Fisheries Research Services Report No 04/01

SOTEAG ROCKY SHORE MONITORING PROGRAMME. TBT CONTAMINATION IN SULLOM VOE, SHETLAND. 2001 DOGWHELK SURVEY

M Harding, G K Rodger and I M Davies

November 2001

Fisheries Research Services
Marine Laboratory
Victoria Road
Aberdeen AB11 9DB

Table of Contents

SOTEAG ROCKY SHORE MONITORING PROGRAMME. TBT CONTAMINATION IN SULLOM VOE, SHETLAND. 2001 DOGWHELK SURVEY

M Harding, G K Rodger and I M Davies

Marine Laboratory
Aberdeen

This report provides the results of a survey carried out by FRS Marine Laboratory, Aberdeen as part of a rockyshore monitoring programme undertaken by Cordah, commissioned by the Shetland Oil Terminal Environmental Advisory Group (SOTEAG), and funded by the Sullom Voe Association.

SUMMARY

Dogwhelks were collected from 20 sites throughout Sullom Voe and Yell Sound in July/August 2001 by Cordah staff, and transported to the FRS Marine Laboratory in Aberdeen for imposex analysis. Dogwhelks of all sizes (juveniles to adults) were collected from five of the sites. Where possible, the sites were chosen to match those established in the 1991 baseline survey. Results of the present survey were compared to the seven previous surveys.

The degree of imposex (RPSI and VDSI measurements) in toothed adults from sites within Sullom Voe in 2001 show that these sites continue to be more impacted by TBT from the oil terminal activities than populations at sites in Yell Sound. The RPSI and VDSI values were high throughout Sullom Voe (RPSI 14.21-34.03%; VDSI 4.00-4.42), similar to the values in the 1999 survey. Outside the Voe, in the well flushed waters of Yell Sound, both the RPSI and VDSI in populations were much lower than within the Voe (RPSI 0.00-1.43%; VDSI 0.17-1.88). As in previous surveys, the degree of imposex in populations in Yell Sound generally decreases with distance from Sullom Voe.

Sites within the Voe and site 4 (in the Yell Sound) were the only ones where a proportion of the females dogwhelks had a blocked reproductive tract and hence were reproductively unviable. The RPSI and VDSI measurements at the sites within the Voe show that these populations are not in immediate danger, and can continue to reproduce. The degree of imposex at the sites between the Yell Sound and Sullom Voe has not declined with time. However, these populations continue to have good reproductive potential.

1. INTRODUCTION

Tributyltin (TBT) compounds have been recognised as some of the most toxic substances released into the aquatic environment. Extensive reviews have been published outlining the toxicity of TBT to aquatic organisms (Hall and Pinkney, 1985; Laughlin and Linden, 1987; Muller *et al.*, 1989; IMO, 1989; IPCS, 1990).

Sullom Voe is a large fiordic inlet on the mainland of Shetland (Figure 1). The mouth of the Voe is approximately 5 km wide, and the Voe extends approximately 13 km southwards (Dooley, 1981). A large oil terminal, situated on the promontory of Calback Ness, was opened in November 1978. There was a peak in the tonnage and number of crude and gas tankers visiting the terminal in 1984. The tonnage and numbers fell from then until 1990, and have since levelled out at about half the peak tonnage and number. There have been no fish farms within the Voe, and no significant small boat activity occurs in the area. TBT contamination therefore arises from tankers (Bailey and Davies, 1988) and, up until 1986, from TBT antifoulants used on towing vessels, navigational buoys and harbour craft (Shetland Islands Ports Authority and Shetland Islands Council, pers comm, 1991).

Extensive laboratory and field investigations have been undertaken demonstrating the occurrence of male sexual characteristics in female dogwhelks (a condition termed imposex; Blaber, 1970) resulting from exposure to TBT. The sensitivity and usefulness of using the dogwhelk as an indicator of TBT contamination is well established (eg Gibbs *et al.*, 1987; Bailey and Davies, 1989) and has been included in international monitoring programmes under the Oslo and Paris Commission (Davies *et al.*, 1997).

The following report details results of a survey which used the common dogwhelk (*Nucella lapillus* L.) as an indicator of TBT contamination arising from oil terminal operations in Sullom Voe. The aim of the survey was to provide continuing comparable time series data on the effects of TBT contamination in and around Sullom Voe and, in particular, assess if the dogwhelk populations have shown any further recovery since the 1999 survey.

2. METHODS

2.1 The Choice of Survey Sites and Dogwhelk Sampling Procedure

Samples of approximately 40 adult dogwhelks (identified by thickened shell rim and the presence of teeth; Crothers, 1985) were collected from 20 sites around Sullom Voe and the waters of Yell Sound (Figure 1, Table 1) in July/August 2001. Juvenile dogwhelks were collected at five of the sites (1, 3, 5, 9 and 12) as in previous surveys. The shell length of each animal was measured, and individuals were classified by their shell length according to observations by Moore (1936); juveniles (10-15 mm shell length); sub-adults (15-21 mm); un-toothed adults (21-26 mm and 26-35 mm). At each of the juvenile and sub adult survey sites, an attempt was made to obtain 20 individuals from each of the above size classes (and 40 toothed adults). The degree of imposex, (Relative Penis Size Index (RPSI) and Vas Deferens Sequence Index (VDSI)), where measured using international standard techniques.

2.2 Determination of the Relative Penis Size Index (RPSI)

The Relative Penis Size Index (or RPSI, Gibbs *et al.*, 1987) was calculated from penis length measurements of the dogwhelks as follows:

$$\frac{(\text{mean female penis length})^3}{(\text{mean male penis length})^3} X\,100 = \%\text{RPSI}$$

The greater the penis growth in females, the higher the RPSI value; an RPSI of 12.5%, for example, indicates that the mean female penis length is half that of the male.

2.3 Determination of the Vas Deferens Sequence Index (VDSI)

The development of imposex in dogwhelks may be divided into seven stages, depending upon the developmental state of both the penis and vas deferens in the female (Gibbs *et al.*, 1987). Stage 0 is identified where no signs of imposex can be seen. Stage 1 can be identified when the vas deferens begins at the site of the vulva with Stage 2 also showing a small penis behind the right eye tentacle. As imposex progresses, the vas deferens starts to develop from the penis (Stage 3) and will become continuous (Stage 4). Eventually, vas deferens tissue may proliferate over the opening of the vulva (Stage 5), rendering the female incapable of breeding since she can no longer release egg capsules. The egg capsules, unable to be released, form a solid mass within the capsule gland. In this final Stage (Stage 6), the capsule gland may eventually rupture, causing premature death of the female. Each of the seven Stages of imposex is known as a Vas Deferens Sequence (VDS), stage and calculation of the mean VDS for a group of females provides the Vas Deferens Sequence Index (VDSI) which may be used to compare the reproductive competency of different populations.

The VDS was determined in each female and the mean VDS calculated to provide an estimate of the VDSI of the population.

3. RESULTS

A. Toothed Adult Survey

The highest RPSI value (Table 1, Figure 2) from the toothed adult populations of *N. lapillus* were found in the vicinity of the oil terminal (site 12, 34.03 %). The RPSI values from toothed adult populations in Yell Sound (sites 1, 2, 3, 5, 14-17 and 19-20) were much lower (0.00-1.43%) than those in Sullom Voe (sites 7-12; 14.21-34.03 %). The low RPSI values in most of the sites in the Yell Sound were below 1%; a value which is associated with areas distant from sources of TBT (Bryan *et al.*, 1986; Bailey and Davies, 1989).

The VDSI values (Table 1, Figure 3) follow a similar distribution to that seen in the RPSI results. Populations within the Voe (sites 7-12) showed VDSI values of 4.0-4.42. Most of the populations within the Yell Sound (sites 1, 2, 3, 5, 14-17, 19, 20) had low VDS indices (0.17-1.88).

The distribution of females at each Vas Deferens Sequence Stage 0-6 from sites 1-20 are shown in Figure 4. 4.8-41.7% of tooted adult females were found to be sterile (blocked reproductive tract with vas deferens tissue, VDS Stage 5 or 6) at five of the sites within the Voe (Table 3). At two of the sites in the Voe, Noust of Burraland (site 8) and Mavis Grind (site 9), 25 and 41.7 % respectively of the females collected were sterile.

Only one female at the Noust of Burraland site 8 was found with a solid mass of egg capsules within the capsule gland (stage 6). 81% of the female toothed adults within the Voe were at VDS stage 4. The populations at most sites outwith the Voe (sites 1, 2, 3, 5, 14-17, 19,20) had no sterile females. Most of the individuals at these sites were at VDS Stages 0-2 showing little or no development of imposex, although one individual from each

of sites 3 and 14 was found at stage 4.

The imposex results show that populations at most sites within the Voe still show clear signs of TBT exposure. Most of the sites outwith the Voe have low levels of imposex indicating a continuing exposure to considerably less TBT than those sites in the Voe. There is a general gradation in imposex from the low levels at the outer sites in Yell Sound with increasing degrees of imposex towards Sullom Voe.

Sites 6, 13 and 18, situated between the Yell Sound and Sullom Voe, have RPSI (6.2%, 23.61% and 8.91% respectively) and VDSI (4.0, 4.29 and 2.19 respectively) values which reflect their intermediate position. The animals from sites 6 and 18 showed RPSI values which were lower than those from dogwhelks in the Voe and higher than the majority of animals from the Yell Sound. The VDSI values in animals from these two sites however were similar to those found in animals from the Voe. The animals from site 13 reflected the proximity to the Voe. All the females from site 6 and the majority of individuals at sites 13 and 18 were at VDS Stage 4.

Site 4 in the Yell Sound had RPSI and VDSI values of 28.81% and 4.59 respectively. These values were markedly different from the results from the other sites in the Yell Sound and were more typical of those found in the Voe. In addition, all the females from this site showed VDS stage 4 or 5.

B. Un-toothed Adults, Sub-adult and Juvenile Surveys

As with the survey of imposex in the toothed adults, the highest RPSI and VDSI values (Table 1, Figure 5) were found in animals collected from site 12 The Kames (104.76% 10-15 mm and 4.33 26-35 mm respectively) within the Voe.

The RPSI values for all the size/age classes at Easterwick (site 1), Billia Skerry (site 3) and East of Ollaberry (site 5), were less than the 1% value associated with areas distant from sources of TBT (Bryan *et al.*, 1986; Bailey and Davies, 1989). There were no individuals at any size/age class who had a VDSI of 4 or greater. The increase in the degree of imposex in adults from populations towards the Sullom Voe is also evident in the younger age classes.

Within the Voe, all the size/age classes from site 12 (The Kames) at the terminal had higher RPSI and VDSI values than the corresponding class from site 9 (Mavis Grind) at the head of the Voe. All the individuals collected at Mavis Grind were at VDS stage 4, whereas at The Kames 4 and 3 individuals from classes 21-26 mm and 26-35 mm respectively were at VDS stage 5. The remainder of individuals at this site were at VDS Stage 4 (except for three animals of 15-21 mm which were at VDS Stage 3).

In dogwhelks from populations distant from TBT, the relationship between penis length and shell length in males is curvilinear, and as the degree of TBT contamination increases, the relationship in males tends towards linearity, and penis and vas deferens development occurs in females (Bailey and Davies, 1990). The relationship between penis length and shell length in males (Figure 6) from sites 1 (Easterwick) and 5 (East of Ollaberry) was curvilinear supporting the position of the sites further from the main source of TBT at the terminal in the Voe. The males from site 12 (The Kames) show a more linear relationship than sites 1 and 5, indicating the higher degree of exposure of the animals at the Kames to TBT from the terminal. The relationship between male penis length and shell height at sites 3 Billia Skerry and 9 Mavis Grind is not clear.

C. Comparison of the 2001 Toothed Adult Dogwhelk Survey with Previous Survey Results (1987, 1990, 1991, 1993, 1995, 1997 and 1999)

A summary of the results of all surveys for sites 1-21 are given in Tables 3 and 4, and Figures 7 (RPSI) and 8 (VDSI). For investigation into temporal trends, the sites have been classified by location and the data obtained in each survey is graphically shown in Figures 9 for RPSI and Figure 10 for VDSI:

- outer sites in the Yell Sound (A: 3, 4, 5, 17; B: 1, 2, 14, 15, 16, 19, 20),
- boundary sites between Yell Sound and Sullom Voe (sites 6, 13 and 18), and
- sites within the Voe itself (sites 7, 8, 9, 10, 11 and 12)

1. Comparison of the degree of imposex in toothed adults

The RPSI and VDSI values for the populations at sites in the Sullom Voe (7-12) have generally decreased with time. There is some variability between the surveys, but the overall pattern of decreasing imposex in animals from the Voe sites with time remains. Consideration of a geographical grouping of sites (Figures 9 and 10) illustrates that the largest decrease in imposex occurred prior to the 1993 survey. Since this time, the degree of imposex in the toothed adults from the Voe has declined more slowly.

Some of the sites in the Yell Sound have also shown a decline in the degree of imposex (Figure 9) eg sites 1, 2, 15 and 16. There have not been any sterile females at these sites in any of the surveys. Sites 1, 2, 16, 19 and 20 remain the sites at which the populations of dogwhelks show least impact of TBT exposure. The RPSI values in all surveys from 1993 onwards at these sites have been at or near the value (1%) found in areas remote from TBT sources.

The only site which has shown an increase in RPSI, VDSI and an increasing number of sterile females during the time of the surveys is site 4. From 1993/1995 onwards the degree of imposex at Scarf Stane has gradually increased, to the appearance of sterile females at this site in 1999.

RPSI values and the percentage of females which were at VDS stage 5 and 6 at site 13 (Skaw Taing) at the mouth of the Voe, has reduced during the time of the surveys. The degree of imposex at sites 6 and 18 have for the most part remained steady reflecting their location, between the Yell Sound and Sullom Voe sites.

2. Comparison of incidence of sterility in the females obtained during 1987-2001

The percentage of the females sampled at each site which were sterile from each sampling survey is shown in Figure 11. Of the sites in the Sullom Voe, only females from sites 8 and 9 showed an increase in the percentage of sterile females. Of the boundary and Yell Sound sites, only sites 4 and 13 have shown an increase in the numbers of sterile females. In the case of site 13 (Skaw Taing) this increase represents 5 sterile individuals when none were present in 1999. The number of sterile females at site 4 has increased from one female out of 18 individuals in 1999 to 10 sterile females out of 17 individuals in 2001.

4. DISCUSSION

The populations of *N. lapillus* within Sullom Voe continue to be more impacted by the TBT usage in relation to the oil terminal than those in the Yell Sound showing higher levels of RPSI and VDSI than the populations in Yell Sound. The continued presence of juveniles and sub-adult dogwhelks at The Kames reflects the lowered numbers of sterile females found at this site during the last few surveys. The results of the 2001 survey show the continued improvement in the populations at sites 7, 10, 11 and 12 within the Voe with time. The RPSI and VDSI measurements at sites within the Voe indicate that these populations have the reproductive potential to continue, with few sterile females in the populations.

The degree of imposex in populations of dogwhelks from the boundary sites 6, 13 and 18, are intermediary between the higher values at sites within the Voe and the lower degrees of imposex at sites within the Yell Sound. The degree of imposex in the dogwhelks at these sites does not appear to have declined with time, and these populations continue to have a good reproductive potential with few, if any, sterile individuals.

The results from the populations within the Yell Sound, for the most part, reflect the distance of the sites from the terminal. The furthest sites from the terminal show degrees of imposex which reflect those of sites distant from sources of TBT. The population of dogwhelks at site 4, Scarf Stane is the only population from the Yell Sound which has shown an increase in the degree of imposex in the 1999 and 2001 surveys. This may reflect a small local source of TBT, for example a discarded paint tin or an abandoned vessel.

Monitoring should continue to chart the course of the recovery. It is recommended that the surveys continue to be carried out at an interval of two years.

5. REFERENCES

Bailey, S.K. and Davies, I.M. 1988. Tributyltin contamination around an oil terminal in Sullom Voe, Shetland. *Environmental Pollution*, **55**, 161-172pp.

Bailey, S.K. and Davies, I.M. 1989. Survey of the effects of tributyltin on dogwhelks (*Nucella lapillus*) from Scottish 7coastal waters. *Journal of the Marine Biological Association of the United Kingdom*, **69**, 335-354pp.

Bailey, S.K. 1990. Sullom Voe 1990. Report to the Department of Agriculture and Fisheries of Scotland on field work undertaken in Sullom Voe, Shetland (6-8 March 1990). Department of Biological Sciences, Napier Polytechnic of Edinburgh.

Bailey, S.K. and Davies, I.M. 1991. SOTEAG Rocky Shore Monitoring Programme. TBT contamination in Sullom Voe, Shetland. 1991 Dogwhelk Survey. *Fisheries Research Services Report No 20/91*.

Blaber, S.J. 1970. The occurrence of a penis like out growth behind the right tentacle in spent females of *Nucella lapillus*. *Proceedings of the Malacological Society*, **39**, 231-233pp.

Bryan, G.W., Gibbs, P.E., Hummerstone, L.G. and Burt, G.R. 1986. The decline of the gastropod *Nucella lapillus* around southwest England: Evidence for the effect of tributyltin from antifouling paints. *Journal of the Marine Biological Association of the United Kingdom*, **66**, 611-640pp.

Crothers, J.H. 1985. Dogwhelks: An introduction to the biology of *Nucella lapillus* (L.). *Field Studies*, **6**, 291-360pp.

Davies, I.M., Minchin, A. and Harding, M.J.C. 1997. OSPAR Working Group on Concentrations, Trends and Effects of Substances in the Marine Environment (SIME) Report on the TBT training Workshop, 24-26 September 1997. *Marine Laboratory, Aberdeen Report No 9/97*, 33pp.

Dooley, H.D. 1981. Oceanographic observations in Sullom Voe, Shetland, in the period 1974-1978. *Proceedings of the Royal Society of Edinburgh*, **80**B, pp55-71.

Gibbs, P.E., Bryan, G.W., Pascoe, P.L. and Burt, G.R. 1987. The use of the dogwhelk, *Nucella lapillus*, as an indicator of tributyltin (TBT) contamination. *Journal of the Marine Biological Association of the United Kingdom*, **67**, pp507-523.

Hall, L.W. and Pinkney, A.E. 1985. Acute and sublethal effects of organotin compounds on aquatic biota: an interpretative literature evaluation. *CRC Critical Reviews in Toxicology*, **14**, No 2, 159-209pp.

Harding, M.J.C., Rodger, G.K. and Davies, I.M. 1997. SOTEAG Rocky Shore Monitoring Programme. TBT contamination in Sullom Voe, Shetland. 1997 dogwhelk survey. *Fisheries Research Services Report No 11/97*.

IMO. 1989. International Maritime Organisation, Scientific group on dumping, 12th meeting, April 1989. Assessment of organotin compounds as marine pollutants and proposed measures for the Mediterranean.

IPCS (International Programme on Chemical Safety). 1990. Tributyltin compounds, Environmental Health Criteria 116, World Health Organisation, Geneva.

Laughlin, R.B. and Linden, O. 1987. Tributyltin, contemporary environmental issue. *Ambio*, **16**, No 5, 252-256pp.

Minchin, A. and Davies, I.M. 1999. Imposex measurement in the dogwhelk *Nucella lapillus* (L.) - temporal aspects of specimen preparation. *Journal of Environmental Monitoring*, **1**(3), 239-242.

Moore, H.B. 1936. The biology of *Purpura lapillus*. I. Shell variation in relation to the environment. *Journal of the Marine Biological Association*, **21**, 61-89pp.

Muller, M.D., Renberg, L. and Rippen, G. 1989. Tributyltin in the environment - sources, fate and determination. An assessment of present status and research needs. *Chemosphere*, **18**, No 9/10, 2015-2042pp.

TABLE 1

Results of the survey of imposex in dogwhelks in Sullom Voe and Yell Sound in 2001.

Site No	Site Name	Size	Incidence of Occurrence	% RPSI	VDSI	No. Females	No. Males
1	Easterwick	10-15	16.7	0.29	0.58	12	7
		15-21	0	0	0.25	8	12
		21-26	0	0	0.08	12	8
		26-35	-	-	-	-	-
		Adults	8.3	1.43	0.17	24	16
2	Burgo Taing	Adults	5	0.03	0.25	20	20
3	Billia Skerry	10-15	30.8	0.07	1	13	6
		15-21	27.3	0	0.73	11	9
		21-26	20	0	0.8	10	10
		26-35	7.7	0	0.15	13	7
		Adults	52.9	0.16	1.76	17	23
4	Scarf Stane	Adults	100	28.81	4.59	17	22
5	East of Ollaberry	10-15	0	0.04	0.27	11	8
		15-21	42.9	0.62	1.14	14	6
		21-26	30.8	0.05	0.46	13	7
		26-35	33.3	0.13	0.75	12	8
		Adults	60	0.09	1.6	15	25
6	Grunn Taing	Adults	100	6.2	4	19	21
7	Tivaka Taing	Adults	100	14.21	4	19	21
8	Noust of Burraland	Adults	100	18.06	4.31	16	24
9	Mavis Grind	10-15	100	47.31	4	7	10
		15-21	100	55.39	3.56	9	10
		21-26	100	50.81	3.56	9	11
		26-35	100	41.35	3.33	6	14
		Adults	100	28.61	4.42	12	28
10	Voxter Ness	Adults	100	27.65	4.05	21	19
11	Northward	Adults	100	30.71	4.33	9	31
12	Kames	10-15	100	104.76	3.43	7	13
		15-21	100	94.64	3.50	12	8
		21-26	100	102.47	4.00	11	9
		26-35	100	60.45	4.33	9	11
		Adults	100	34.03	4.25	20	20
13	Skaw Taing	Adults	100	23.61	4.29	17	24
14	Grunna Taing	Adults	68.7	0.5	1.88	16	24
15	Orfassary	Adults	31.3	0.02	0.81	16	24
16	Samphrey	Adults	14.3	0	0.43	14	26
17	Uynarey	Adults	22.2	0.02	0.78	18	22
18	Little Roe	Adults	100	8.91	2.19	16	23
19	The Brough	Adults	21.1	0	0.61	19	22
20	Norther Geo	Adults	4.3	0	0.17	23	17

- = No sample

TABLE 2

Summary of sampling carried out at sites 1-21 in Yell Sound and Sullom Voe for imposex development in toothed adult (*) and juvenile/sub-adult un-toothed adult (J) dogwhelks (*Nucella lapillus*). Data from Bailey and Davies (1991), Harding *et al.* (1997), Minchin and Davies (2000) and the present survey.

Site	1987	1990	1991	1993	1995	1997	1999	2001
1	-	-	*J	*J	*J	*J	*J	*J
2	-	-	*	*	*	*	*	*
3	*	*	*J	*J	*J	*J	*J	*J
4	*	*	*	*	*	*	*	*
5	*	*J	*J	*J	*J	*J	*J	*J
6	*	*J	*	*	*	*	*	*
7	*	*	*	*	*	*	*	*
8	*	*J	*	*	*	*	*	*
9	*	*J	*J	*J	*J	*J	*J	*J
10	*	*	*	*	*	*	*	*
11	*	*J	*	*	*	*	*	*
12	*	*J	*	*J	*J	*	*J	*J
13	*	*	*	*	*	*	*	*
14	-	-	*	*	*	*	*	*
15	-	-	*	*	*	*	*	*
16	-	-	*	*	*	*	*	*
17	*	*	*	*	*	*	*	*
18	*	*	*	*	*	*	*	*
19	-	-	*	*	*	*	*	*
20	-	-	*	*	*	*	*	*
21	-	-	-	-	-	*J	*	-

TABLE 3

The numbers of toothed animals and the percentage of females obtained from the surveys in 1987-2001. Of these females the percentages which were sterile at each site have been calculated. F = Females; FS = Females sterile; - = No sampling; 0 = No sterile females found.

Site	Site name	1987			1990			1991			1993		
		Total	%F	%FS	Total	%F	%FS	Total	%F	%FS	Total	%F	%FS
1	Easterwick	-	-	-	-	-	-	48	60.4	0.0	40	45.0	0.0
2	Burgo Taing	-	-	-	-	-	-	40	72.5	0.0	40	42.5	0.0
3	Billia Skerry	41	53.7	0.0	41	56.1	0.0	40	50.0	0.0	40	42.5	0.0
4	Scarf Stane	40	62.5	0.0	41	46.3	0.0	38	44.7	0.0	40	40.0	18.8
5	East of Ollaberry	40	50.0	0.0	42	54.8	4.5	37	62.2	0.0	40	50.0	5.0
6	Grunn Taing	40	45.0	0.0	40	57.5	0.0	39	48.7	0.0	36	41.7	0.0
7	Tivaka Taing	40	45.0	22.2	39	41.0	71.4	39	43.6	29.4	38	42.1	18.8
8	Noust of Burraland/ Blanches Geo	40	35.0	21.4	28	32.1	33.3	38	28.9	90.9	40	32.5	15.4
9	Mavis Grind	40	47.5	21.1	43	48.8	54.5	29	27.6	62.5	26	15.4	50.0
10	Voxter Ness	30	56.7	64.7	40	75.0	76.7	39	25.6	60.0	40	25.0	60.0
11	Northward	40	40.0	43.8	36	27.8	30.0	40	27.5	90.9	41	31.7	76.9
12	The Kames	38	42.1	93.3	40	50.0	95.2	39	43.6	100.0	40	30.0	91.7
13	Skaw Taing	40	50.0	0.0	37	43.2	68.8	39	43.6	35.3	40	45.0	61.7
14	Moss Bank/ Grunna Taing	-	-	-	-	-	-	40	50.0	15.0	40	32.5	0.0
15	Orfasay	-	-	-	-	-	-	40	47.5	0.0	40	45.0	0.0
16	Samphrey/The Helliack	-	-	-	-	-	-	40	47.5	0.0	40	37.5	0.0
17	Uynarey	34	55.9	0.0	40	52.5	0.0	40	52.5	0.0	40	50.0	0.0
18	Little Roe	38	55.3	0.0	42	59.5	4.0	39	53.8	14.3	38	63.2	12.5
19	Brough	-	-	-	-	-	-	40	52.5	0.0	40	27.5	0.0
20	Norther Geo	-	-	-	-	-	-	40	42.5	0.0	40	22.5	0.0
21	Berwick	-	-	-	-	-	-	-	-	-	-	-	-

Site	Site name	1995			1997			1999			2001		
		Total	%F	%FS	Total	%F	%FS	Total	%F	%FS	Total	%F	%FS
1	Easterwick	41	56.1	0.0	40	40.0	0.0	40	45.0	0.0	40	60	0
2	Burgo Taing	41	19.5	0.0	40	62.5	0.0	40	40.0	0.0	40	50	0
3	Billia Skerry	40	47.5	0.0	40	57.5	0.0	40	50.0	0.0	40	42.5	0
4	Scarf Stane	40	42.5	0.0	40	52.5	0.0	40	45.0	5.5	39	17	41.2
5	East of Ollaberry	40	37.5	0.0	38	39.5	0.0	40	47.5	0.0	40	37.5	0
6	Grunn Taing	40	60.0	12.5	39	33.3	0.0	40	57.5	0.0	40	47.5	0
7	Tivaka Taing	40	30.0	25.0	39	53.5	9.5	40	65.0	9.5	40	47.5	0
8	Noust of Burraland/ Blanches Geo	40	42.5	58.8	40	42.5	23.5	40	55.0	9.1	40	40	25
9	Mavis Grind	40	42.5	35.3	40	27.5	27.3	40	20.0	12.5	40	30	41.7
10	Voxter Ness	40	35.0	57.1	40	37.5	6.7	40	25.0	0.0	40	52.5	4.8
11	Northward	40	25.0	40.0	40	35.0	7.1	40	35.0	0.0	40	22.5	0
12	The Kames	40	30.0	83.3	23	13.0	66.7	40	40.0	18.7	40	50	0.25
13	Skaw Taing	40	32.5	38.5	40	47.5	15.8	40	47.5	0.0	040	42.5	29.4
14	Moss Bank/ Grunna Taing	40	32.5	0.0	40	40.0	0.0	41	41.4	0.0	40	40	0
15	Orfasay	40	57.5	0.0	40	60.0	0.0	40	57.5	0.0	40	40	0
16	Samphrey/ The Helliack	40	60.0	0.0	40	37.5	0.0	40	45.0	0.0	40	35	0
17	Uynarey	40	47.5	0.0	40	45.0	0.0	40	40.0	0.0	40	45	0
18	Little Roe	40	40.0	6.3	40	37.5	0.0	40	45.0	0.0	39	41	6.3
19	Brough	41	46.3	0.0	40	35.0	0.0	40	45.0	0.0	40	47.5	0
20	Norther Geo	38	63.2	0.0	40	57.5	0.0	40	47.5	0.0	40	57.5	0
21	Berwick	-	-	-	20	30.0	50.0	40	42.5	11.7	-	-	-

TABLE 4

RPSI and VDSI in adult dogwhelks (*Nucella lapillus*) from populations in Sullum Voe and Yell Sound from the eight surveys (*sites at which juvenile/subadult surveys were carried out in 1993, 1995, 1997, 1999 and 2001; - = No sample taken)

Site No	Site name	1987	1990	1991	1993	1995	1997	1999	2001
1*	Easterwick	-	-	0.00	0.00	0.00	0.00	0.00	1.43
2	Burgo Taing	-	-	3.37	<0.01	<0.01	0.02	0.003	0.03
3*	Billia Skerry	0.64	1.45	0.24	0.06	0.02	0.02	0.05	0.16
4	Scarf Stane	2.16	1.67	3.76	4.38	2.69	15.24	22.29	28.81
5*	East of Ollaberry	2.41	7.51	3.53	0.31	0.23	0.94	0.39	0.09
6	Grunn Taing	12.71	13.52	15.00	4.92	7.33	7.18	4.69	6.2
7	Tivaka Taing	58.85	34.19	23.72	14.06	20.34	19.90	21.52	14.21
8	Noust of Burraland	54.50	45.59	50.75	39.39	21.44	21.88	24.26	18.06
9*	Mavis Grind	40.91	30.24	30.15	23.19	11.63	24.11	21.33	28.61
10	Voxter Ness	58.54	39.59	41.32	32.38	27.65	28.05	24.27	27.65
11	Northward	34.03	30.54	42.57	31.37	26.70	36.70	40.26	30.71
12*	The Kames	56.78	69.44	54.93	37.49	31.32	73.12	35.65	34.03
13	Skaw Taing	42.46	32.34	45.00	18.26	20.59	27.16	20.02	23.61
14	Moss Bank/ Grunna Taing	-	-	5.04	0.18	0.37	0.76	0.64	0.5
15*	Orfasay	-	-	0.54	0.05	0.09	0.01	0.59	0.02
16	Samphrey/ The Helliack	-	-	1.30	<0.01	0.01	0.02	0.004	0
17	Uynarey	0.99	1.25	0.18	0.01	0.02	0.11	0.027	0.02
18	Little Roe	13.46	9.69	18.89	14.10	5.30	12.00	5.81	8.91
19	The Brough	-	-	0.63	<0.01	<0.01	0.00	0.003	0
20	Norther Geo	-	-	0.13	0.01	0.00	0.00	0.00	0
21	Breiwick	-	-	-	-	-	38.89	33.51	-

TABLE 4 (Continued)

Site No	Site name	VDSI							
		1987	1990	1991	1993	1995	1997	1999	2001
1*	Easterwick	-	-	0.26	0.05	0.04	0.06	0.33	0.17
2	Burgo Taing	-	-	1.72	1.13	1.00	0.92	1.125	0.25
3*	Billia Skerry	2.32	2.35	2.30	2.06	1.11	1.04	1.25	1.76
4	Scarf Stane	3.44	3.42	3.53	3.75	3.82	3.67	4.06	4.59
5*	East of Ollaberry	3.21	3.95	3.39	2.55	2.47	2.33	2.68	1.6
6	Grunn Taing	4.00	4.00	4.00	3.73	4.13	4.00	4.00	4
7	Tivaka Taing	4.22	4.93	4.41	4.19	4.25	4.09	4.00	4
8	Noust of Burraland	4.21	4.33	5.00	4.15	4.65	4.24	4.09	4.31
9*	Mavis Grind	4.26	4.64	4.75	4.50	4.35	4.27	4.125	4.42
10	Voxter Ness	4.71	4.83	4.80	4.60	4.57	4.07	4.00	4.05
11	Northward	4.44	4.87	5.18	4.77	4.40	4.07	4.07	4.33
12*	The Kames	5.27	5.33	5.59	5.08	5.17	4.67	4.19	4.25
13	Skaw Taing	4.00	4.69	4.41	4.61	4.31	4.16	4.00	4.29
14	Moss Bank/ Grunna Taing	-	-	4.05	1.77	2.46	2.13	2.65	1.88
15*	Orfasay	-	-	2.74	1.78	1.04	0.88	1.65	0.81
16	Samphrey/ The Helliack	-	-	2.32	0.53	0.63	0.87	0.72	0.43
17	Uynarey	2.58	2.86	2.05	1.20	0.90	1.56	1.375	0.78
18	Little Roe	4.00	4.04	4.14	4.13	4.06	3.93	3.94	2.19
19	The Brough	-	-	2.57	1.09	1.16	0.43	0.83	0.61
20	Norther Geo	-	-	1.35	0.56	0.00	0.30	0.43	0.17
21	Breiwick	-	-	-	-	-	4.50	4.10	-

Figure 1. Map of Sullom Voe and Yell Sound showing the sampling sites.

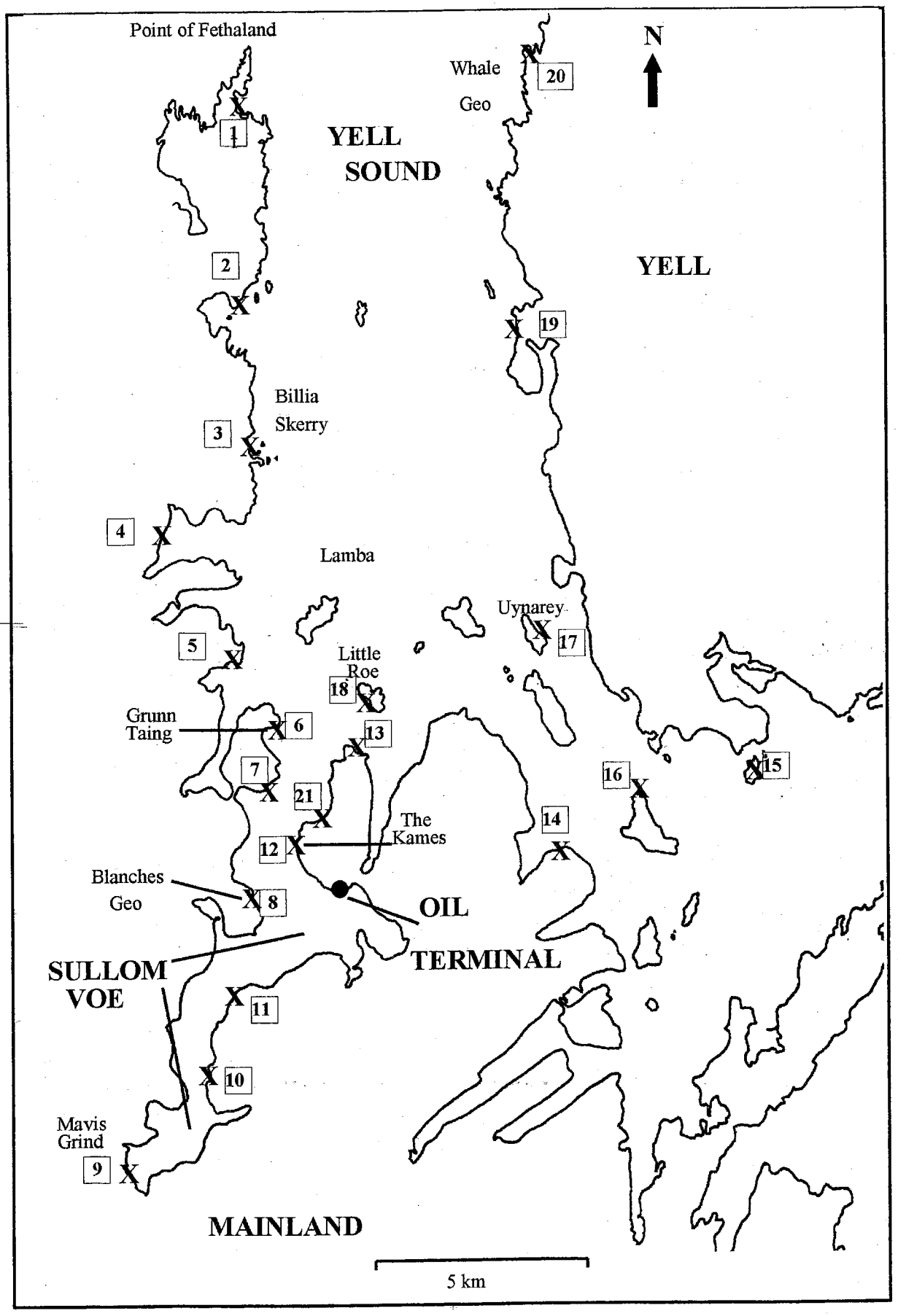


Figure 2. RPSI values in adult dog-whelk populations from the sampling sites in 2001.

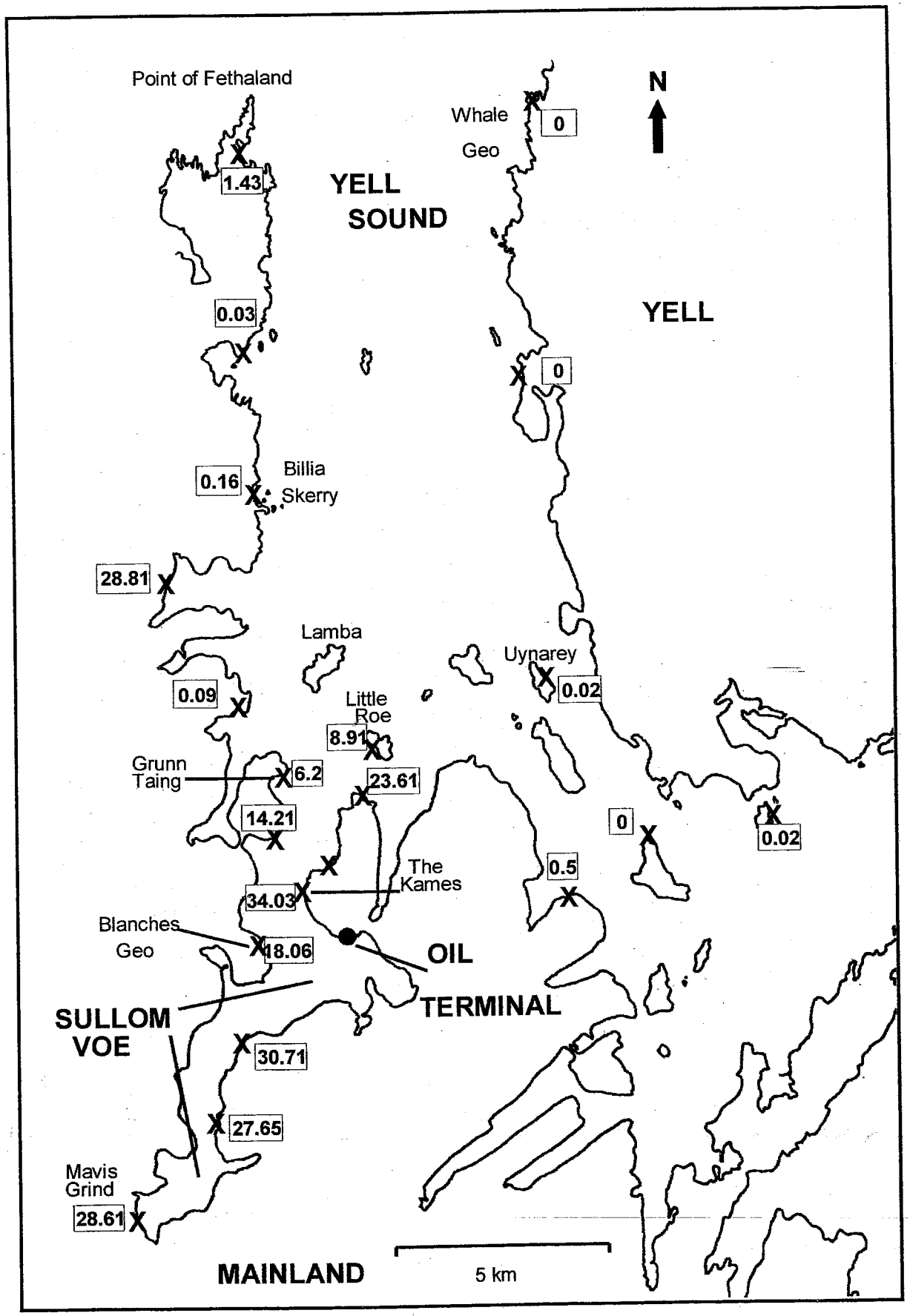


Figure 3. VDSI values in adult dog-whelk populations from the sampling sites in 2001.

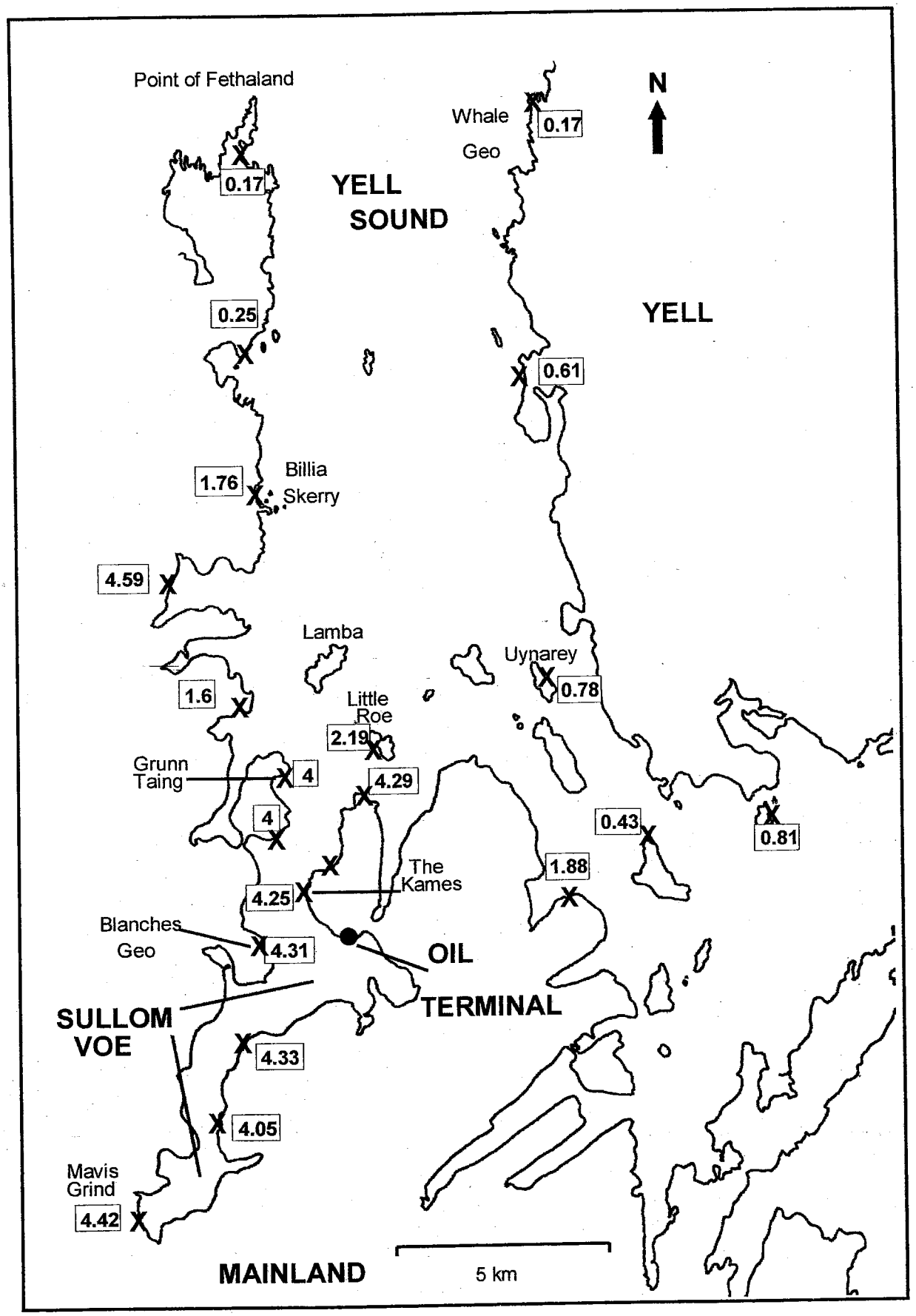


Figure 4. The percentage of females at each VDS stage from the sampling sites in 2001.

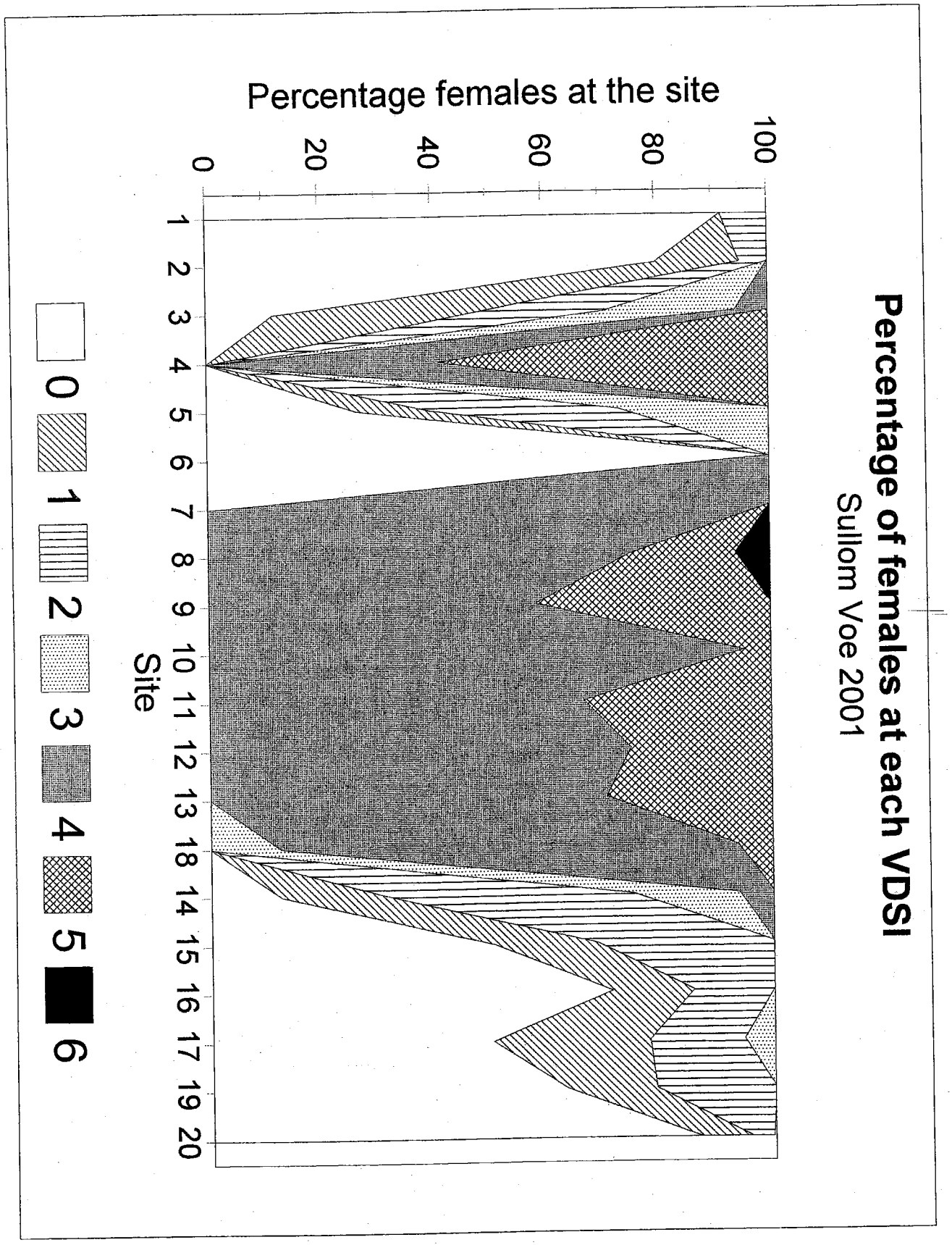
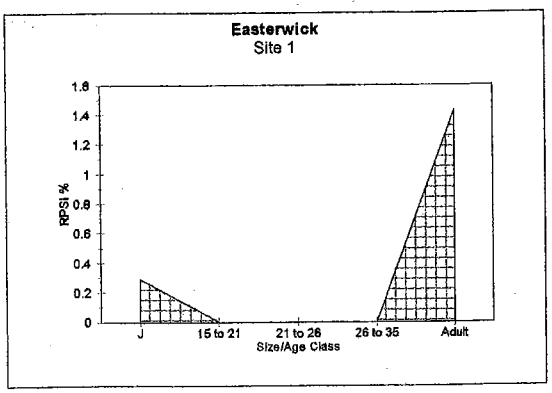
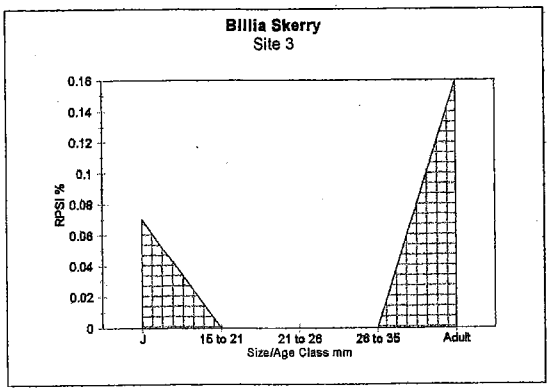
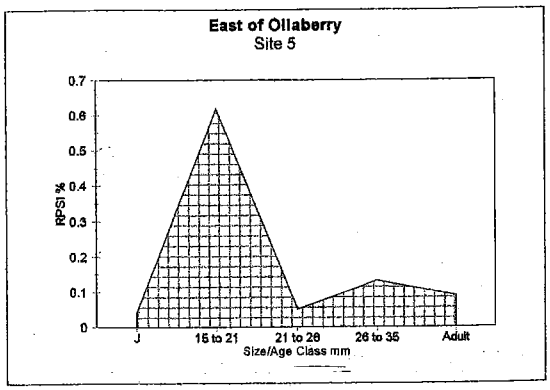
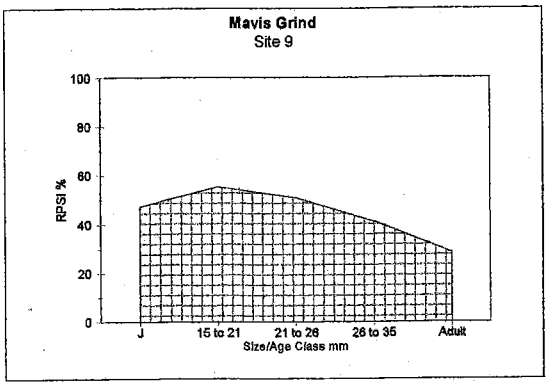


Figure 5. The RPSI values for all the size/age classes of dog-whelks in the juvenile, sub-adult and un-toothed adult survey in 2001.









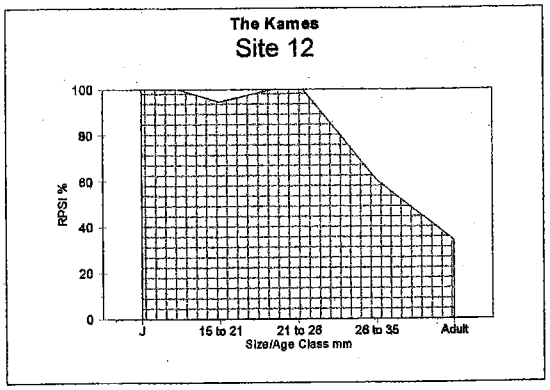
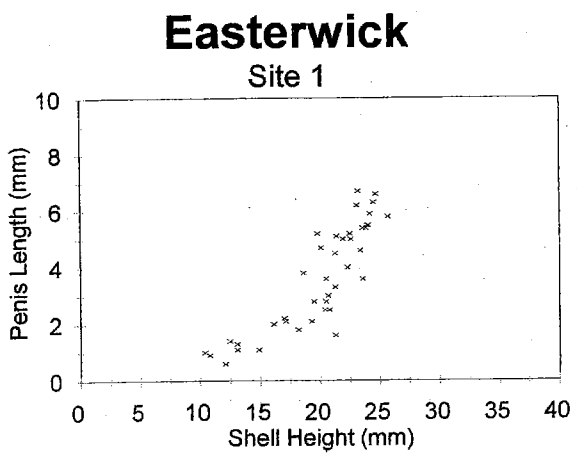
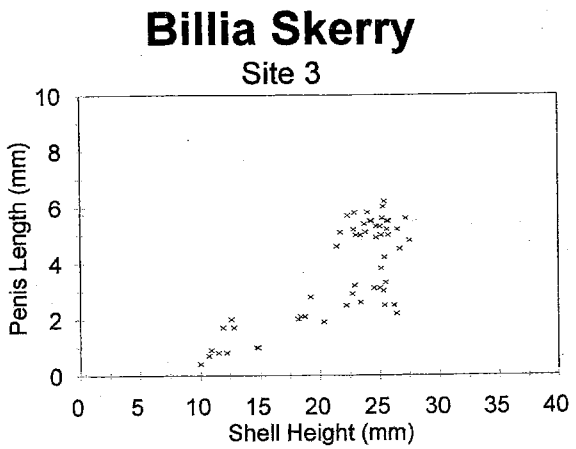
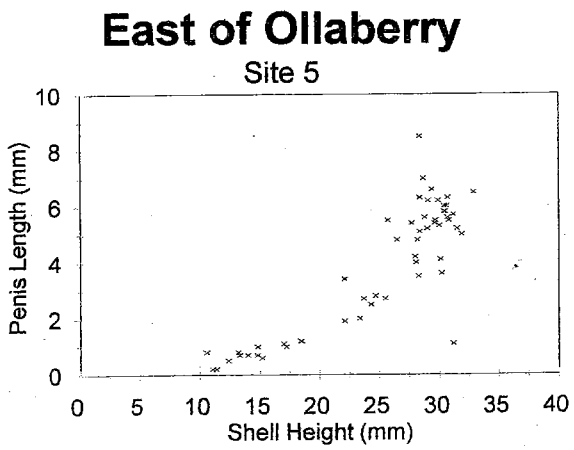
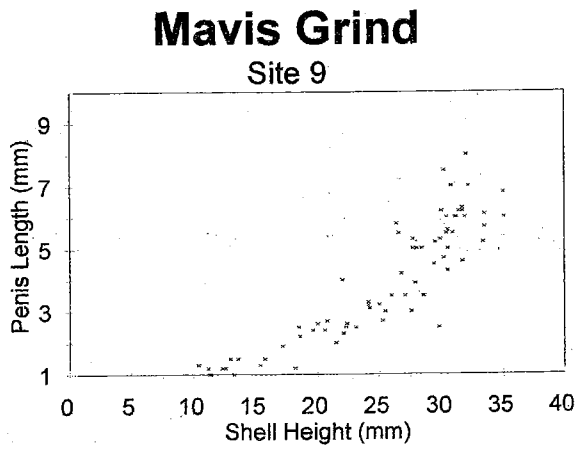


Figure 6. Penis length verses shell height in male dog-whelks from the juvenile, sub-adult and un-toothed adult survey in 2001.









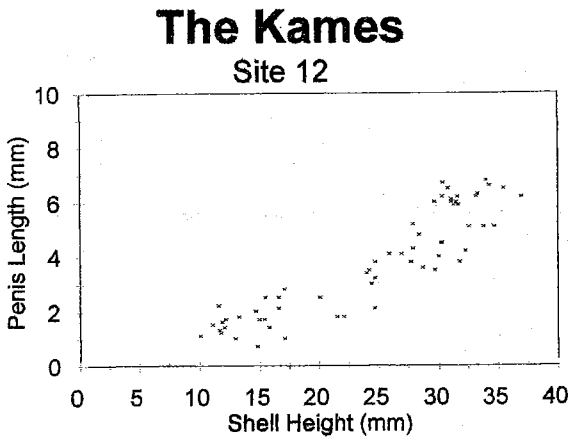
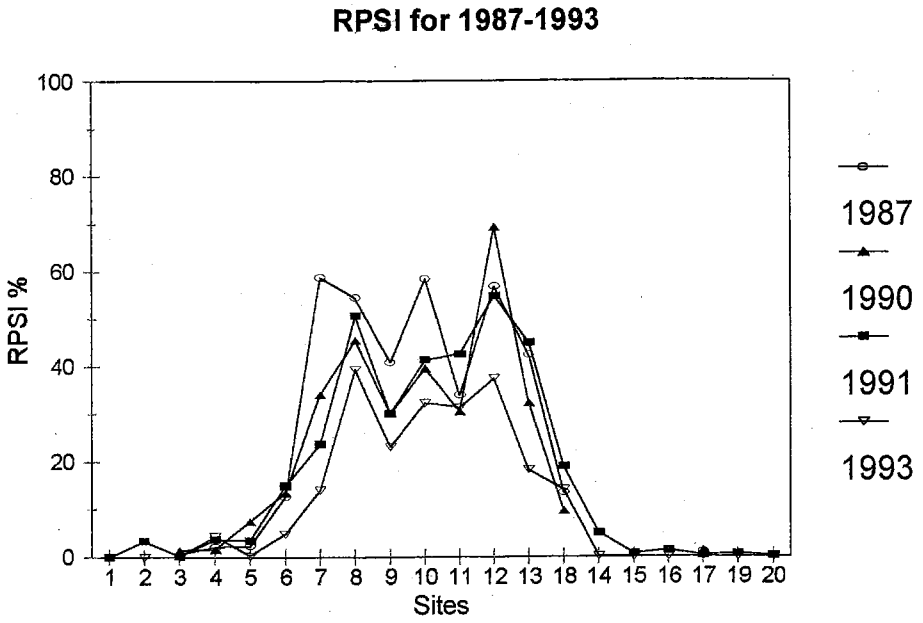


Figure 7. RPSI values for populations in the surveys from 1987-2001.



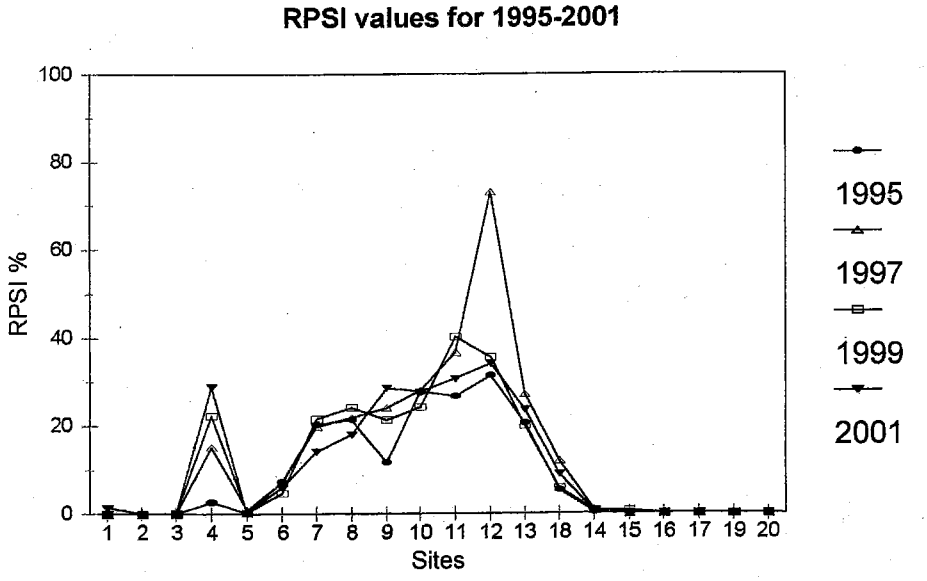
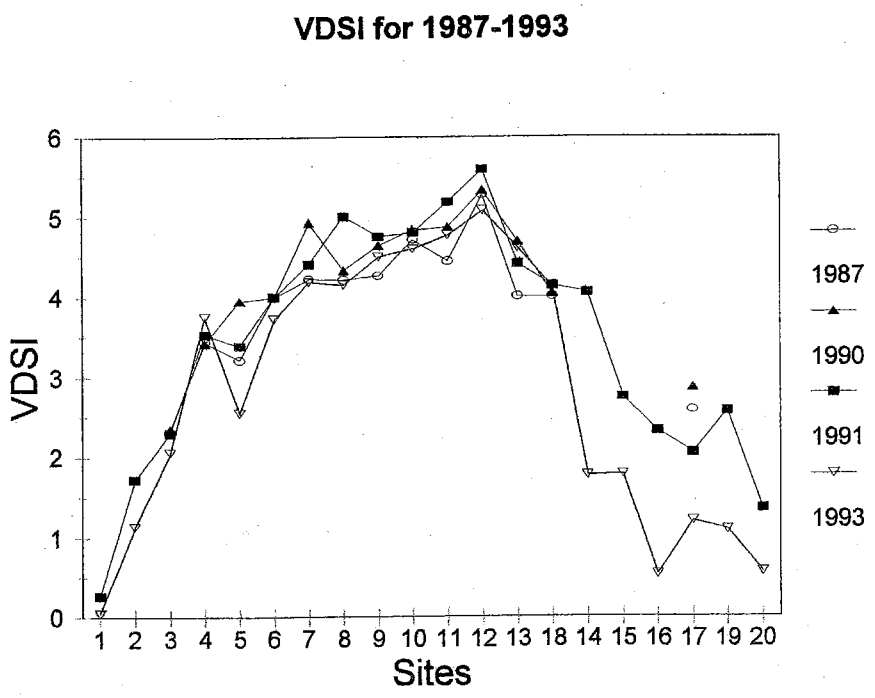


Figure 8. VDSI values for populations in the surveys from 1987-2001.



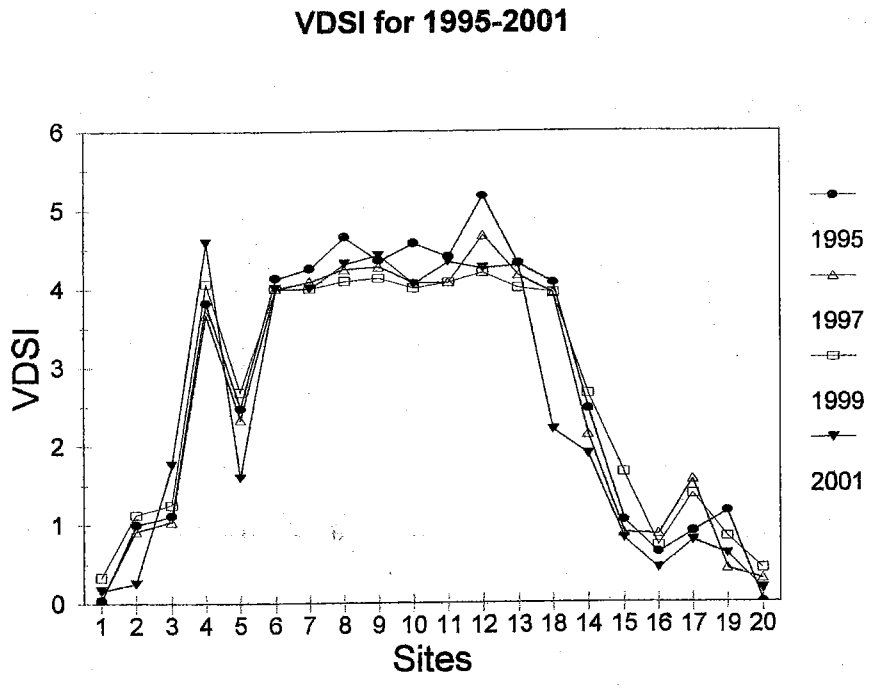


Figure 9. RPSI values for the populations in the surveys from 1987-2001 shown in the geographical groupings.

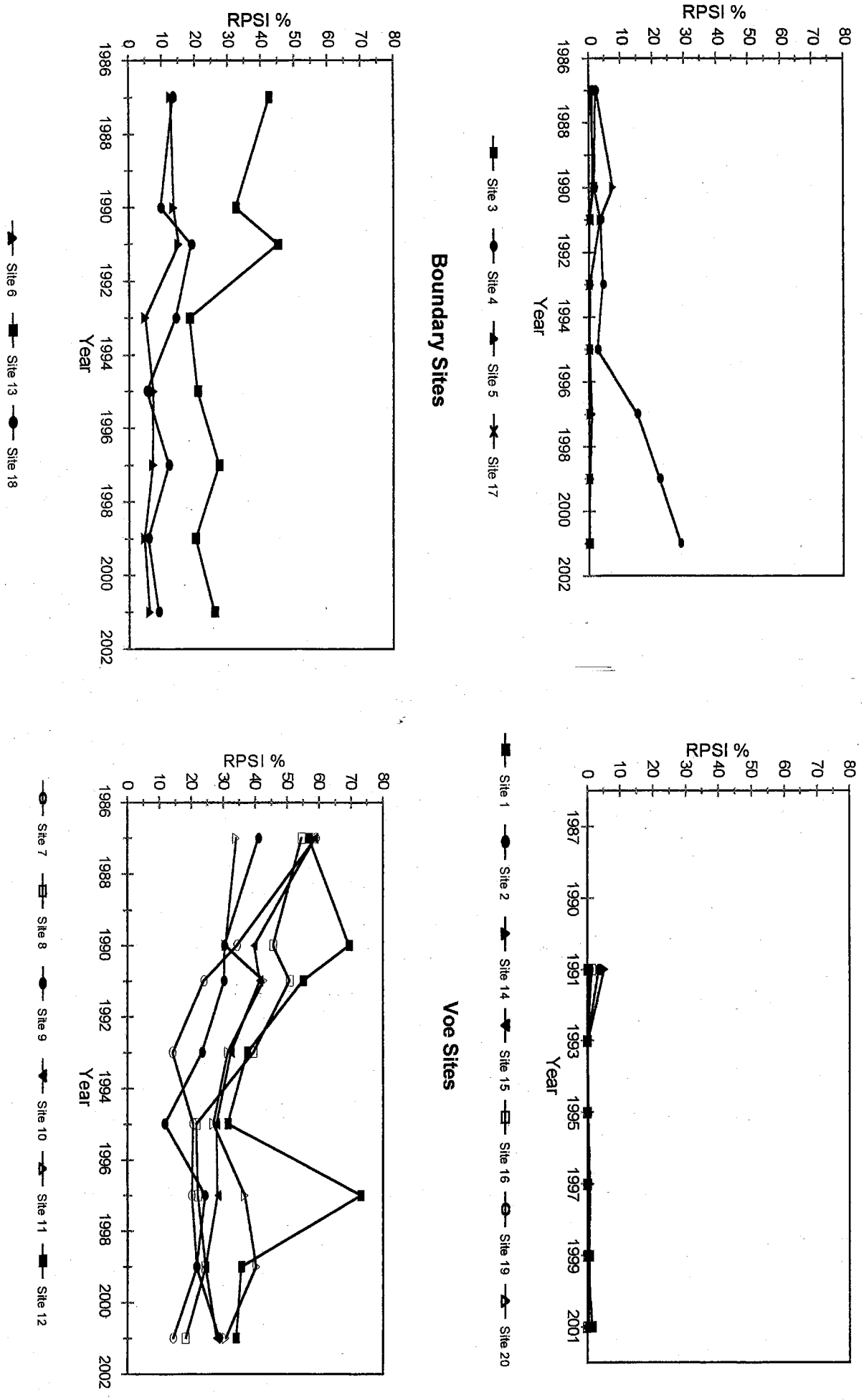


Figure 10. VDSI values for the populations in the surveys from 1987-2001 shown in the geographical groupings.

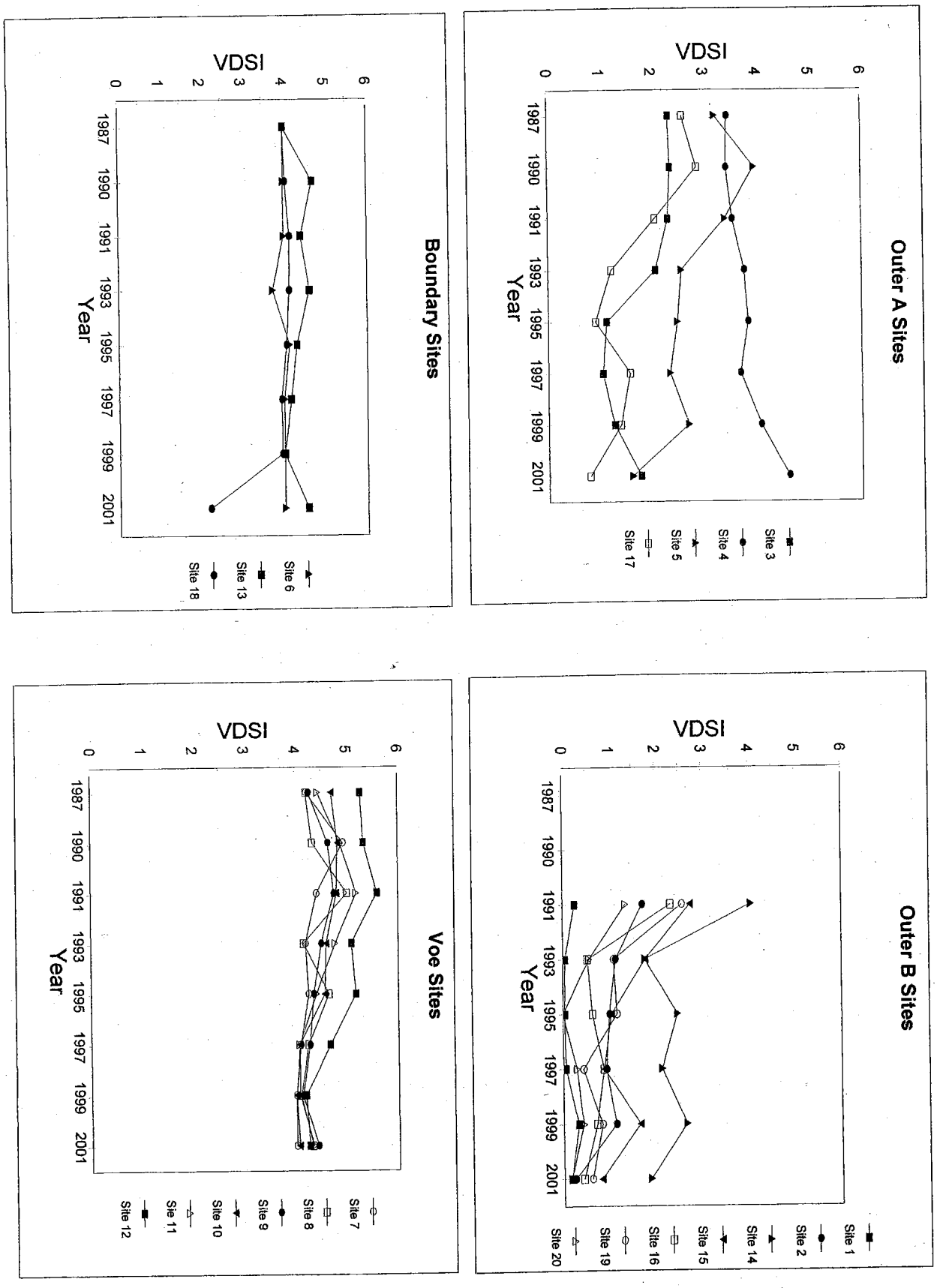


Figure 11. The percentage of females sampled in the surveys from 1987-2001 which were sterile.