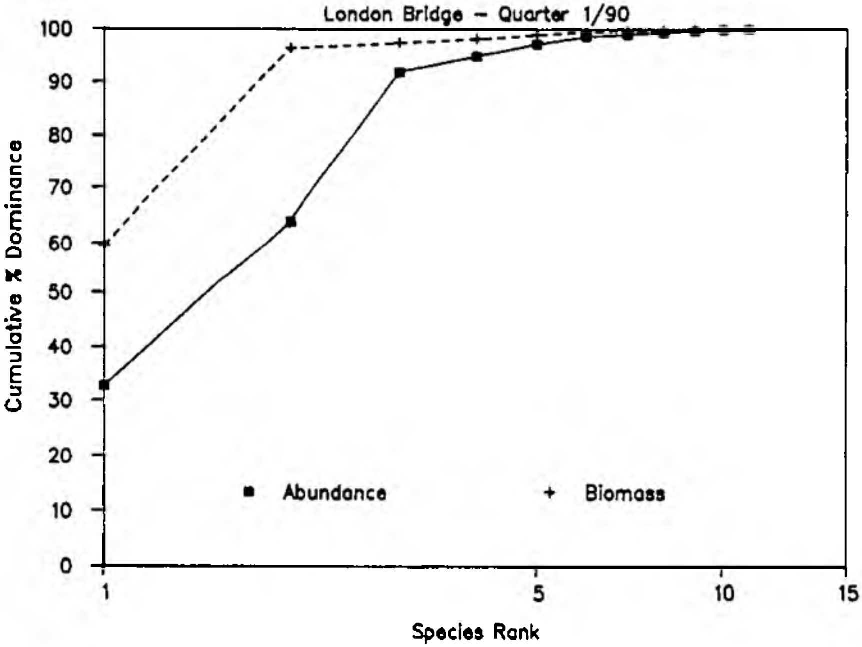
ABC plots

London Bridge – Quarter 2/89

Only 2 species present

ABC plots

London Bridge – Quarter 1/90



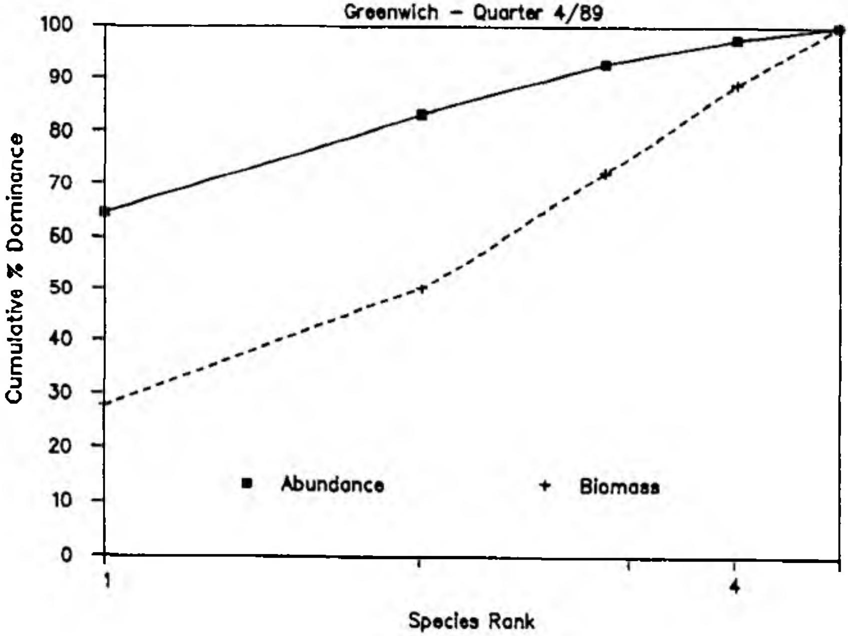
ABC plots

Greenwich - Quarter 2/89

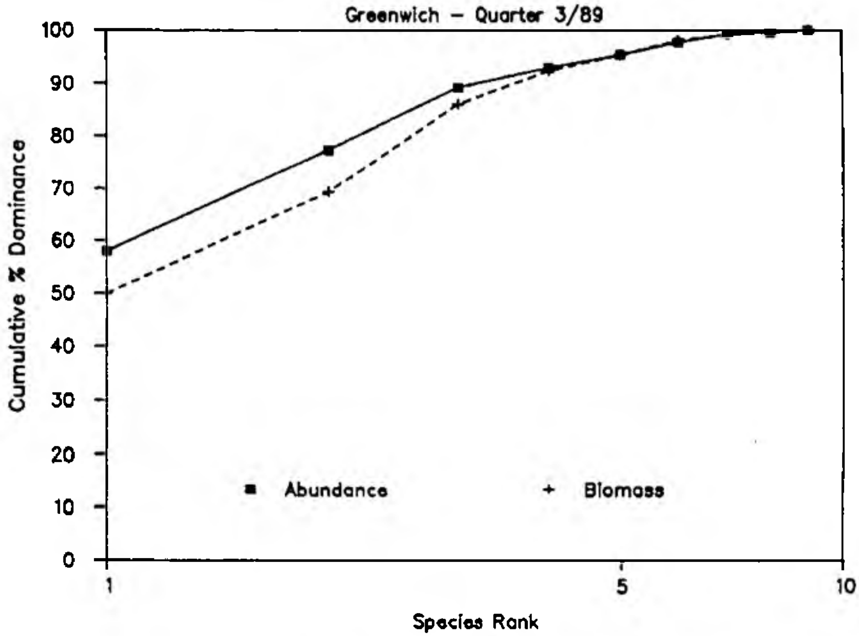
Only 1 species present

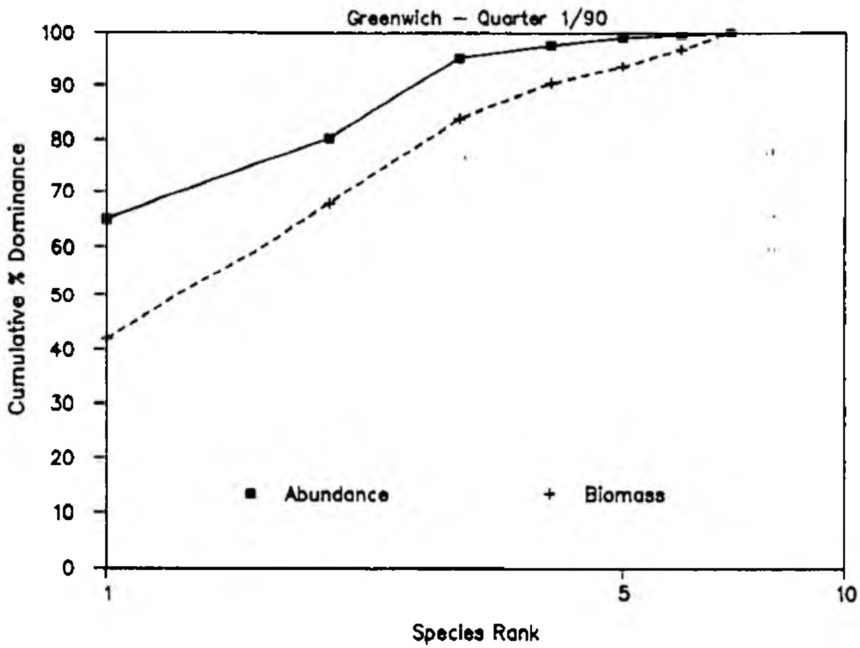
ABC plots

Greenwich - Quarter 4/89

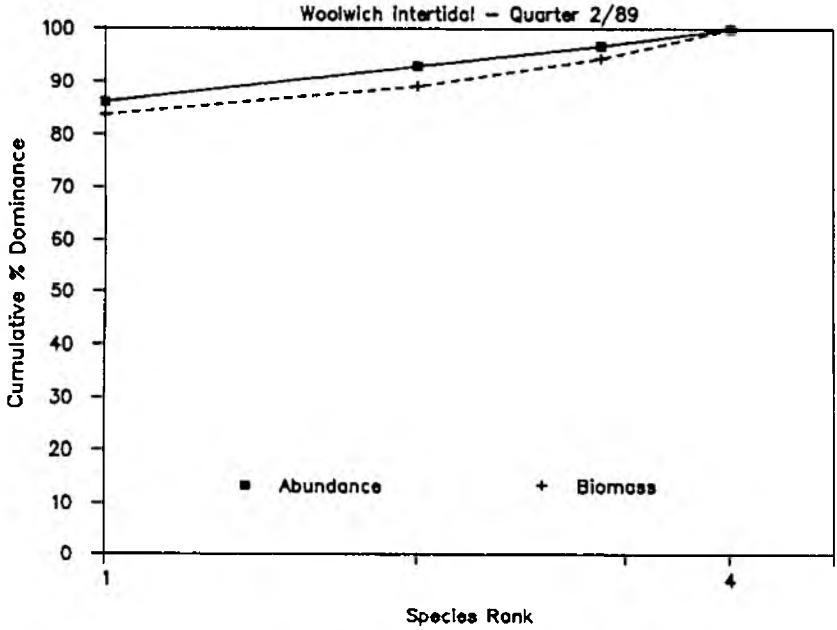


ABC plots

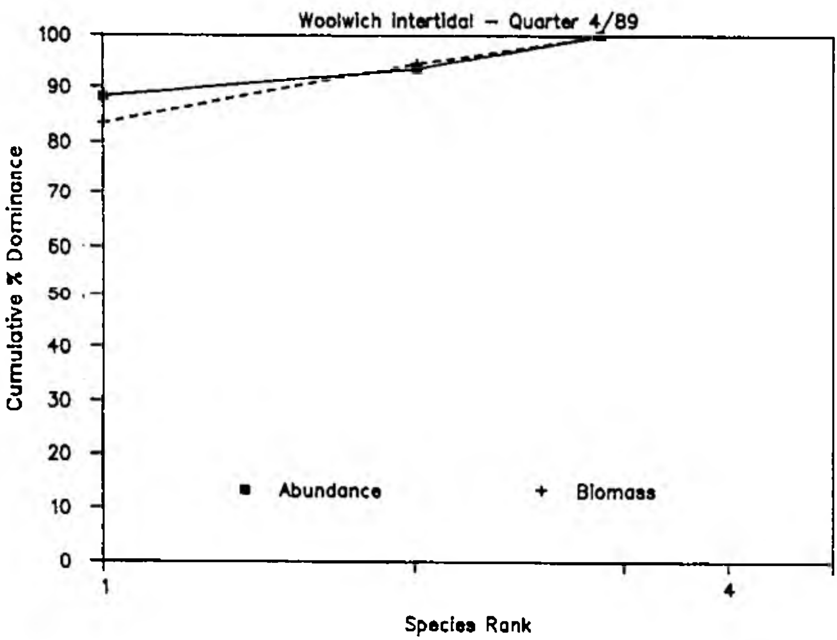

Greenwich – Quarter 3/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
1
5
10
Species Rank
Abundance
Biomass


Greenwich – Quarter 1/90
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
1
5
10
Species Rank
Abundance
Biomass

ABC plots

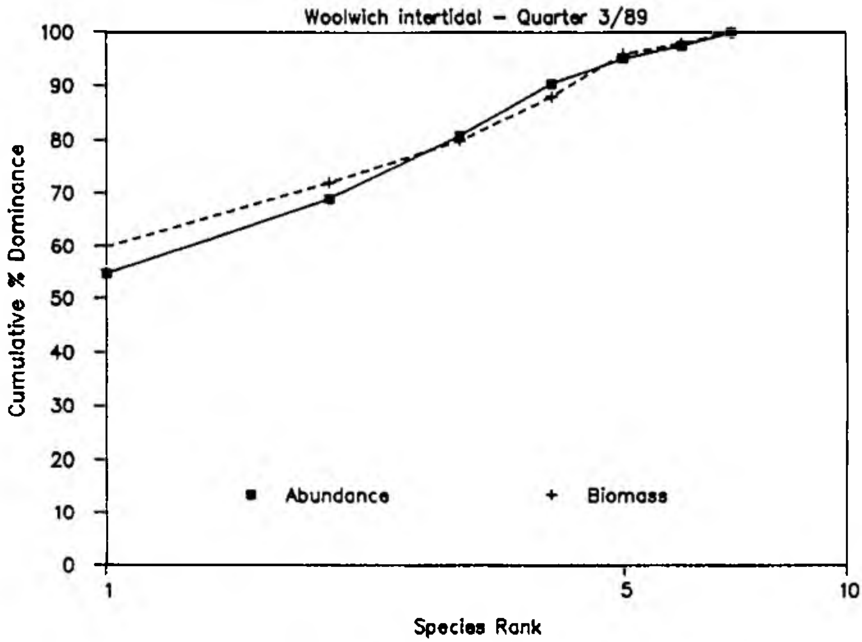


Woolwich intertidal – Quarter 2/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
4
Species Rank

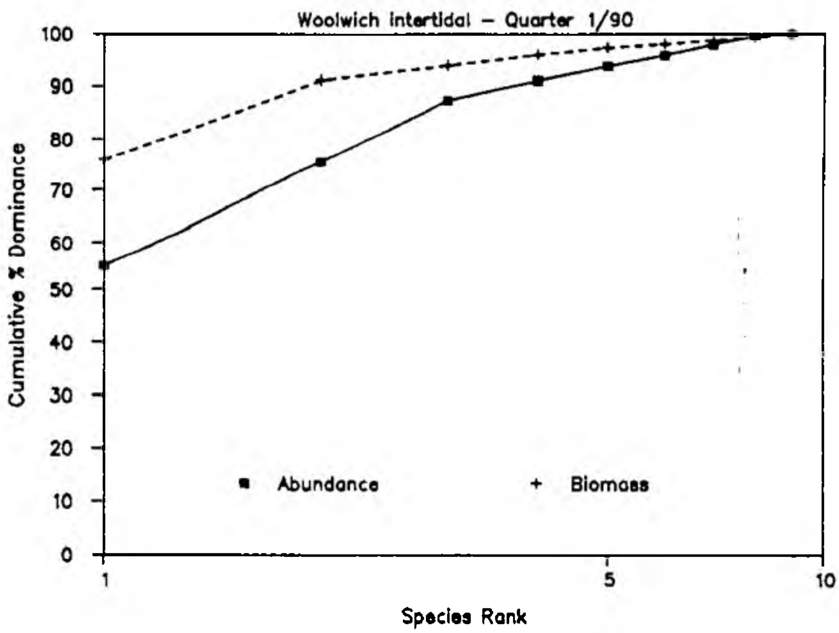


Woolwich intertidal – Quarter 4/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
4
Species Rank

ABC plots

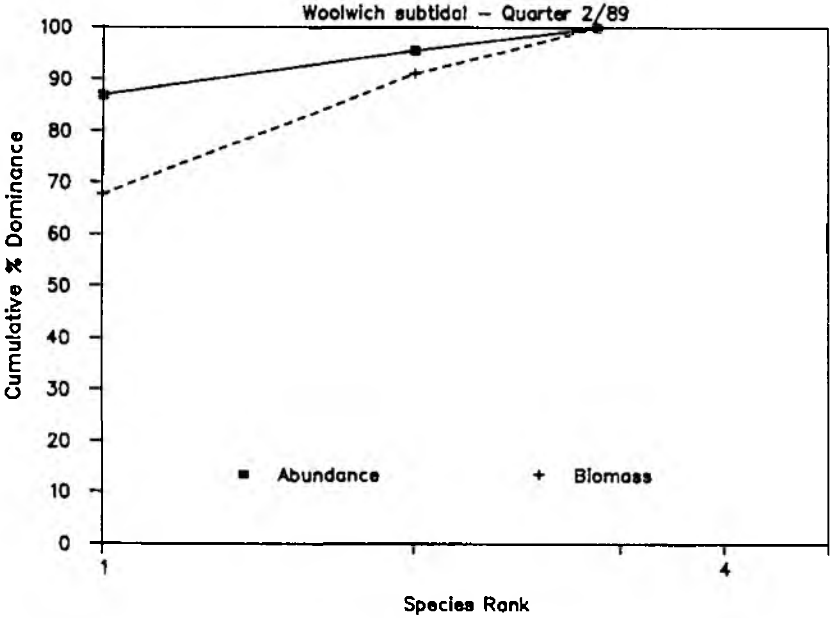


Woolwich intertidal - Quarter 3/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

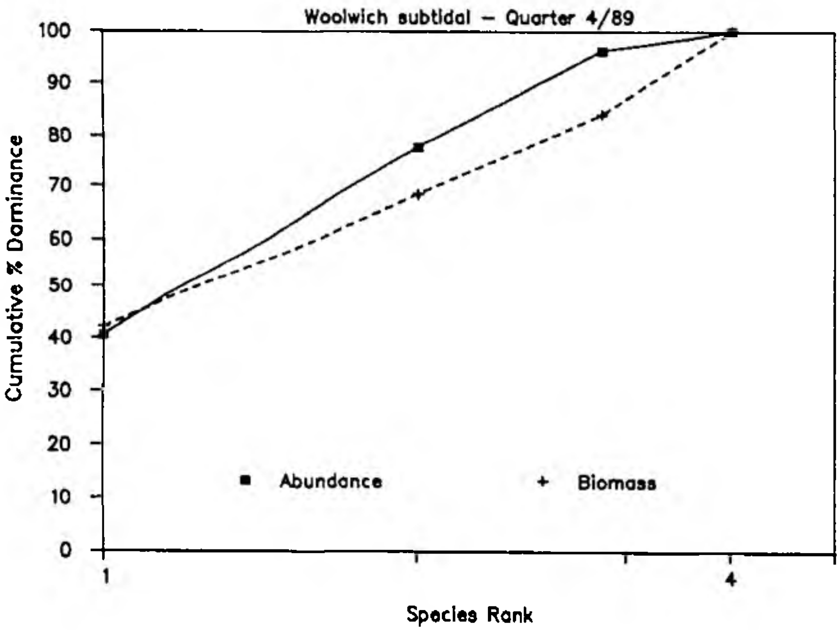


Woolwich intertidal - Quarter 1/90
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

ABC plots

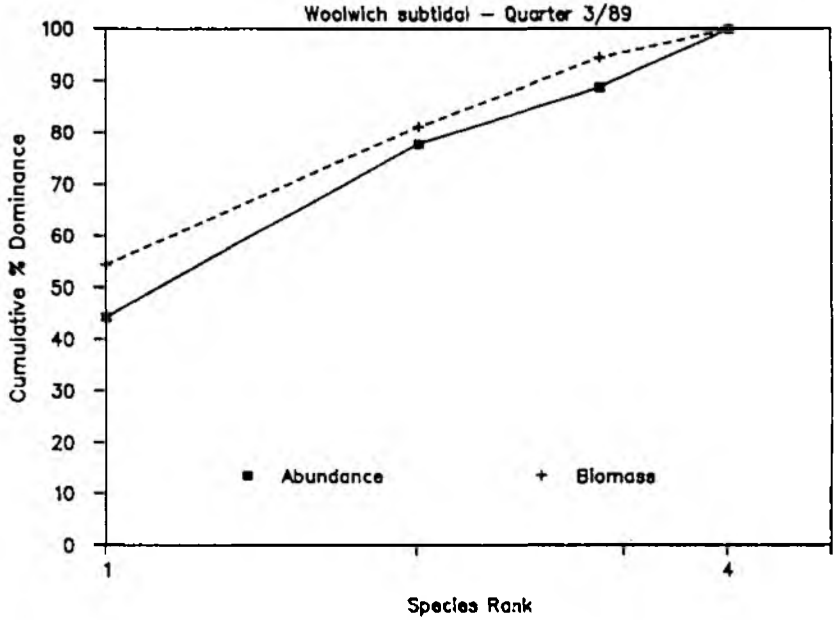


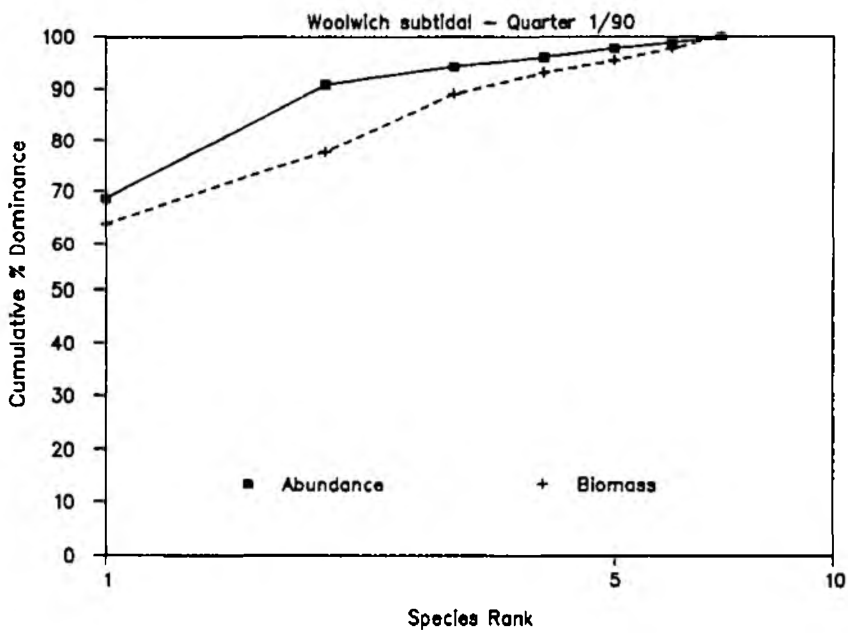
Woolwich subtidal – Quarter 2/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
4
Species Rank



Woolwich subtidal – Quarter 4/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
4
Species Rank

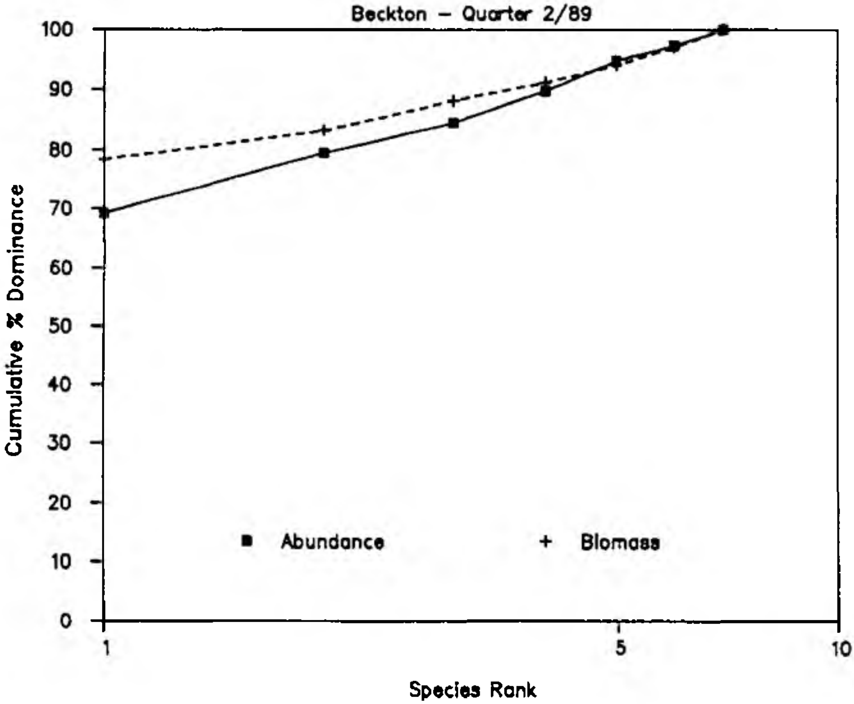
ABC plots


Woolwich subtidal – Quarter 3/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
4
Species Rank


Woolwich subtidal – Quarter 1/90
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

ABC plots

Beckton – Quarter 2/89



ABC plots

Beckton – Quarter 4/89

Only 1 species present

ABC plots

Beckton – Quarter 3/89

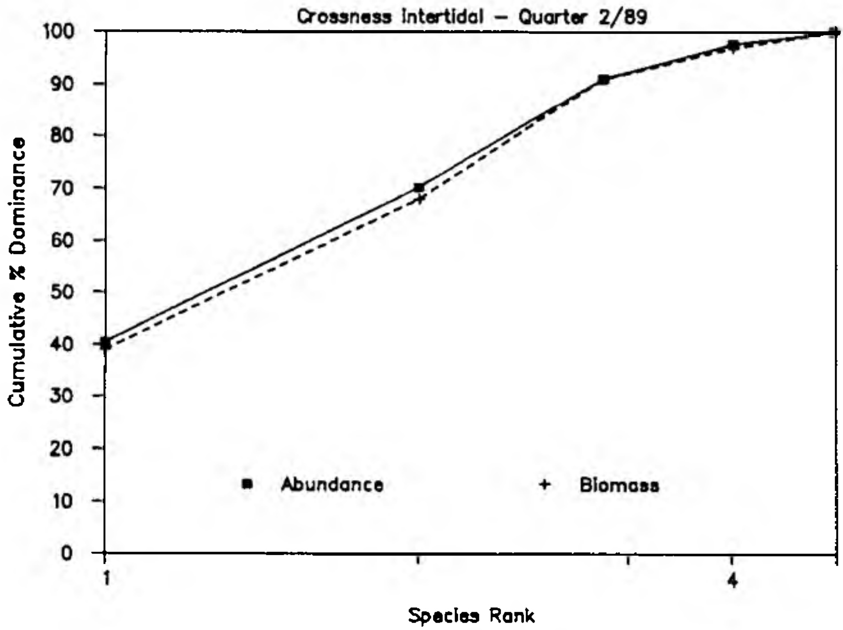
Only 1 species present

ABC plots

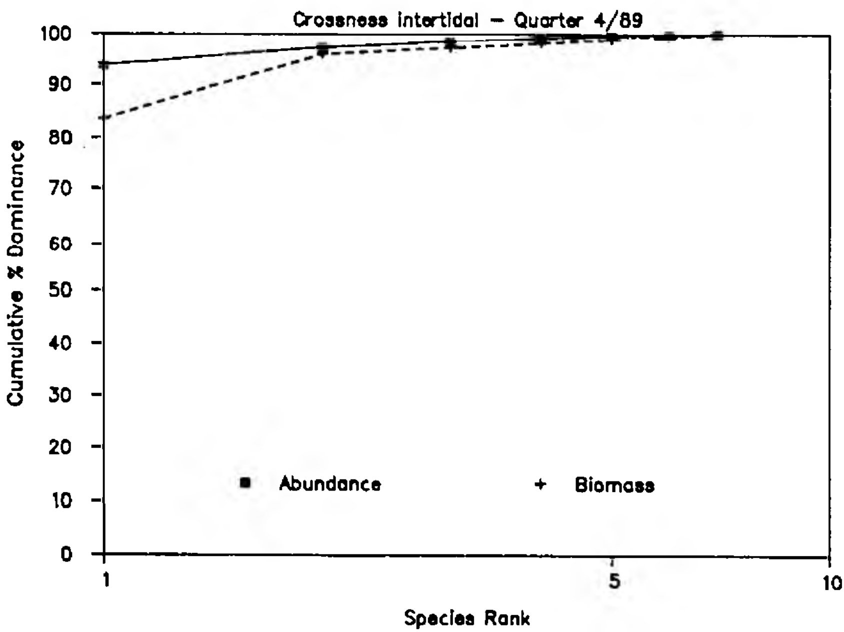
Beckton – Quarter 1/90

Only 1 species present

ABC plots

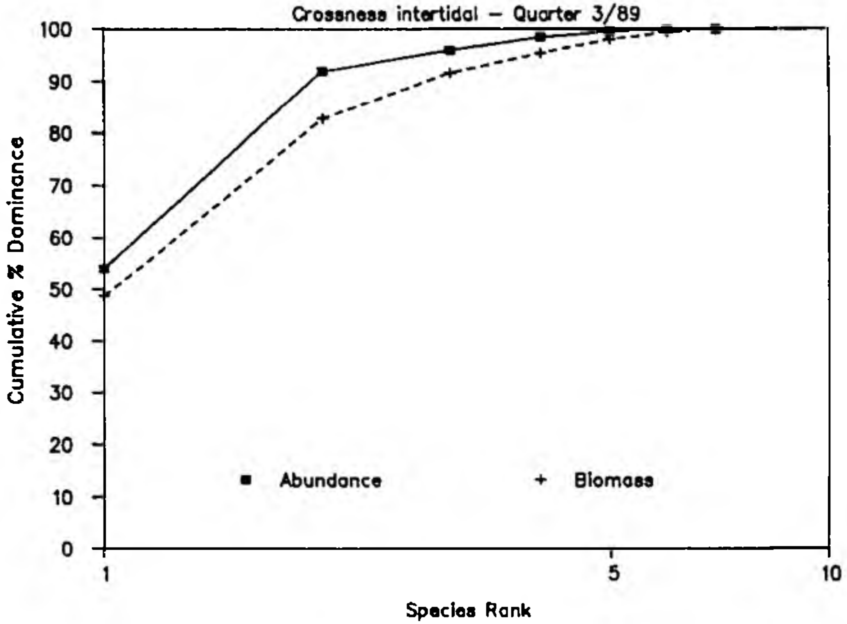


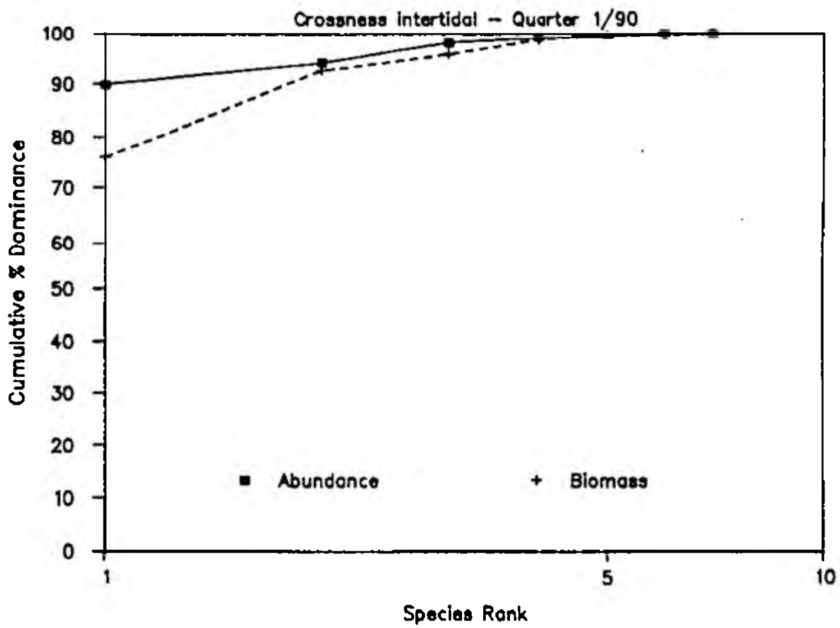
Crossness Intertidal – Quarter 2/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
1
4
Species Rank
Abundance
Biomass



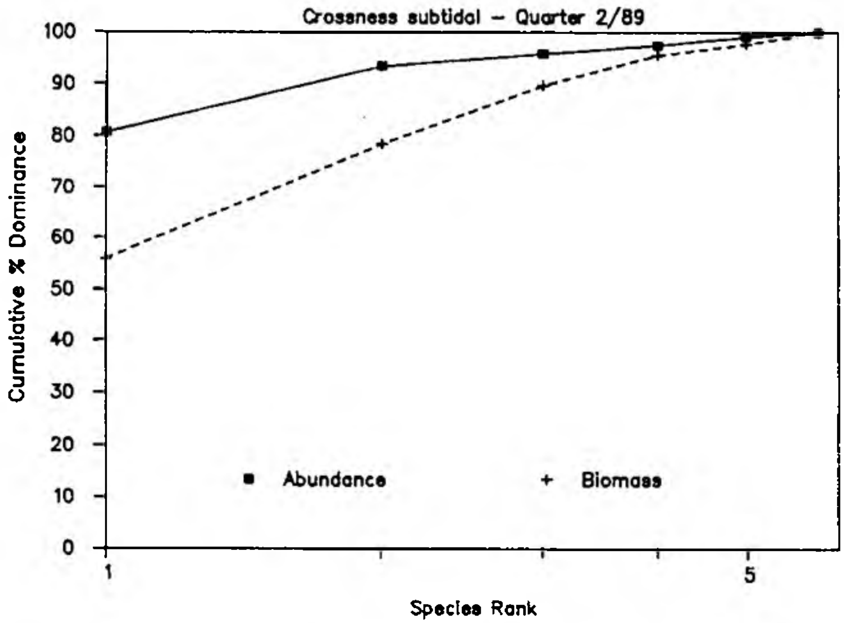
Crossness Intertidal – Quarter 4/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
1
5
10
Species Rank
Abundance
Biomass

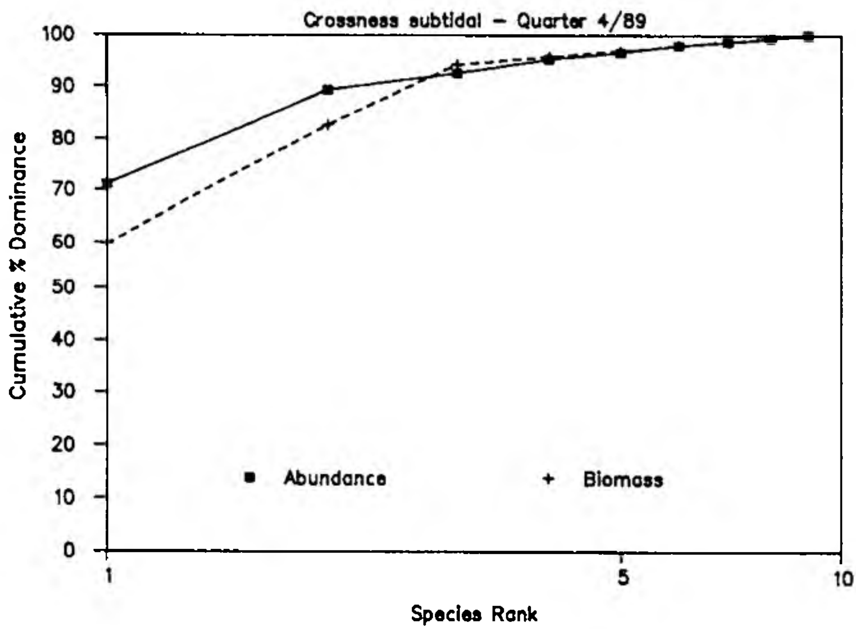
ABC plots


Crossness intertidal – Quarter 3/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank


Crossness intertidal – Quarter 1/90
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

ABC plots


Crossness subtidal – Quarter 2/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
Species Rank


Crossness subtidal – Quarter 4/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

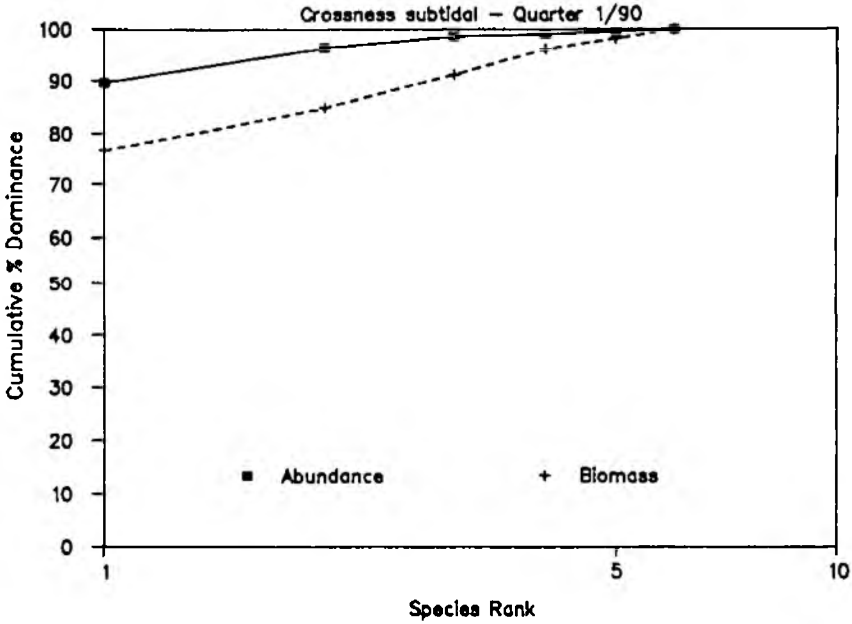
ABC plots

Crossness subtidal – Quarter 2/89

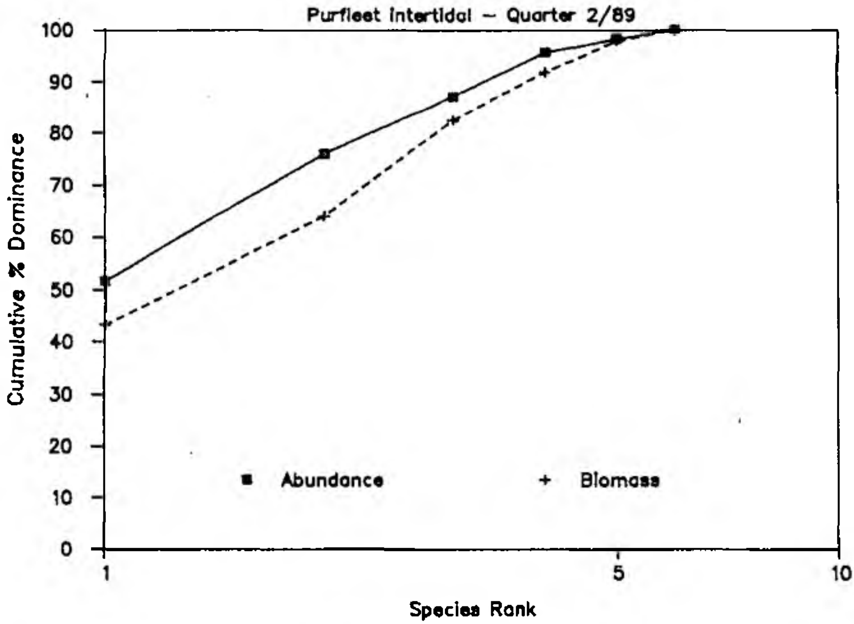
Only 1 species present

ABC plots

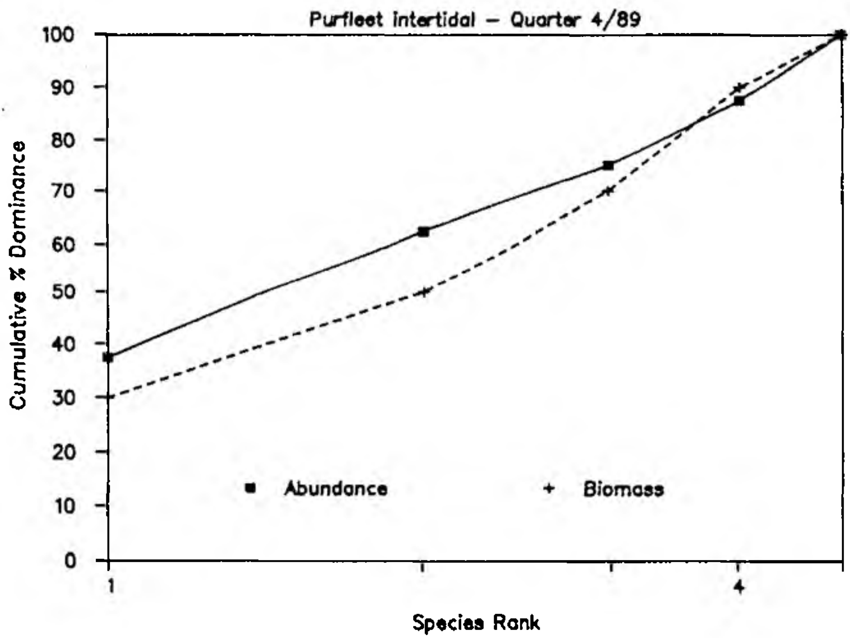
Crossness subtidal – Quarter 1/90



ABC plots



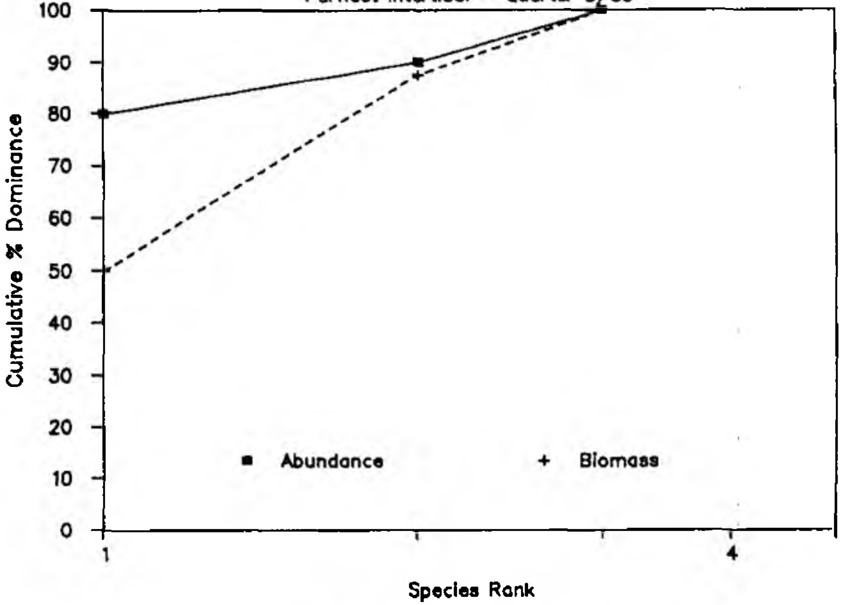
Purfleet Intertidal – Quarter 2/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank



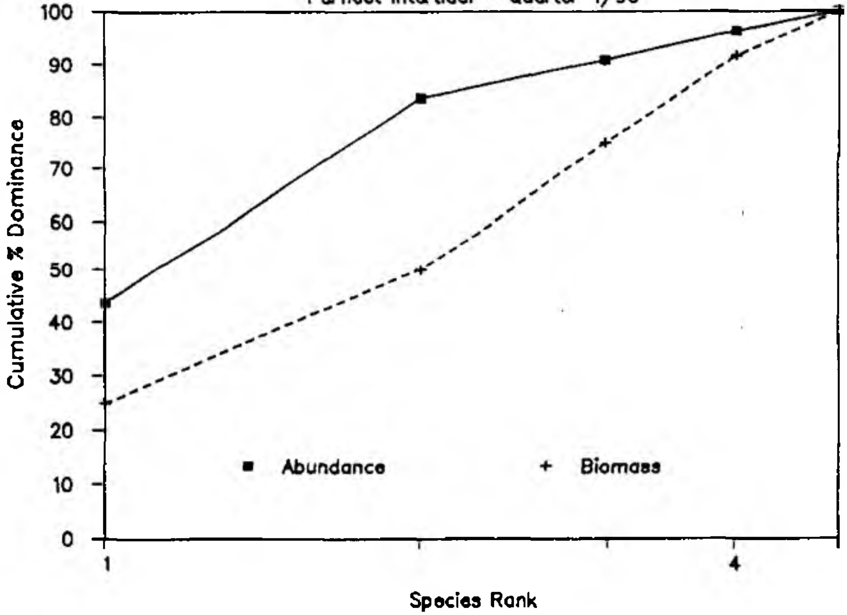
Purfleet Intertidal – Quarter 4/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
4
Species Rank

ABC plots

Purfleet intertidal – Quarter 3/89

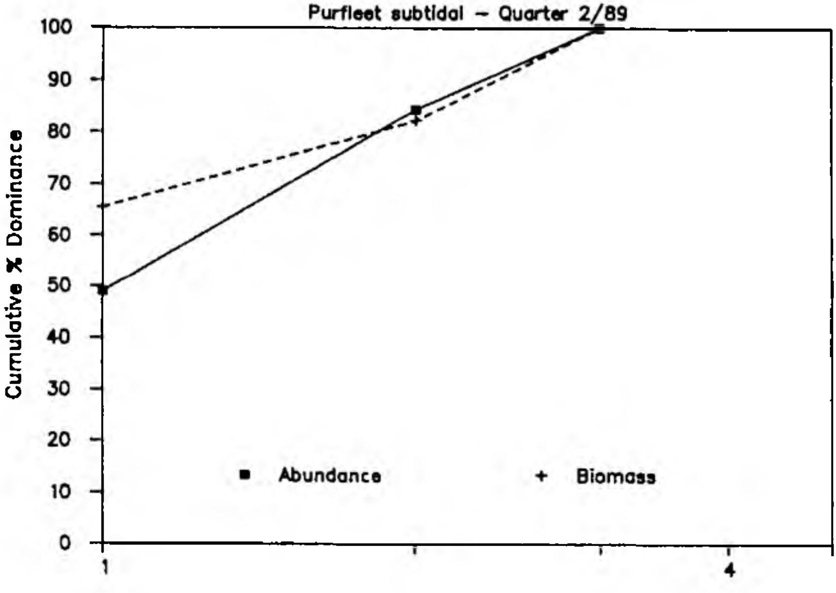


Purfleet intertidal – Quarter 1/90



ABC plots

Purfleet subtidal – Quarter 2/89

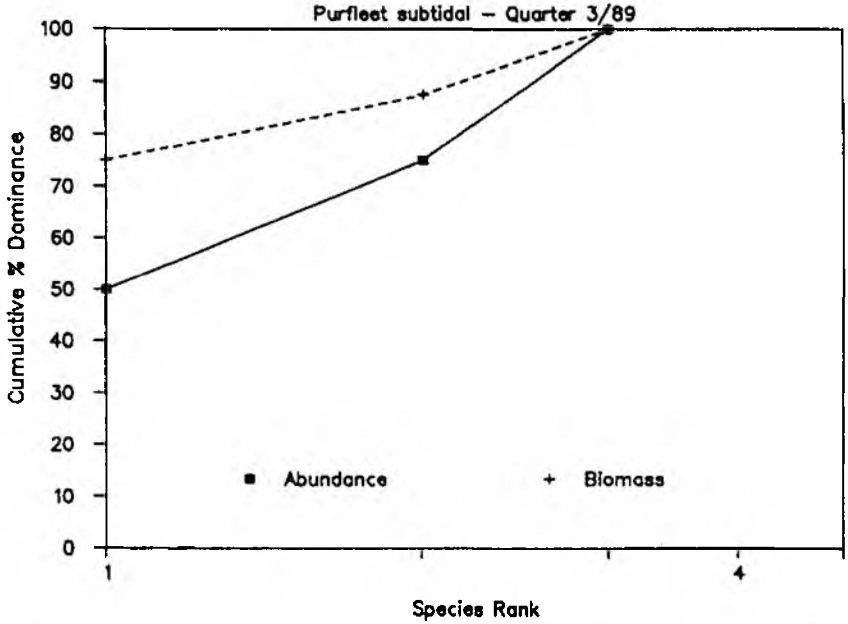


ABC plots

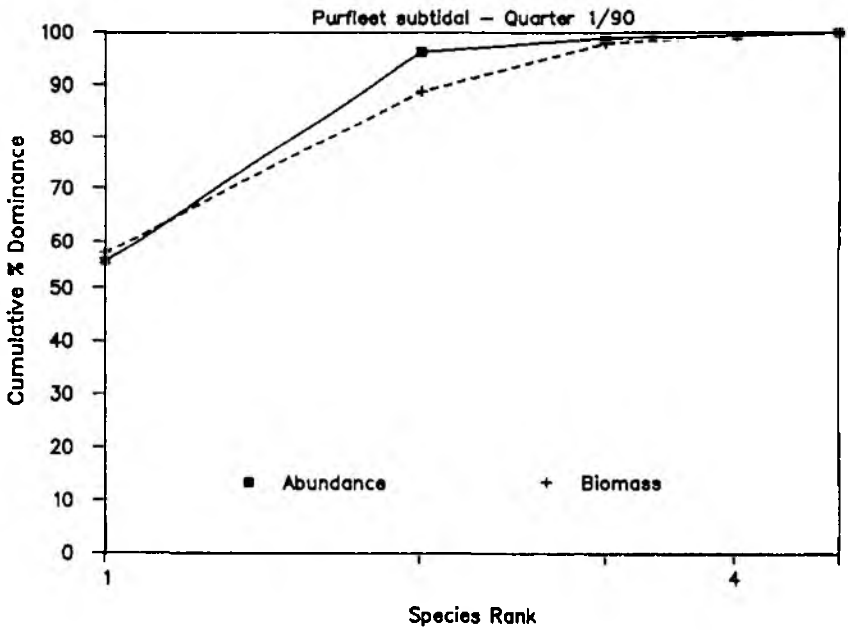
Purfleet subtidal – Quarter 4/89

Only 2 species present

ABC plots

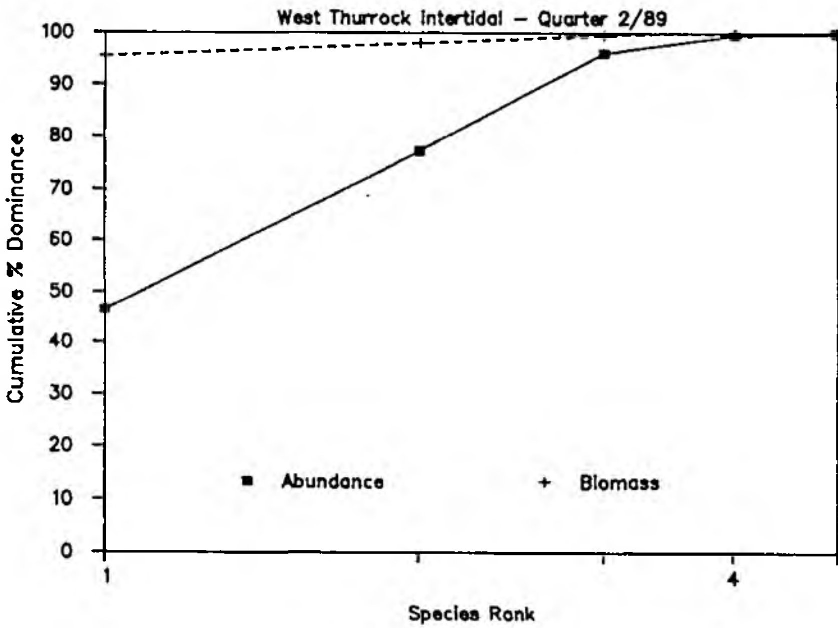


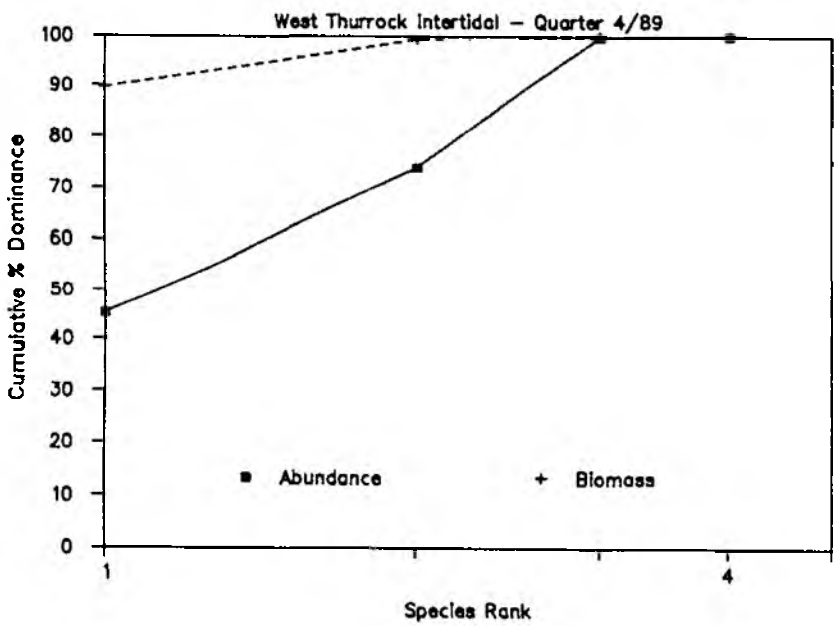
Purfleet subtidal - Quarter 3/89
Cumulative % Dominance
Abundance
Biomass
Species Rank



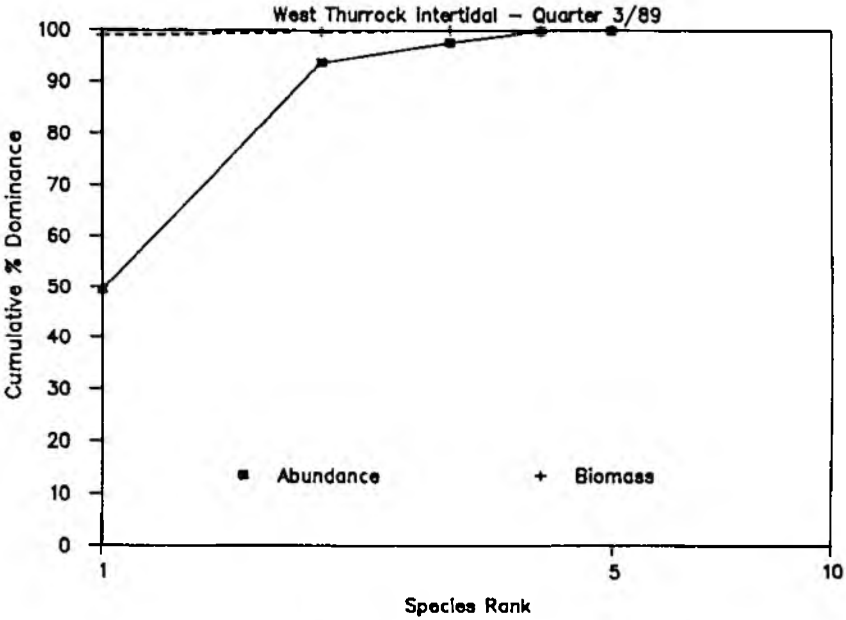
Purfleet subtidal - Quarter 1/90
Cumulative % Dominance
Abundance
Biomass
Species Rank

ABC plots

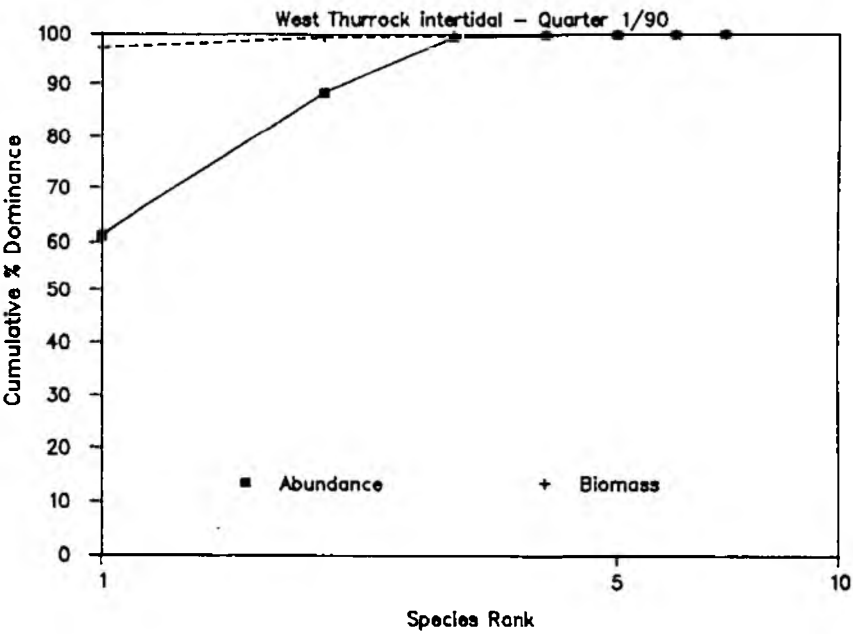

West Thurrock Intertidal – Quarter 2/89
100
90
80
70
60
50
40
30
20
10
0
Cumulative % Dominance
Abundance
Biomass
1
4
Species Rank


West Thurrock Intertidal – Quarter 4/89
100
90
80
70
60
50
40
30
20
10
0
Cumulative % Dominance
Abundance
Biomass
1
4
Species Rank

ABC plots

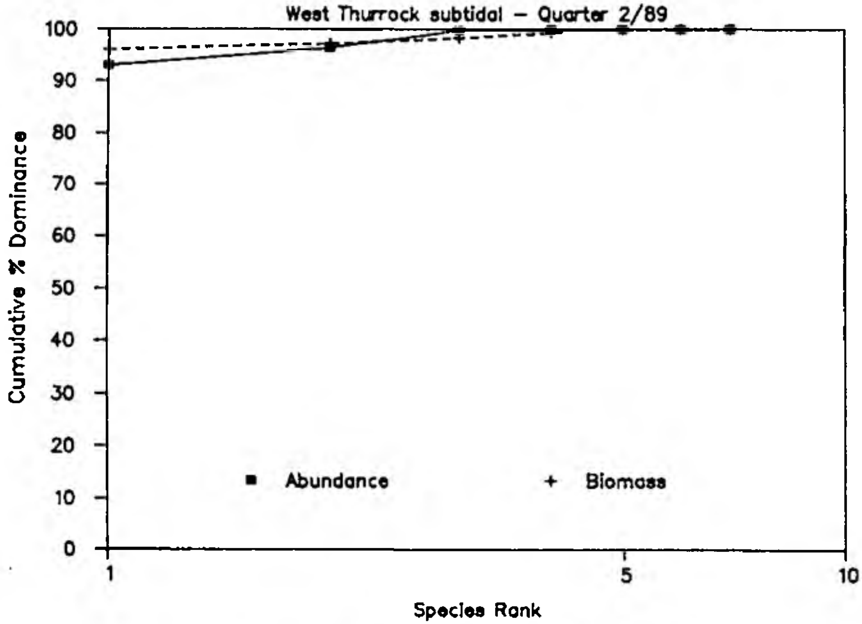


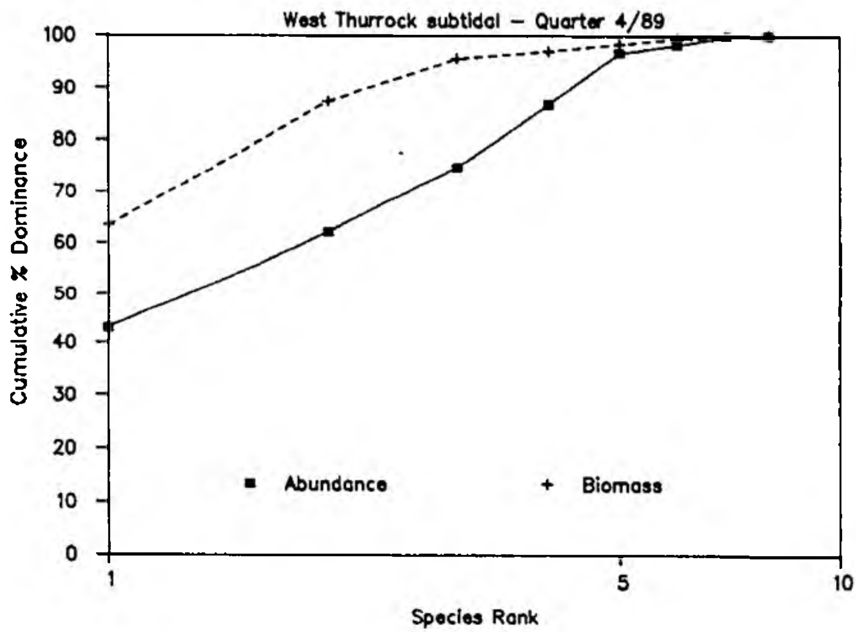
West Thurrock Intertidal – Quarter 3/89
100
90
80
70
60
50
40
30
20
10
0
Cumulative % Dominance
Abundance
Biomass
1
5
10
Species Rank



West Thurrock intertidal – Quarter 1/90
100
90
80
70
60
50
40
30
20
10
0
Cumulative % Dominance
Abundance
Biomass
1
5
10
Species Rank

ABC plots


West Thurrock subtidal – Quarter 2/89
Cumulative % Dominance
0
10
20
30
40
50
60
70
80
90
100
Abundance
Biomass
1
5
10
Species Rank


West Thurrock subtidal – Quarter 4/89
Cumulative % Dominance
0
10
20
30
40
50
60
70
80
90
100
Abundance
Biomass
1
5
10
Species Rank

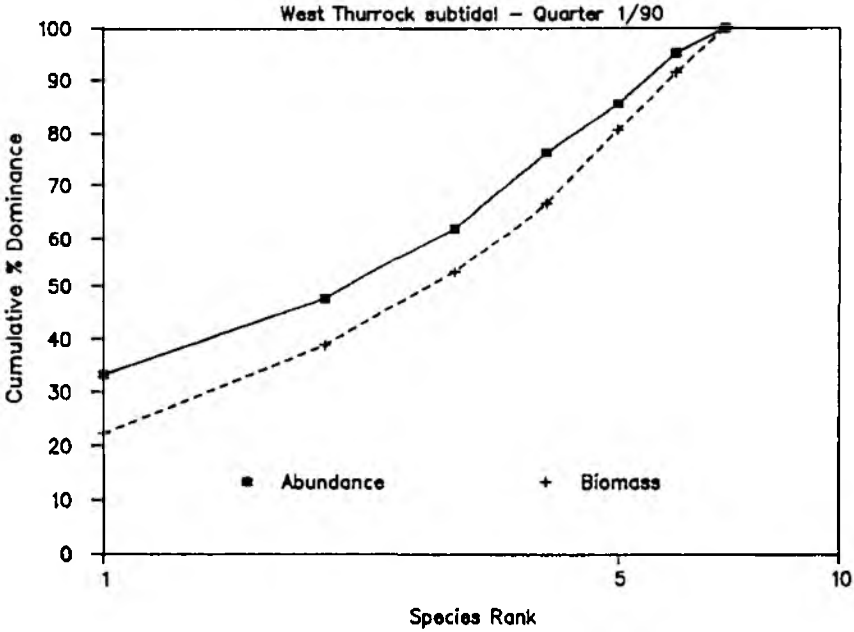
ABC plots

West Thurrock subtidal – Quarter 3/89

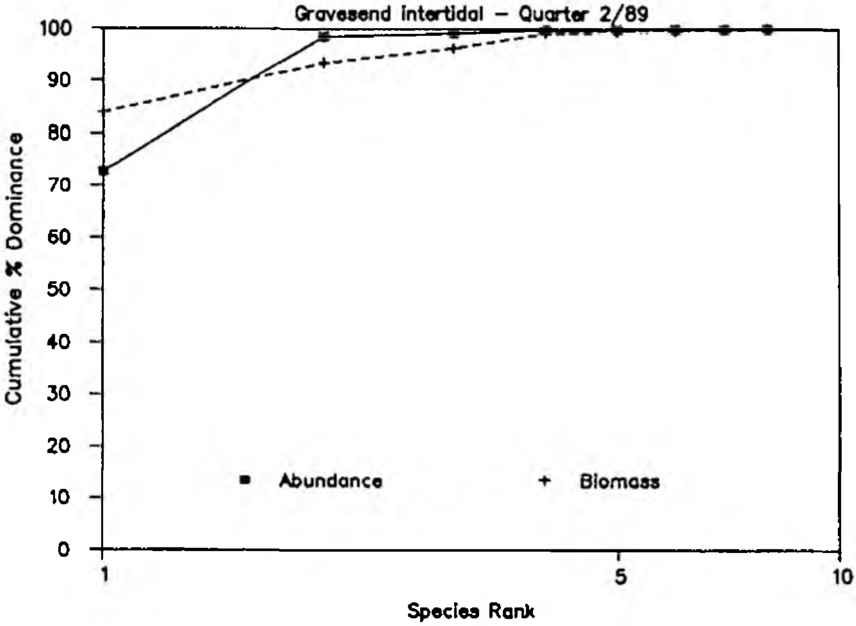
Only 1 species present

ABC plots

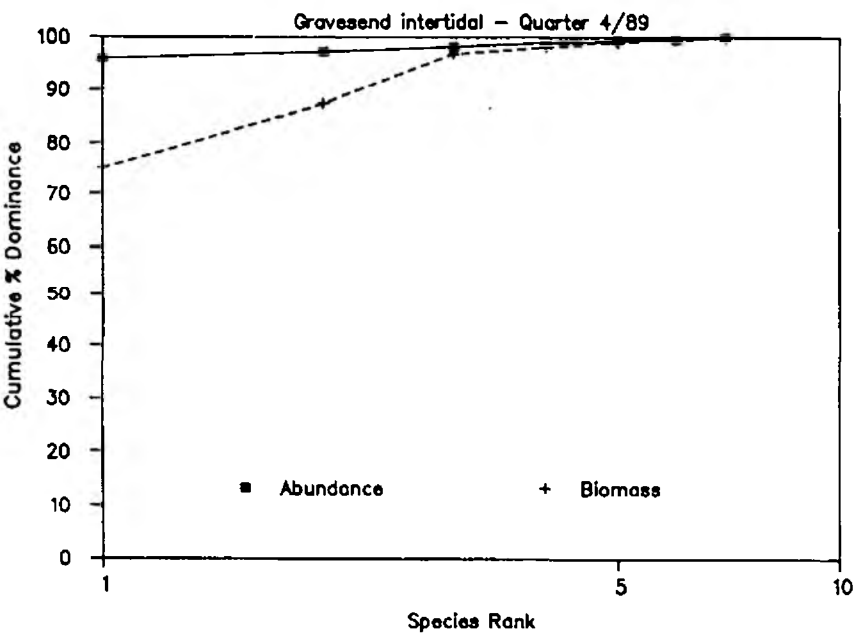
West Thurrock subtidal – Quarter 1/90



ABC plots

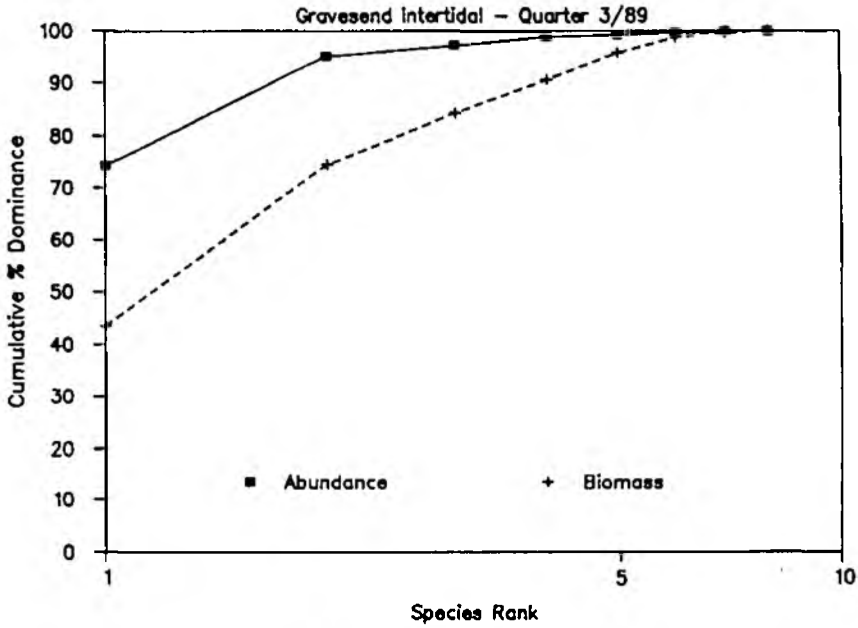


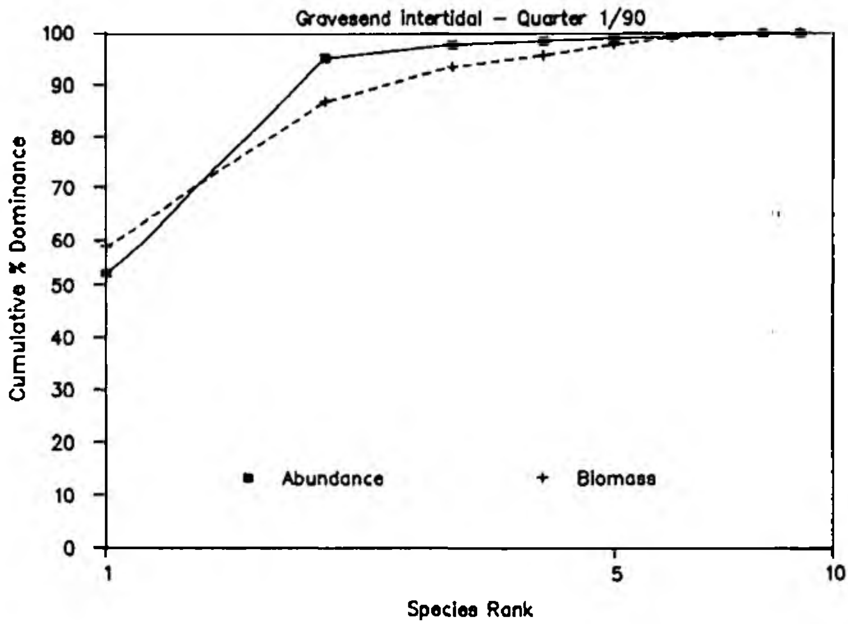
Gravesend intertidal – Quarter 2/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank



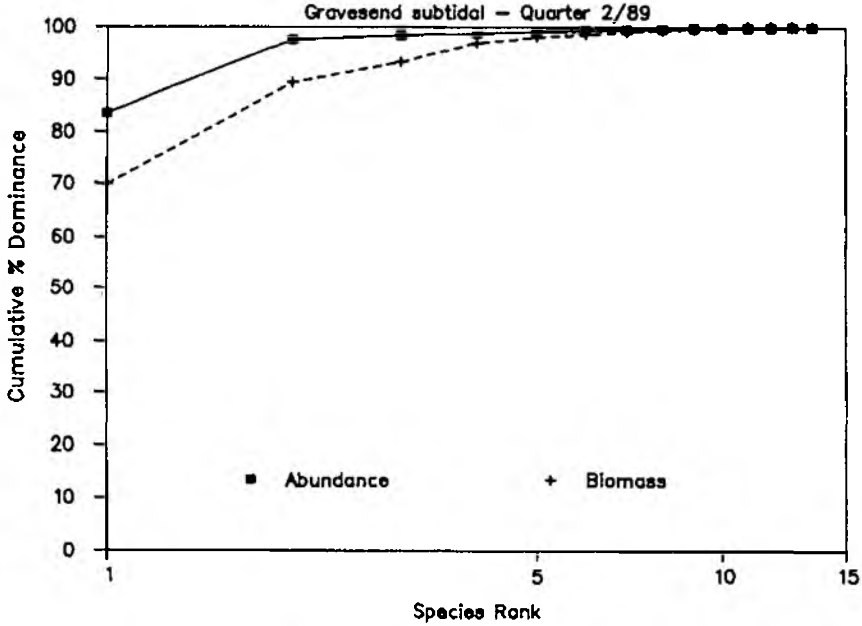
Gravesend intertidal – Quarter 4/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

ABC plots

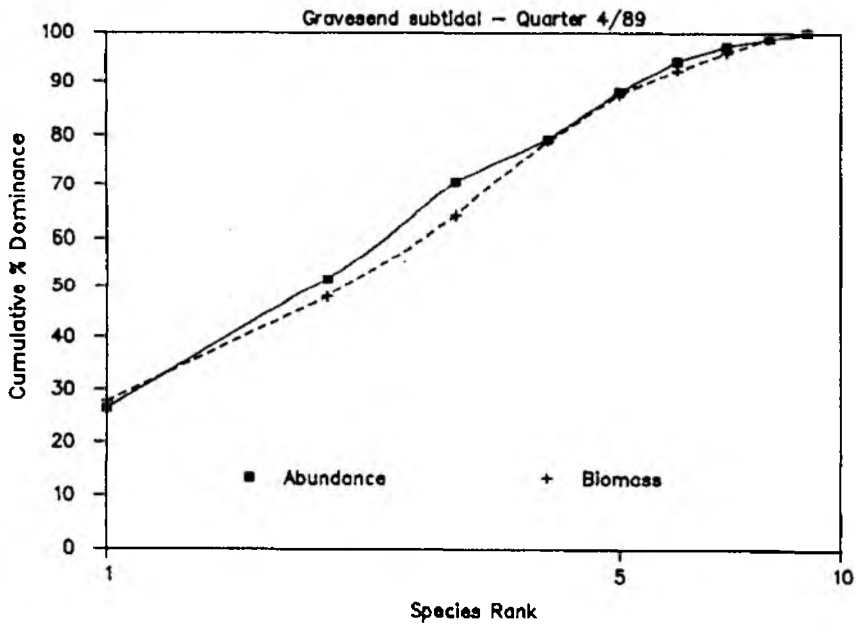

Gravesend Intertidal - Quarter 3/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank


Gravesend Intertidal - Quarter 1/90
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

ABC plots

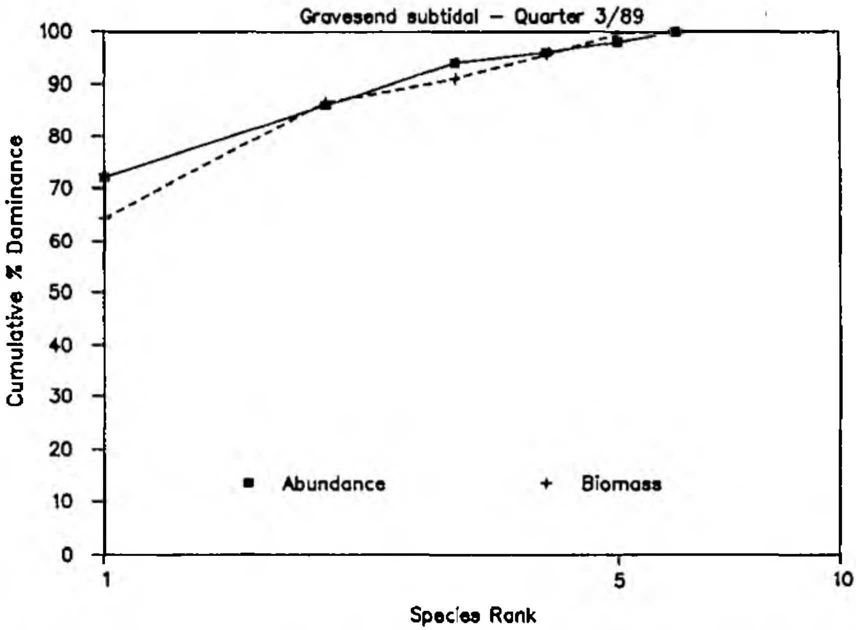


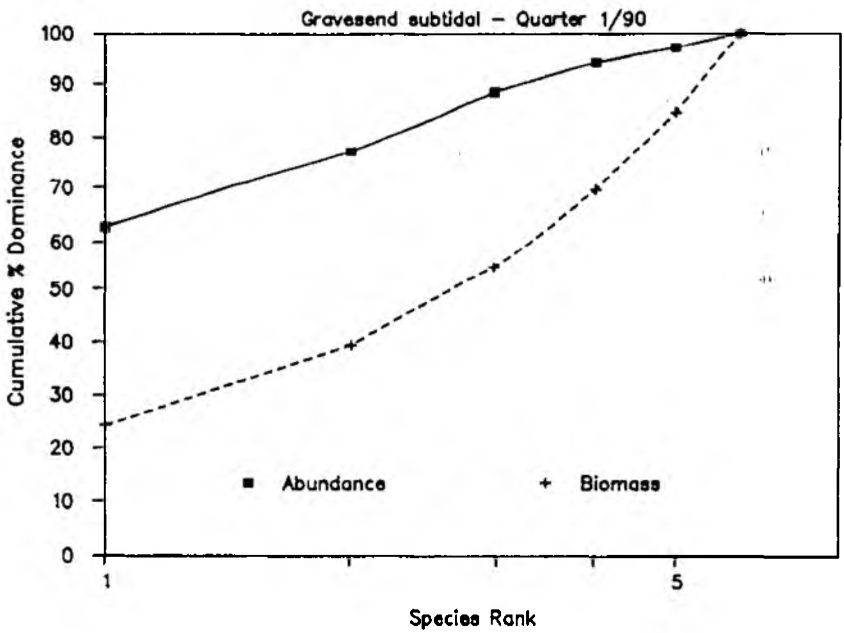
Gravesend subtidal – Quarter 2/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
15
Species Rank



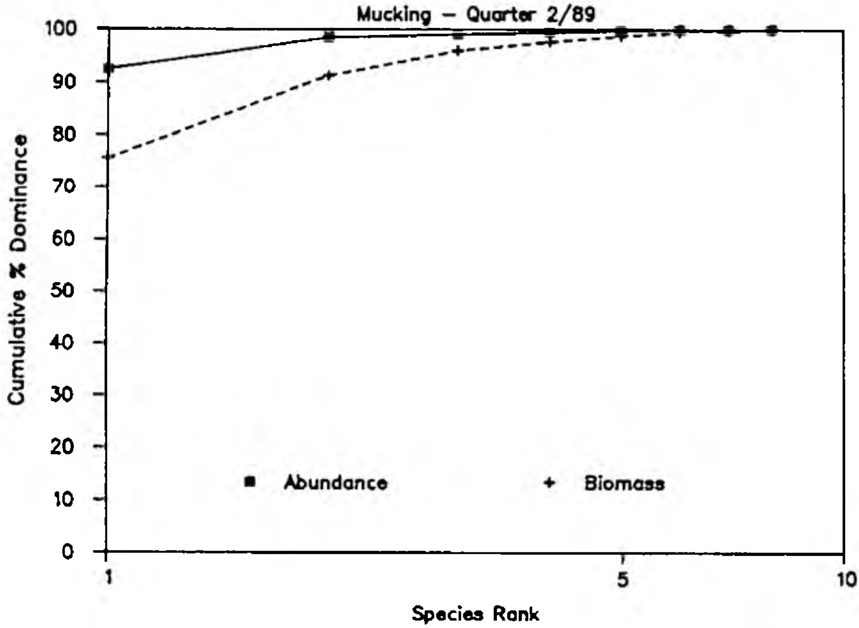
Gravesend subtidal – Quarter 4/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

ABC plots

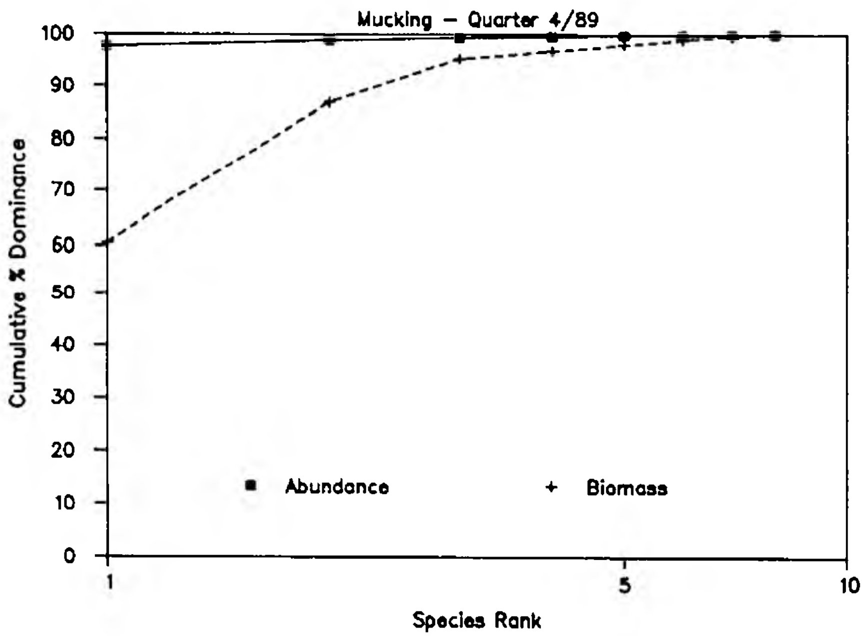

Gravesend subtidal - Quarter 3/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
1
5
10
Species Rank
Abundance
Biomass


Gravesend subtidal - Quarter 1/90
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
1
5
Species Rank
Abundance
Biomass

ABC plots

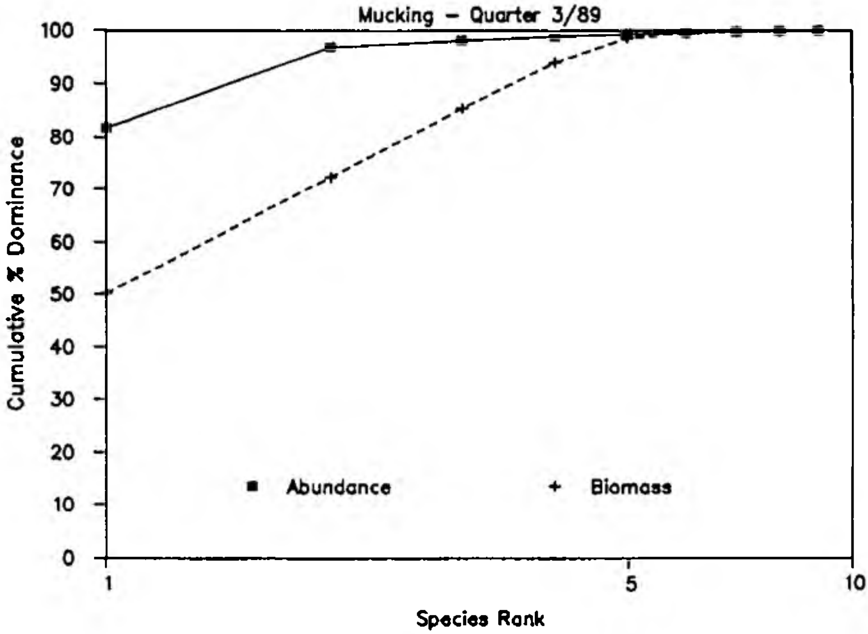


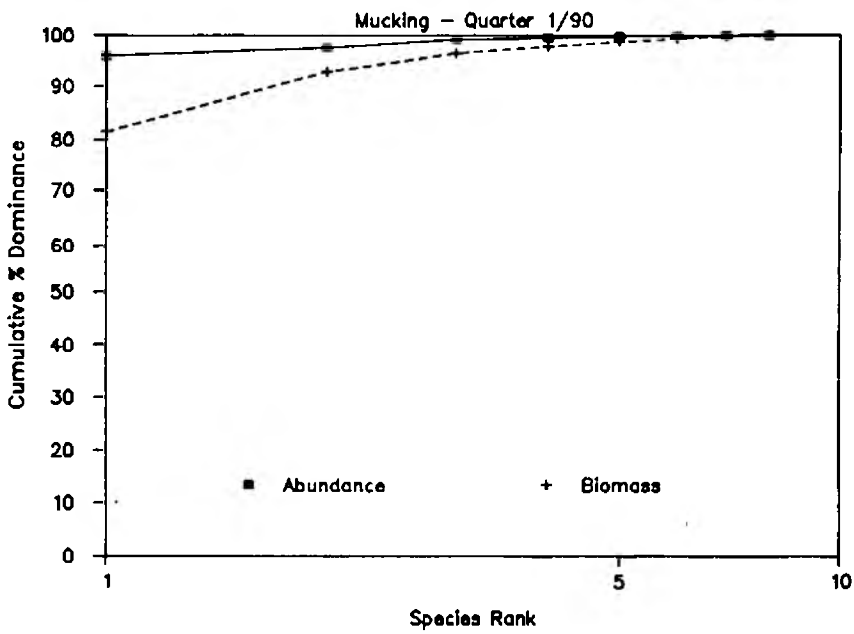
Mucking – Quarter 2/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank



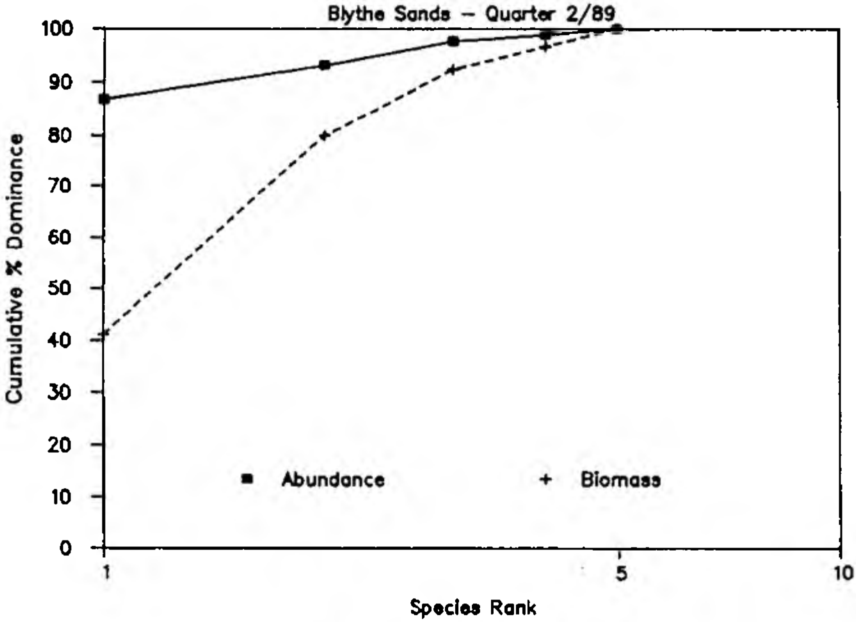
Mucking – Quarter 4/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

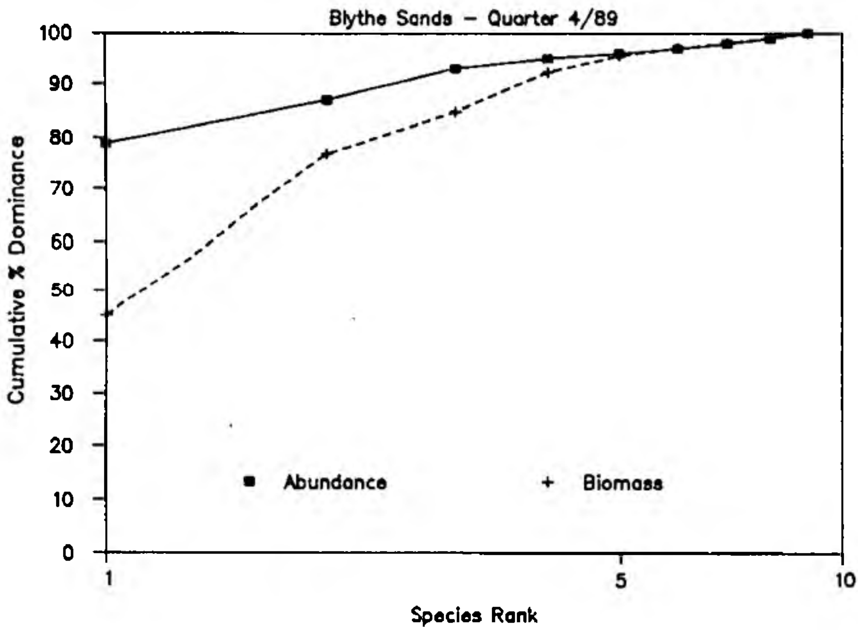
ABC plots


Mucking – Quarter 3/89
100
90
80
70
60
50
40
30
20
10
0
Cumulative % Dominance
Abundance
Biomass
1
5
10
Species Rank

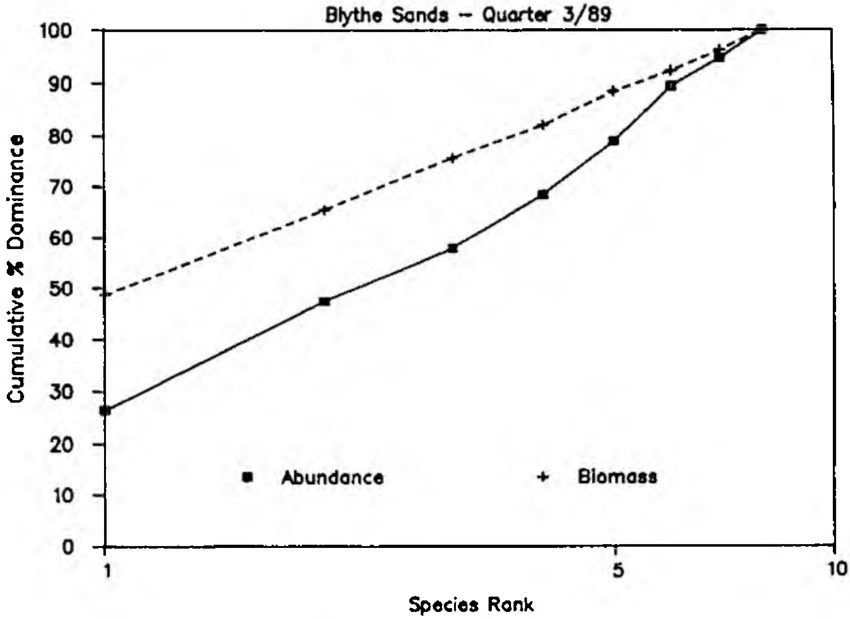

Mucking – Quarter 1/90
100
90
80
70
60
50
40
30
20
10
0
Cumulative % Dominance
Abundance
Biomass
1
5
10
Species Rank

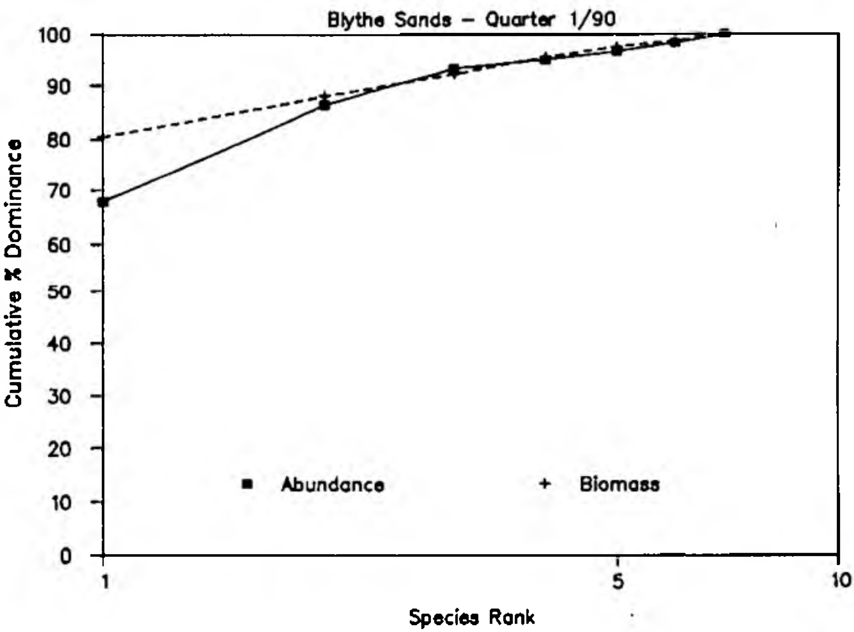
ABC plots


Blythe Sands – Quarter 2/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

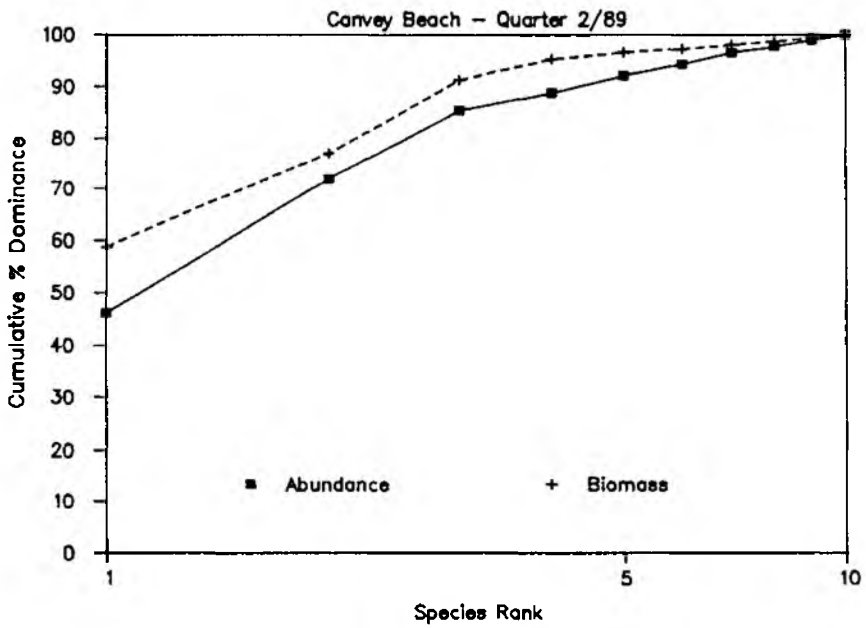

Blythe Sands – Quarter 4/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

ABC plots

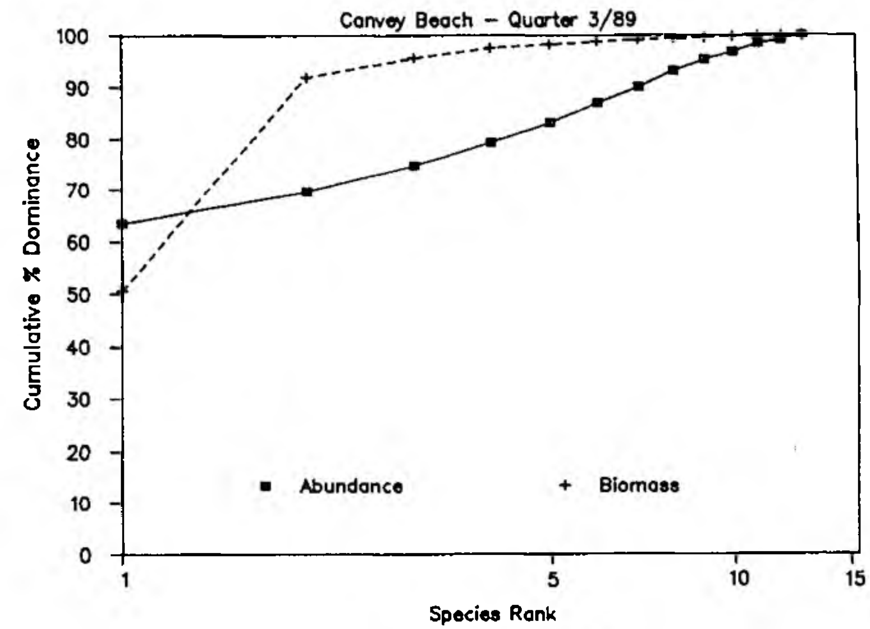

Blythe Sands - Quarter 3/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

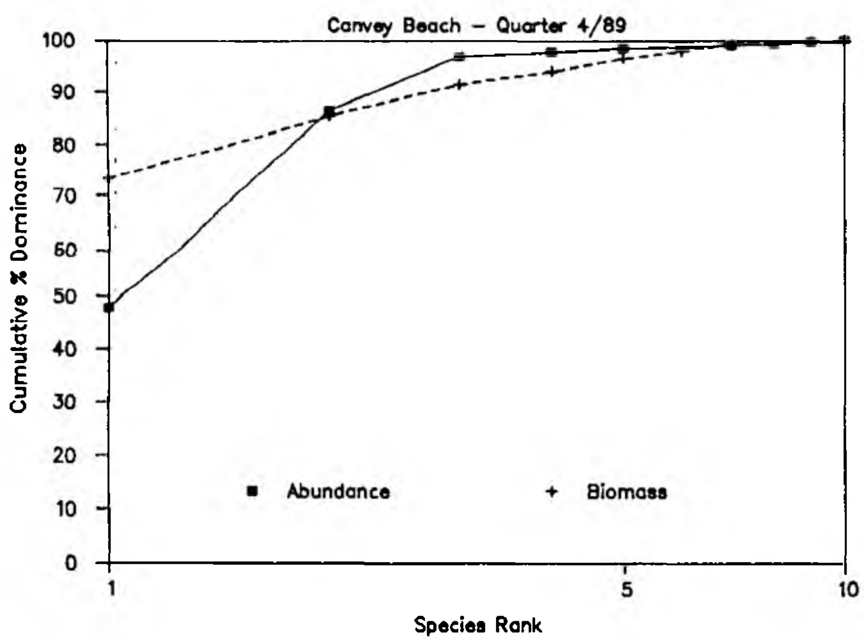

Blythe Sands - Quarter 1/90
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
Species Rank

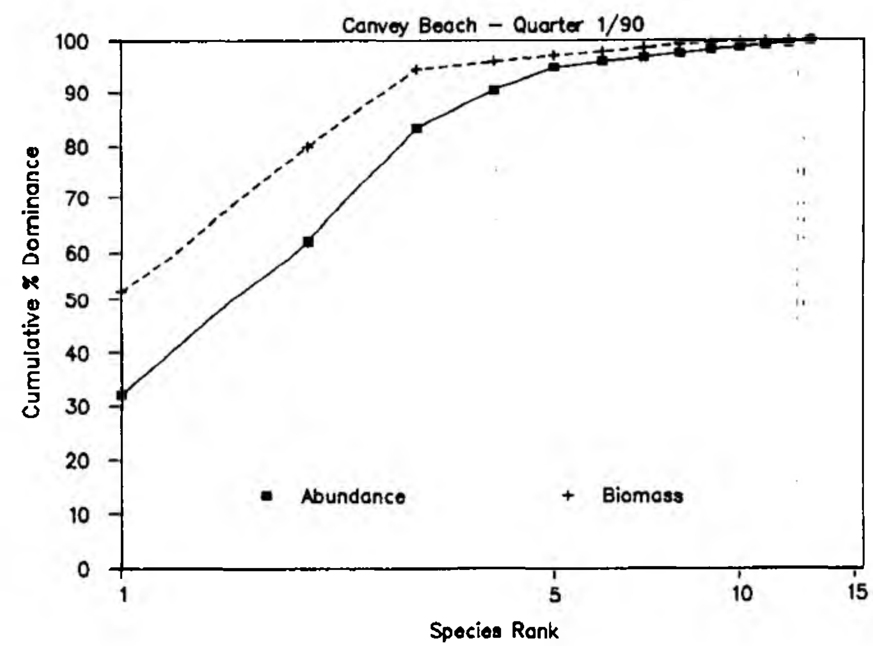
ABC plots



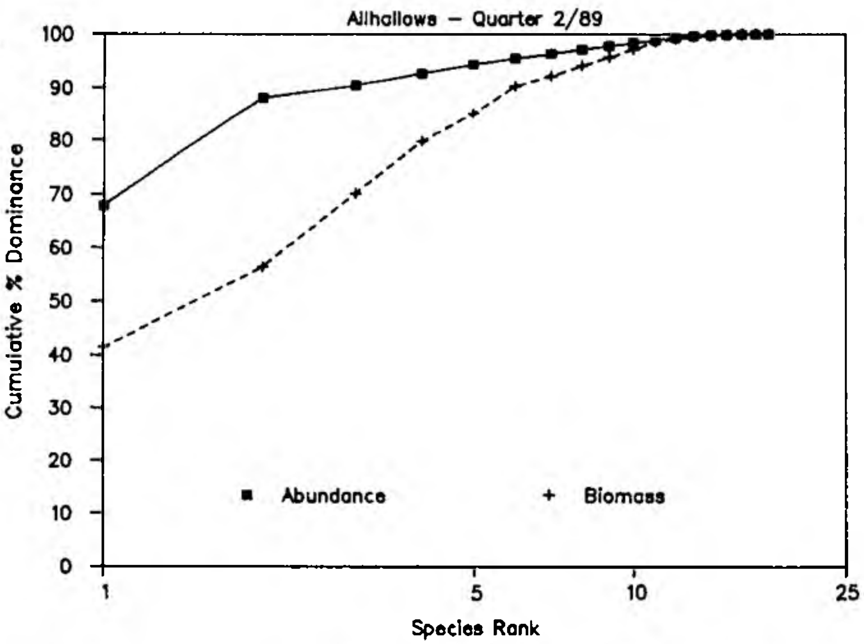
ABC plots



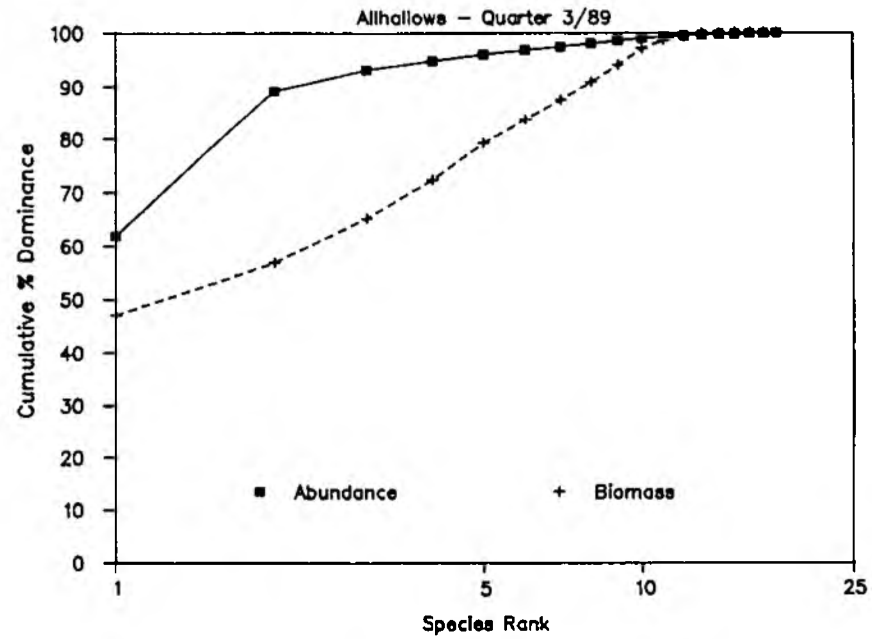


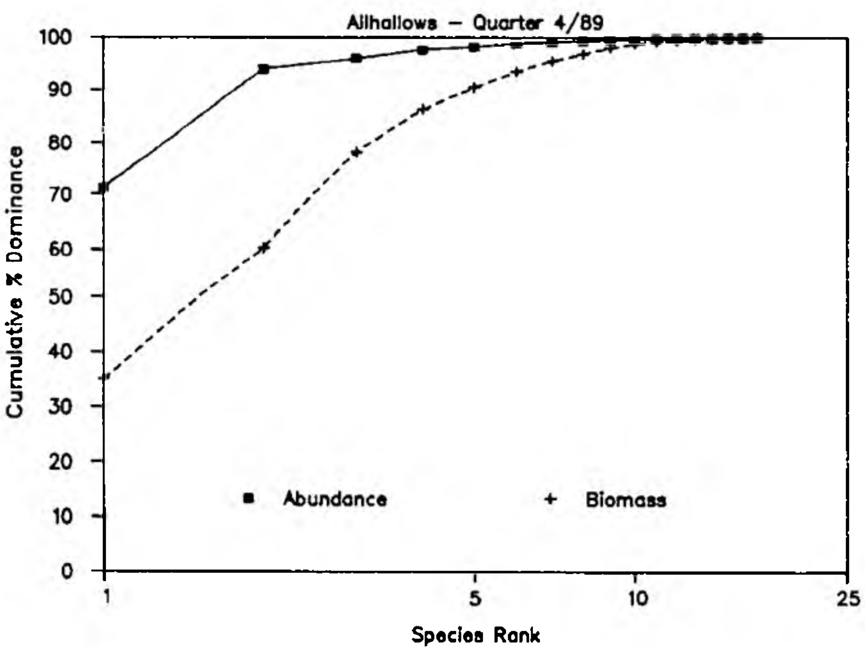


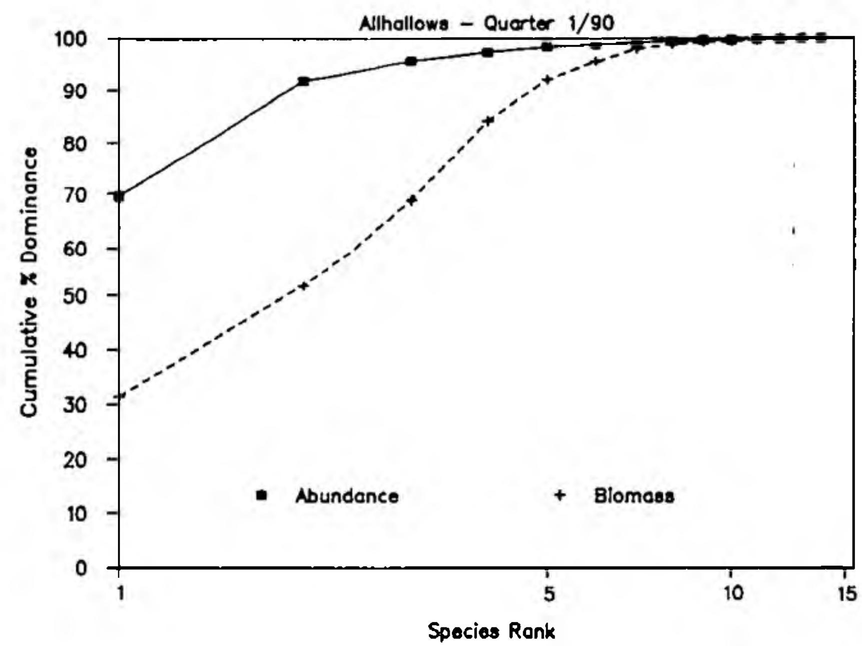
ABC plots



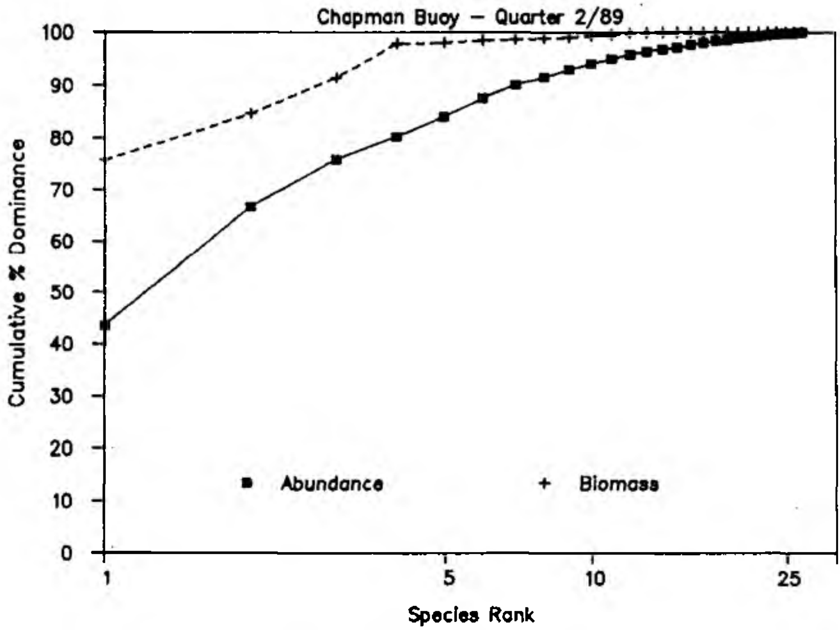
ABC plots

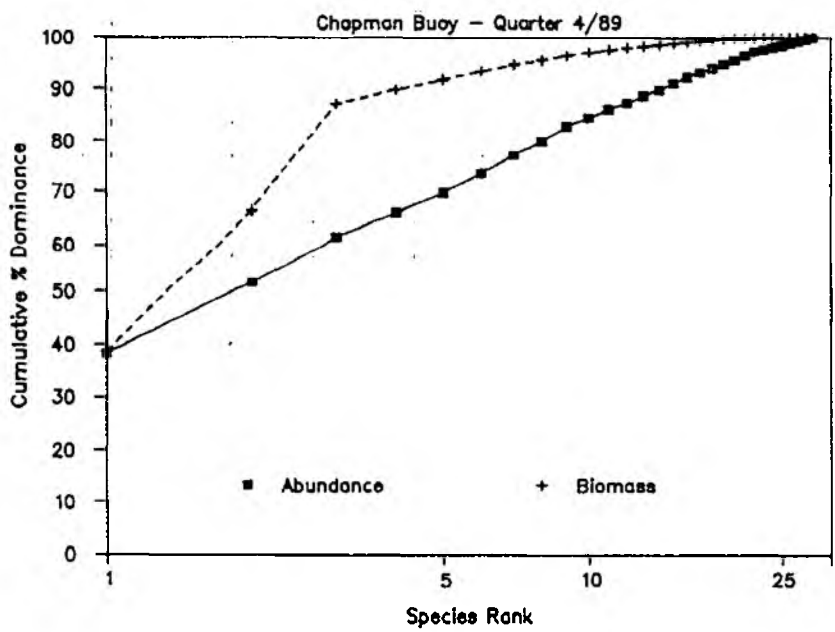




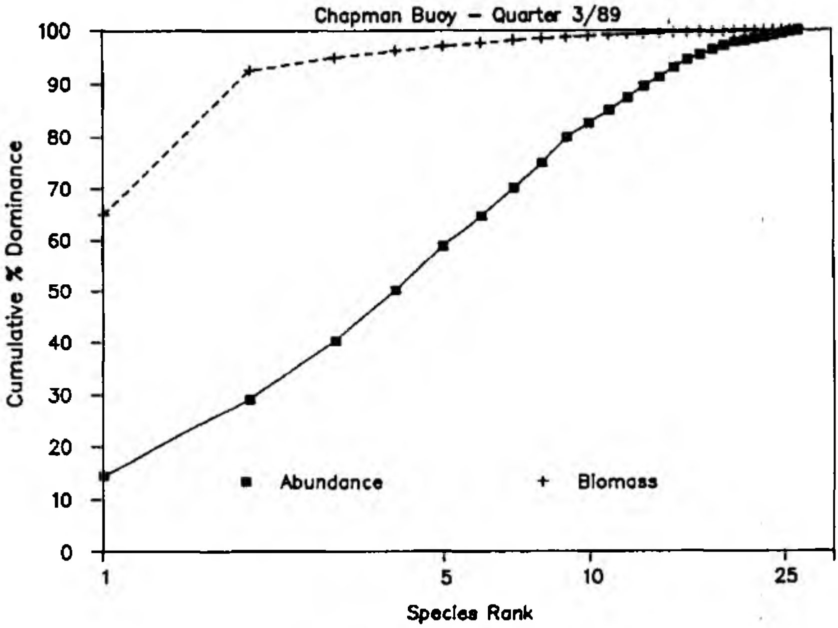


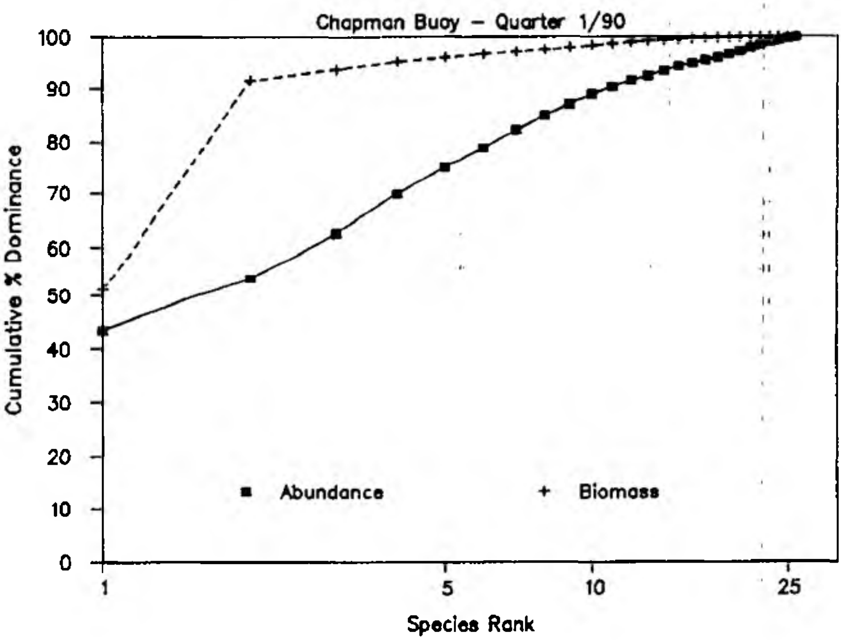
ABC plots


Chapman Buoy - Quarter 2/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
1
5
10
25
Species Rank
Abundance
Biomass

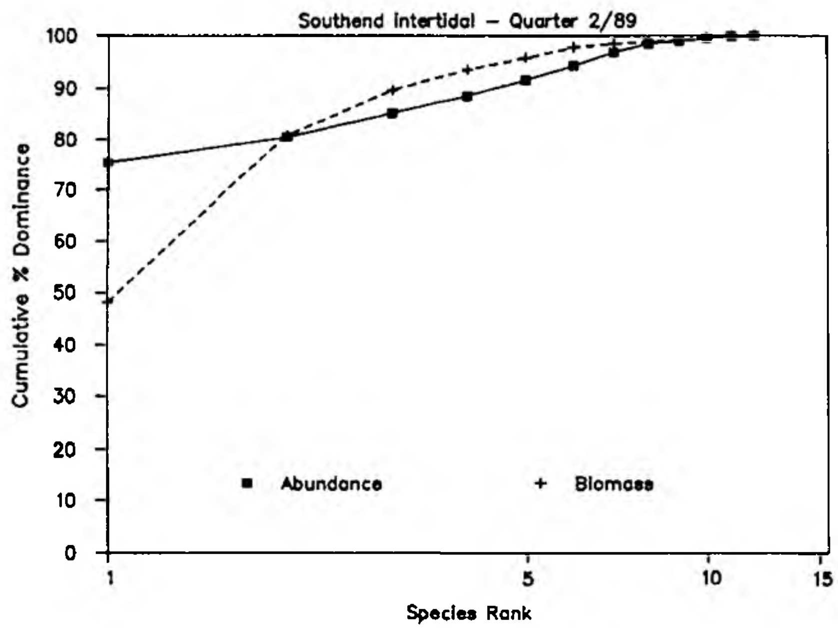

Chapman Buoy - Quarter 4/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
1
5
10
25
Species Rank
Abundance
Biomass

ABC plots

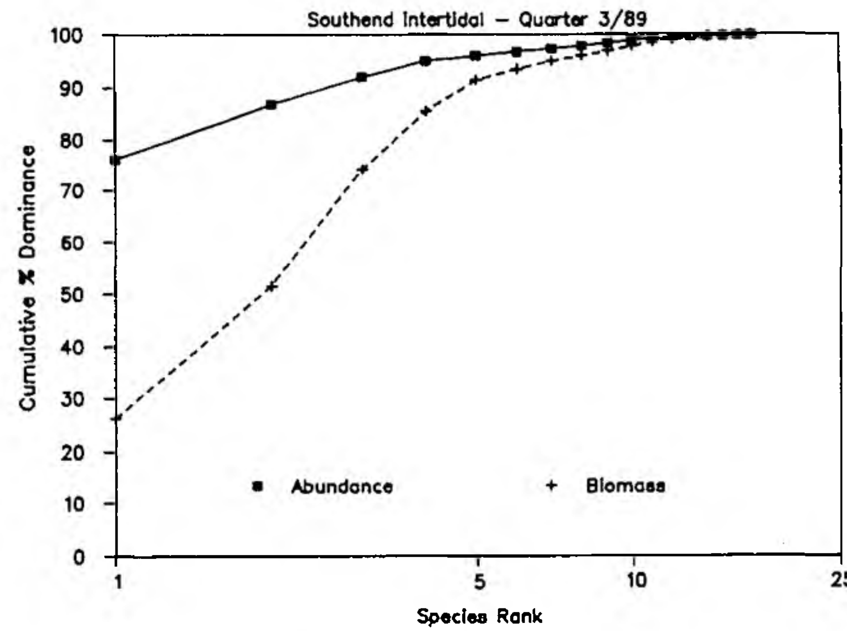

Chapman Buoy - Quarter 3/89
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
25
Species Rank

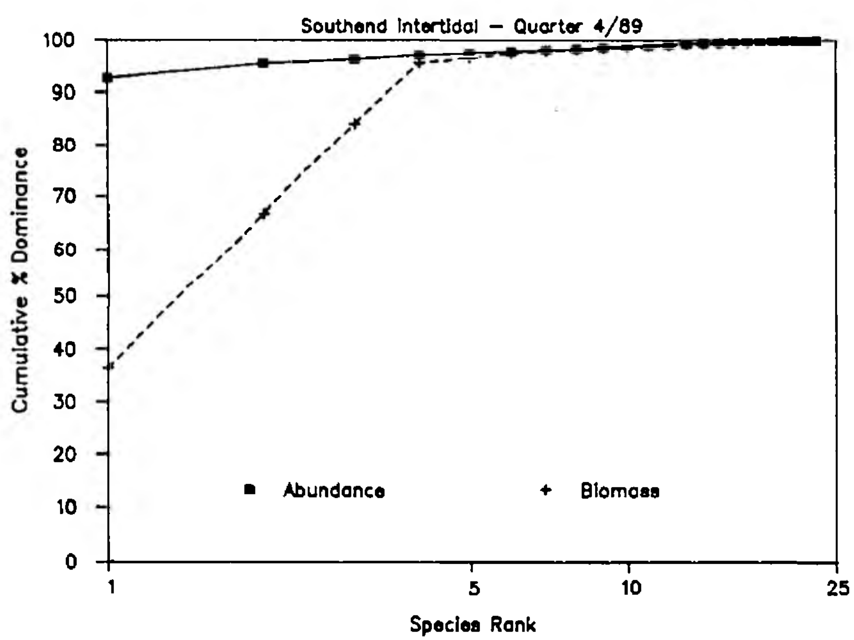

Chapman Buoy - Quarter 1/90
Cumulative % Dominance
100
90
80
70
60
50
40
30
20
10
0
Abundance
Biomass
1
5
10
25
Species Rank

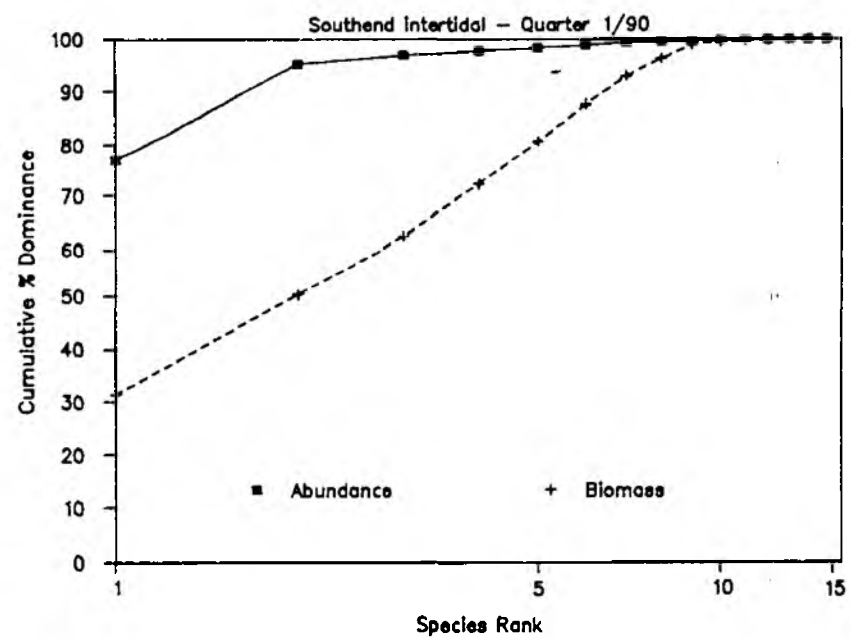
ABC plots



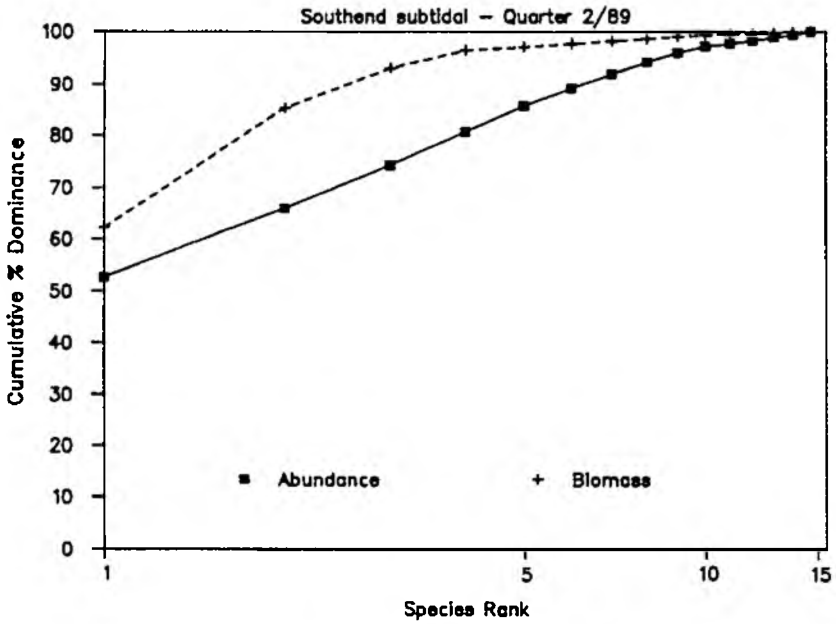
ABC plots



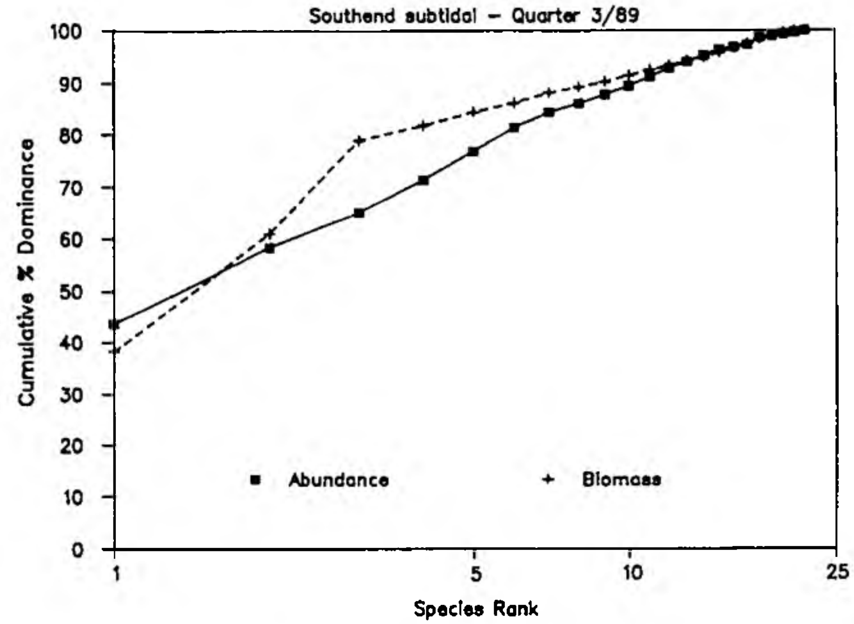


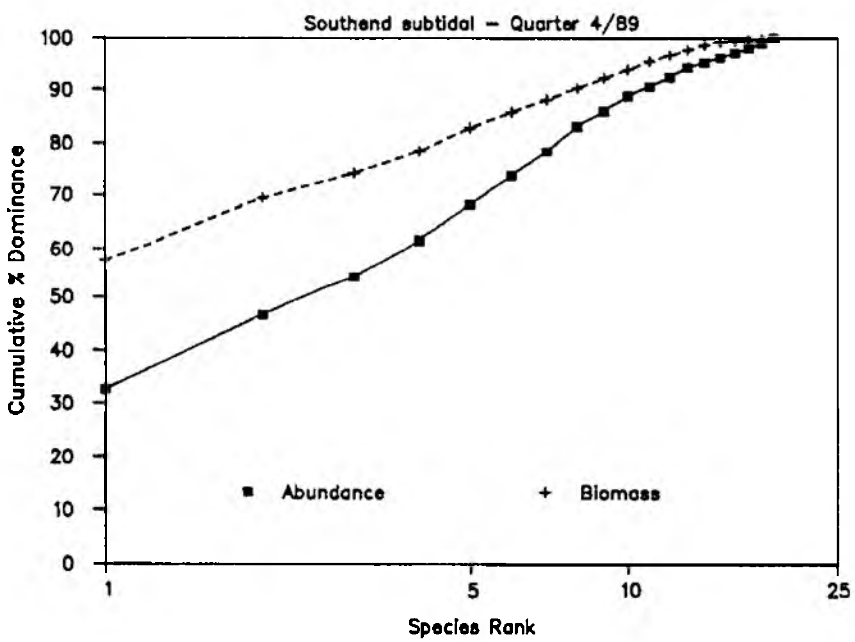


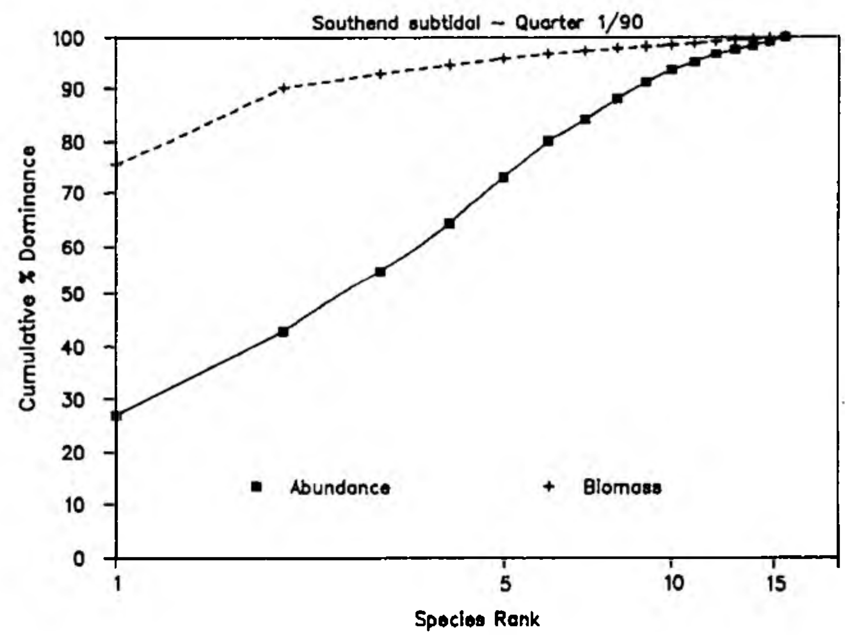
ABC plots



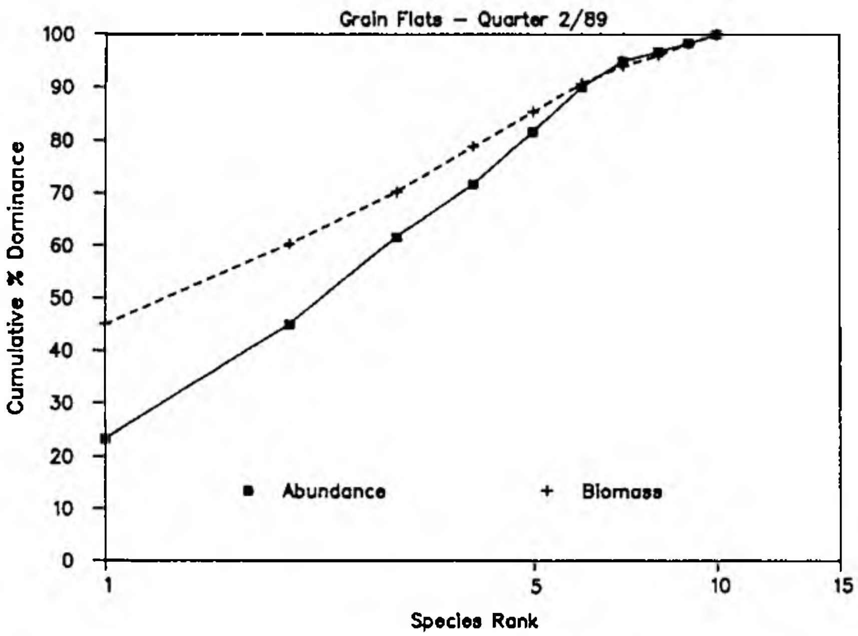
ABC plots



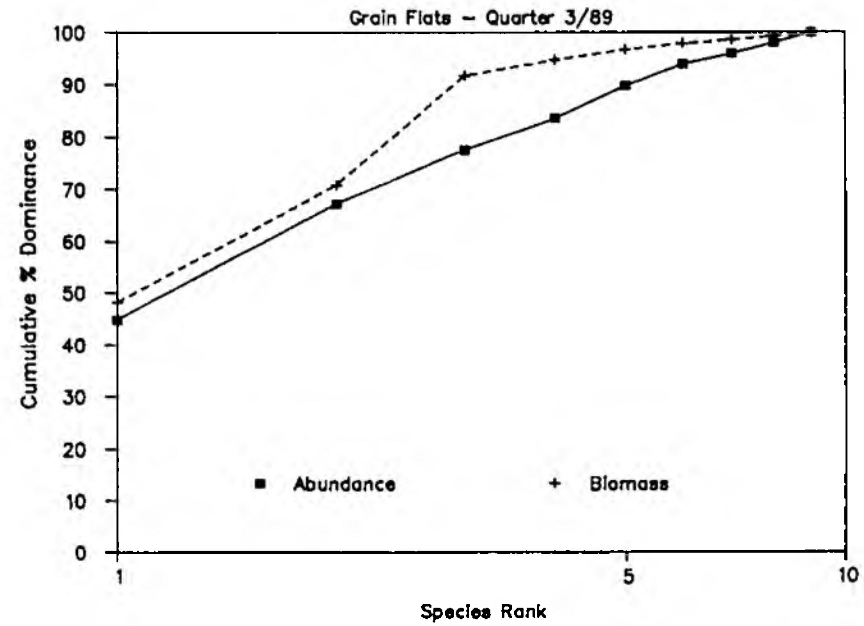


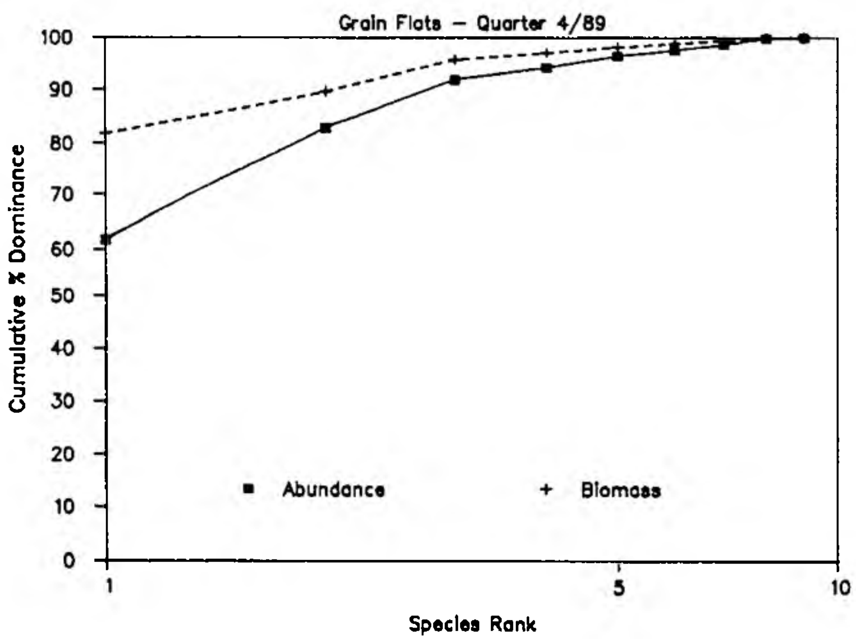


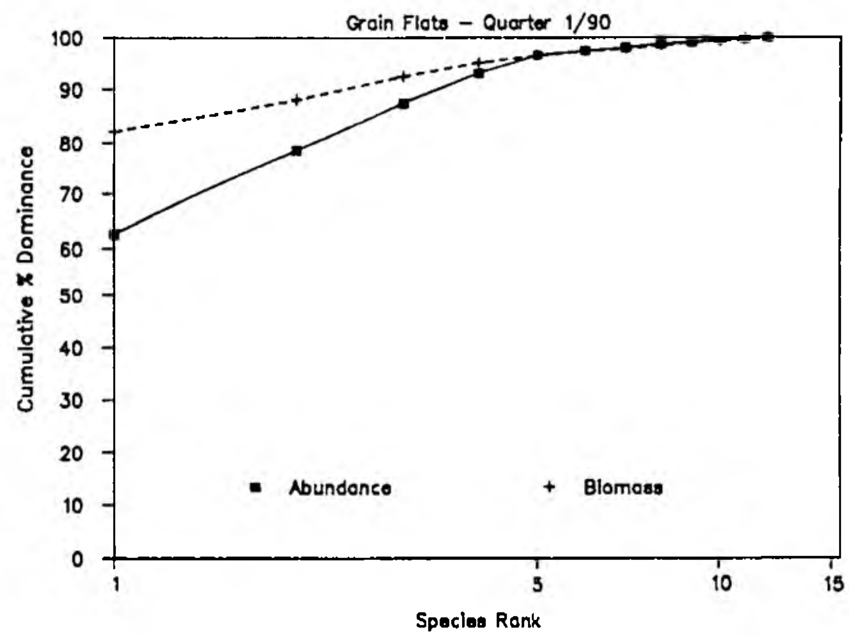
ABC plots



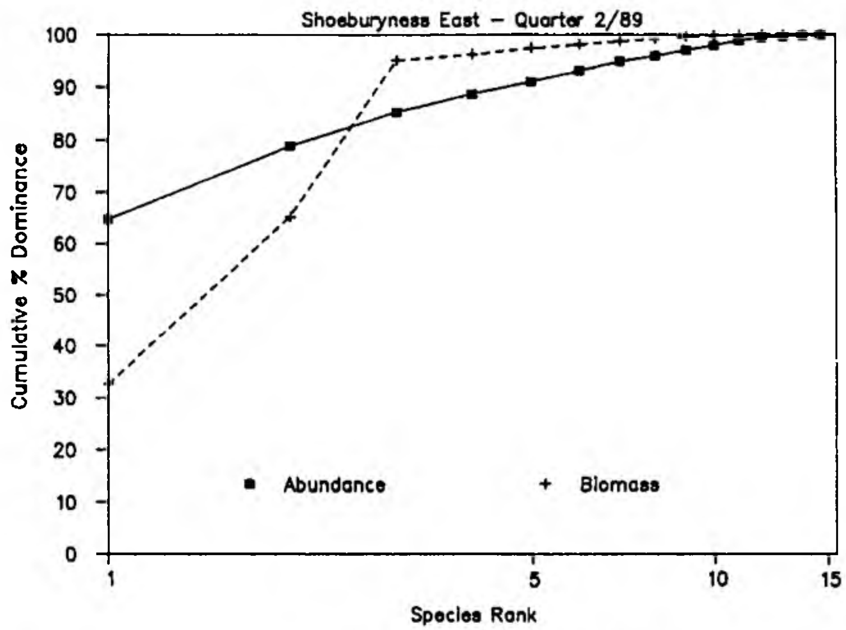
ABC plots



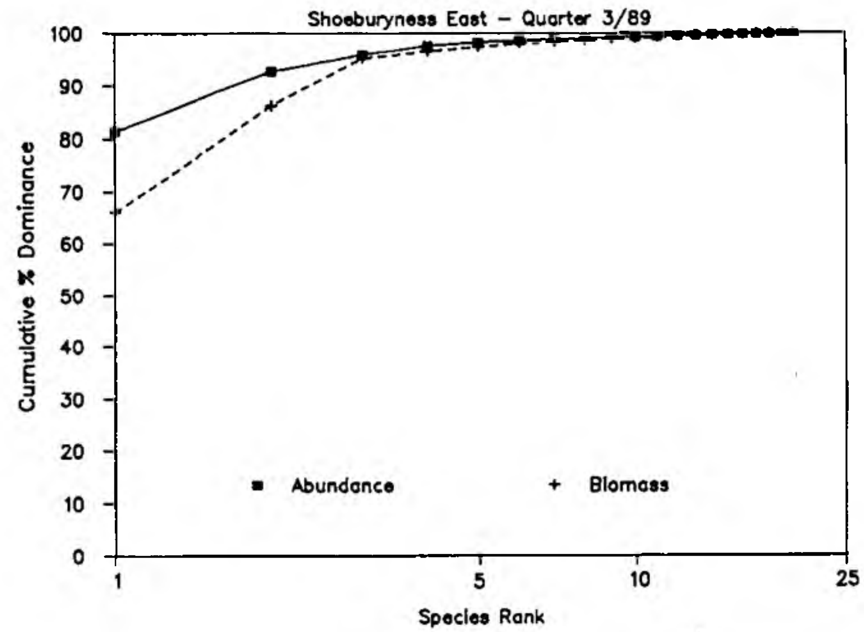


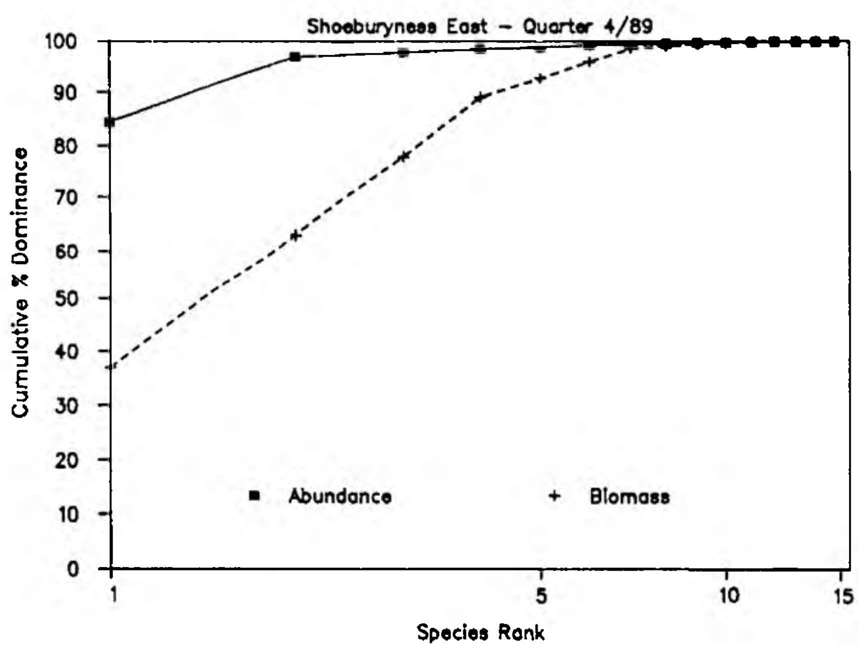


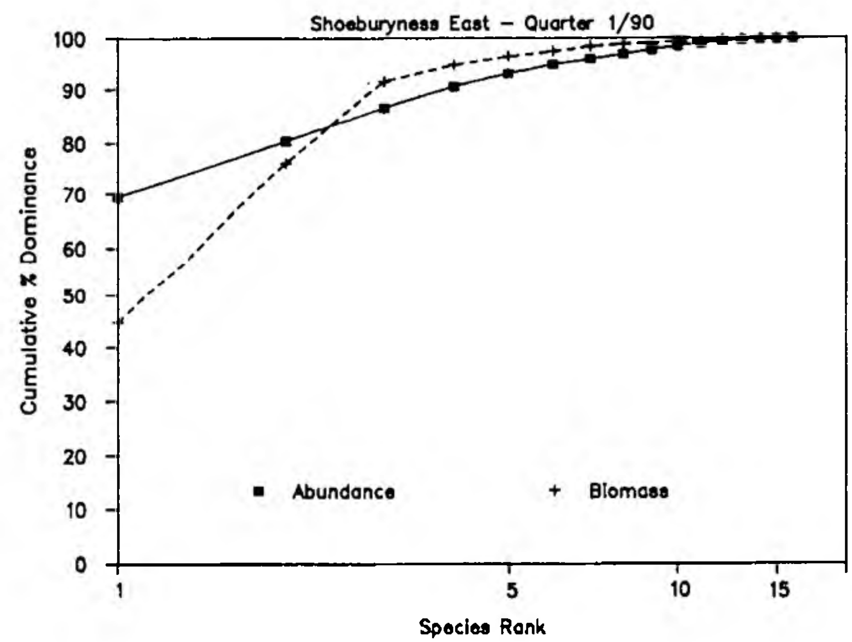
ABC plots



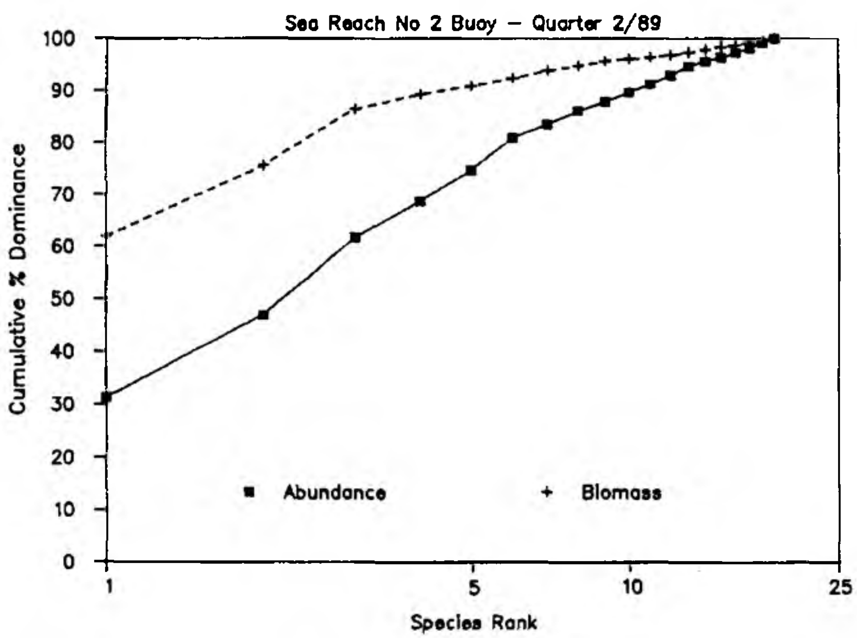
ABC plots

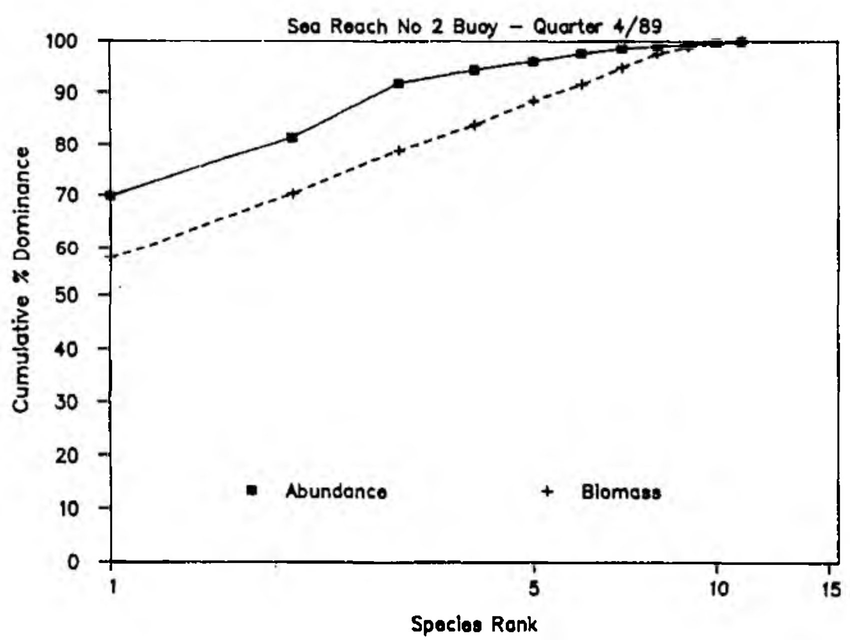






ABC plots





ABC plots