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SOTEAG ROCKY SHORE MONITORING PROGRAMME. TBT CONTAMINATION IN SULLOM VOE, SHETLAND. 2011 DOGWHELK SURVEY

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This report provides the results and assessment of a survey carried out by Marine Scotland Science, Marine Laboratory, Aberdeen as part of a rocky shore monitoring programme undertaken by Aquatic Survey and Monitoring Limited, 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 August 2011 by Aquatic Survey and Monitoring Limited, and transported to Marine Scotland Science, Marine Laboratory in Aberdeen for imposex analysis. Dogwhelks of all sizes (8 mm juveniles to adults) were collected from five of the sites. Results of the present survey were compared to the eleven previous surveys and assessed against the Oslo and Paris Commission (OSPAR) assessment criteria.

The degree of imposex measured as Relative Penis Size Index (RPSI) and Vas Deferens Sequence Index (VDSI) in toothed adults from sites within Sullom Voe in 2011 show that these sites continue to be more impacted by TBT than populations at sites in Yell Sound. Since TBT inputs to the voe have ceased following the International Maritime Organisation (IMO) ban on use on large vessels in 2008, this is likely be due to reservoirs of residual concentrations in sub-tidal sediments in the area of the terminal. Throughout Sullom Voe, RPSI and VDSI values in adults (RPSI 0.02-0.31%; VDSI 1.25-2.73) were generally lower than the values in the 2009 survey. The RPSI values of populations outside the Voe (RPSI 0.00-0.07%), in the well flushed waters of Yell Sound, were generally lower than at sites within the voe and showed either no change (increases of <0.01%) or a decrease from 2009 values. VDSI at sites in Yell Sound were much lower (0.06-0.67) than at all sites inside the voe and just outside (the boundary sites: 0.62-1.6). As in previous surveys, the degree of imposex in populations in Yell Sound tends to decrease with distance from Sullom Voe.

In 2009, for the first time since the survey began, there was no evidence of sterility in any of the populations. This trend continues in 2011 as the VDSI measurements at the sites within the voe showed that these populations can continue to reproduce. RPSI and VDSI levels at all sites showed either no significant change or a decrease in levels (except at site 6, Grunn Taing where a small increase in VDSI was observed). RPSI levels at all sites were close to zero. The substantial decrease in VDSI observed at all sites within the voe and at boundary sites between the Voe and Yell Sound in 2009 continued in 2011. These decreases in VDSI

resulted in no change in OSPAR Classification for the sites inside Sullom Voe, however the continued decrease of VDSI at sites outside of the voe resulted in improvements in OSPAR classification at sites 1, 5, 13, 14, 15, 16, 17 and 19. At site 14 (Grunna Taing) the unexpected increase in VDSI observed in 2009 had returned to levels more in line with the expected continual decline of imposex across the region.

Generally, the survey indicates continued improvement in imposex incidence across the area, likely resulting from the cessation of inputs from shipping to the area as a result of the IMO TBT ban on large vessels in 2008 and a reduction in environmental concentrations through degradation.

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 (e.g. Hall and Pinkney, 1985; Laughlin and Linden, 1987; Muller *et al.*, 1989; IMO, 1989; IPCS, 1990).

Sullom Voe is a large fjordic 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 and the tonnage and numbers have since fallen. 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). Reducing shipping traffic, a historical change from free association to co-polymer TBT based antifoulants and recent IMO restrictions on the use of TBT on large vessels (no new applications in 2003 and no exposed TBT paints on vessels in 2008) means that TBT inputs to the area from marine sources have been reducing and should now have ceased.

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 (e.g. 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; Gubbins *et al*., 2004).

The following report details results of a survey that 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 last survey which took place in 2009 (Gubbins, 2009).

2. Methods

2.1 The choice of Survey Sites and Dogwhelk Sampling Procedure

Between 15-26 August 2011, 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).

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), i.e. juveniles (10-15 mm shell length), sub-adults (15-21 mm), and 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) although at several sites this was not possible, particularly for the smallest size classes. Due to mortality of the adult samples prior to analysis, less than 40 individuals were analysed from 14 sites, with one site, Scarf Stane, having shown considerable mortality during transportation/storage and only 10 individuals remained for analysis.

In 2011, sites Norther Geo and Breiwick returned no sample (due to inaccessibility or lack of individuals on site) so a new site, Sweinna Stack, in the vicinity was sampled in place. (Figure 1).

The degree of imposex, as measured by Relative Penis Size Index (RPSI) and Vas Deferens Sequence Index (VDSI), was determined using standard internationally approved techniques (OSPAR, 2002).

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:

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

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 trapped egg capsules 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 for each female and the mean VDS calculated to provide an estimate of the VDSI of the population.

3. Results

3.1 Toothed Adult Survey

RPSI values in toothed adults ranged from 0.02-0.31% inside Sullom Voe to 0.00-0.07% outside the voe at 'boundary' sites and in the waters of Yell Sound (Table 1, Figure 2). The highest RPSI value (Table 1, Figure 2) from the toothed adult populations of *N. lapillus* was found in the middle of Sullom Voe (site 11, Northward, 0.31%) and very low compared to historical values. The RPSI values from toothed adult populations in Yell Sound and at boundary sites close to the voe were at or close to zero (<0.01%) with the exception of site 13 (Skaw Taing) with VDSI 0.07. These low values of RPSI are generally associated with areas distant from sources of TBT (Bryan *et al.*, 1986; Bailey and Davies, 1989).

All sites either showed a decrease in RPSI levels or a very small change from previous close to zero values (increases of 0.01% or less).

The VDSI values (Table 1, Figure 3) follow a similar distribution to that seen in previous surveys. Populations within Sullom Voe (sites 7-12) showed VDSI values of 1.25-2.73. Most of the populations outside the voe in Yell Sound (sites 1-5, 14-17, 19,22) showed low VDS indices (0.06-0.67) and boundary sites just outside the voe (6, 13, 18) had populations demonstrating intermediate levels of VDSI (0.62-1.6). Site 14 (Grunna Taing) had shown unusually high levels of imposex in 2009 (3.24) increasing from previous surveys. The current survey returned a result of 0.19, more in line with expectations for a site in Yell Sound removed from sources of TBT, that has been showing recovery in imposex levels over time.

At none of the sites within or outwith the Voe, were any toothed adult females (Table 3) found to be sterile (reproductive tract blocked by vas deferens tissue, VDS Stage 5) and no females were found with a solid mass of egg capsules within the capsule gland (stage 6).

The imposex results show that populations at most sites within Sullom Voe still show clear signs of TBT exposure. At five sites (7, 8, 9, 11, 12) these levels are in excess of criteria values (VDSI >2) used for marine assessment purposes including Water Framework Directive water body classification and OSPAR ecological quality objectives for the North Sea. Most of the sites outwith the Voe have very low levels of imposex indicating a continuing exposure to considerably less TBT than those sites within the Voe. There is still a general gradation in imposex from the low levels at the outer sites in Yell Sound with increasing degrees of imposex towards Sullom Voe.

In 2011, for the first time a new site was sampled, Sweinna Stack (22). The location of this site is intermediate between The Brough and Norther Geo and was included due to the absence of sufficient dogwhelks in the population at Norther Geo (20). The population sampled at this new site returned very low levels of imposex (RPSI 0.00, VDSI 0.06) in line with its location, far removed from any sources of historical TBT contamination.

3.2 Un-toothed Adults, Sub-Adult and Juvenile Surveys

Untoothed adults (21-35 mm shell length), sub-adults (15-21 mm) and juveniles (10-15 mm) were sampled at 5 sites, 2 from within Sullom Voe (sites 9 and 12) and 3 from the Western shores of Yell Sound (sites 1, 3 and 5) (Table 1, Figure 1; sites marked with a J). As for the survey of adult dogwhelks, the highest levels of imposex (RPSI and VDSI) in these size classes were recorded from the two sites inside Sullom Voe, The Kames (site 12, e.g. 21-26 mm, 0.23% RPSI, 1.7 VDSI) and Mavis Grind (site 9, e.g. 10-15 mm, 0.46% RPSI, 1.33 VDSI) (Table 1, Figures 4 and 5).

Sites outwith Sullom Voe displayed a much lower level of imposex development in the smaller size classes. Untoothed adults, sub-adults and juveniles from Easterwick (1), Burgo Taing (3) and East of Ollaberry (5) demonstrate low RPSI (0.05% or less) associated with sites distant from sources of TBT (Bryan et al., 1986; Bailey and Davies, 1989). VDS in individuals of the smaller size classes from these sites outside of Sullom Voe was also low, at 1.00 (26-35 mm, site 3) or less. The levels of imposex indicators in the smaller size classes were generally lower than have been recorded in previous surveys, suggesting a continued improvement in the levels of exposure to TBT being experienced by dogwhelks at these five sites. The high levels of imposex observed in some size classes of young dogwhelks at Billia Skerry in 2009 were no longer evident in the 2011 survey.

At sites within Sullom Voe (9, 12) levels of VDSI experienced by juvenile and sub-adult dogwhelks were lower than that experienced by the adults. This may also be symptomatic of a recovery of populations, with reduced levels of imposex observed in younger individuals (Table 1, Figure 5).

None of the untoothed adults, sub-adults or juveniles sampled showed VDS >4, implying an absence of sterile females from these size classes of the sampled populations.

3.3 Comparison of the 2004 Toothed Adult dogwhelk Survey with previous Survey Results (1987, 1990, 1991, 1993, 1995, 1997, 1999, 2001, 2004, 2007 and 2009)

A summary of the results of all surveys for sites 1-21 is given in Tables 3 and 4 and Figures 6 and 7. For investigation of temporal trends in imposex, the sites have been classified by location and the data obtained in each survey is graphically shown in Figure 8 for RPSI,

Figure 9 for VDSI and Figure 10 for the incidence of sterile females, using the following site designations:

- outer sites in the Yell Sound (I: 3, 4, 5, 17; II: 1, 2, 14-16, 19, 20),
- boundary sites between Yell Sound and Sullom Voe (sites 6, 13, 18)
- sites within the Voe itself (sites 7-12, 21)

3.3.1 Comparison of the degree of imposex in toothed adults

The RPSI and VDSI values for the populations at sites in Sullom Voe (7-12) have generally decreased with time. There is some variability between surveys, however the overall pattern remains one of decreasing imposex with time for populations from the Voe sites. While RPSI values declined only slowly from 1993 to 2001, there has been a marked decrease in RPSI at all sites in Sullom Voe (7-12) between 2001 and 2009, with further smaller decline from already very low values in 2011. Changes in VDSI between 2001 and 2007 were smaller than the changes in RPSI, but since 2007 show a marked decrease that continues to 2011. In 2009, significantly, for the first time, all sites within Sullom Voe show VDSI <4.00, showing that populations appear to be no longer reproductively impaired. This remains the case in 2011.

VDSI has decreased since 2009 at all sites except 6 (from 0.59 to 1.44). RPSI has also decreased or remained at very lows levels since 2009 at every site surveyed and in all cases either remained at very low levels (increases of <0.01% at 3 sites) or decreased further.

3.3.2 Comparison of incidence of sterility in the females obtained during 1987-2011

The incidence of female sterility at each site from each sampling survey from 1987-2011 is shown in Figure 10. The proportion of sterile females at all sites has decreased to 0% for the first time in 2009 and this state is maintained for 2011.

3.4 Assessment of Imposex Data against OSPAR Assessment Criteria

In order to aid environmental assessments, the Oslo and Paris Commission (OSPAR) have derived a set of biological effect assessment criteria for TBT, based on the development of imposex in gastropod species (OSPAR, 2004). For dogwhelks, these criteria are based on VDSI, and the values chosen relate to effects on the reproductive capability of females in the populations and the effects expected from exposure to TBT concentrations in water equivalent to Environmantal Quality Standard (EQS). The VDSI values used to discriminate 6 assessment classes (A-F) and the effects that these values relate to are given in Table 5. In 2011 a proposal to change the assessment of imposex data was proposed to OSPAR to allow more integration of assessment across other contaminants and effect types. This includes the derivation of Background Assessment Criteria (BAC) at VDSI 0.3 and Environmental Assessment Criteria at VDSI 2. Failure of the EAC level may be used by the

UK (and other OSPAR Contracting Parties) as an indicator for Descriptor 8 of the Marine Strategy Framework Directive (MSFD).

The VDSI data from the 2011 survey were assessed against the criteria presented in Table 5 and the results are shown in Figure 11. In 2011 no sites showed a deterioration of assessment status. None of the sites within Sullom Voe change assessment class in 2011 and five sites within the voe remain at Class C (above the proposed EAC for imposex). Seven sites outside of Sullom Voe itself have improved status to assessment class A (Table 6).

4. Discussion

The higher RPSI and VDSI values of *N. lapillus* populations in Sullom Voe relative to those of the dogwhelk populations in Yell Sound indicate that the Sullom Voe populations continue to be more impacted by TBT released from around the oil terminal until 2008. However, the results of the current 2011 survey show a continued improvement of populations at sites within the Voe. The RPSI and VDSI measurements at sites within the Voe indicate that these populations have good reproductive potential, with no recorded sterile females in the populations. Indeed intertidal shoreline surveys are revealing that population abundance is increasing at previously heavily affected sites close to the terminal. In addition, the continued and increased presence of juvenile and sub-adult dogwhelks at The Kames (site 12) reflects the fact that sterile females have not been found at the site since 2007 (Moore and Gubbins 2012).

The degree of imposex in populations of dogwhelks from the boundary sites (13 and 18) is continuing to decline and these populations continue to have a good reproductive potential, with no sterile individuals found in the last two surveys. Site 6 however shows an increase in VDSI on previous values, but not sufficient to alter assessment class or suggest any significant impairement of reproductive capacity for the population.

Sites in Yell Sound, farthest from the terminal show degrees of imposex which continue to reflect those of sites distant from sources of TBT (close to background/zero) and all sites show a decline in VDSI. RPSI values at these sites were already close to zero and either remain so or show small further declines.

The most notable changes since 2009 are the continued marked decrease in VDSI at sites within the voe. Only five sites now remain as ‘cause for concern’ with imposex levels above international standards (OSPAR EcoQO, WFD classification tool, proposed OSPAR EAC).

Since the ban on TBT on large vessels in 2008, direct inputs to Sullom Voe from ship-based sources have ceased. The continued presence of imposex in dogwhelk populations is likely to be caused by a combination of continued exposure to TBT in sub-tidal sediments from historical contamination and older surviving dogwhelks expressing higher levels of imposex relevant to historical exposure levels (the condition is irreversible).

This series of surveys of dogwhelk imposex in Sullom Voe represent the longest consistent data set of biological effects of contaminants on marine organisms in the UK, and possibly over a much wider area as well. Monitoring should continue to chart the course of the recovery following the recent IMO ban on exposed TBT based paints on hulls of large vessels. It is recommended that the surveys continue to be carried out at an interval of every two - three years at least until all sites have shown a decline in imposex levels to below cause for concern levels (VDSI 2).

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Table 1

Results of the 2011 survey of imposex in dogwhelks (*Nucella lapillus*) in Sullom Voe and Yell Sound.

Site No	Site Name	Size	Incidence of Occurrence %	% RPSI	VDSI	No. Females	No. Males
1	Easterwick	10-15	0	0.00	0.00	5	5
		15-21	0	0.00	0.00	8	8
		21-26	18	0.00	0.18	11	7
		26-35	13	<0.01	0.25	8	2
		Adults	14	<0.01	0.21	28	12
2	Burgo Taing	Adults	21	<0.01	0.31	29	9
3	Billia Skerry	10-15	50	0.01	0.67	6	4
		15-21	50	<0.01	0.57	6	1
		21-26	50	0.00	0.50	10	9
		26-35	60	<0.01	1.00	5	5
		Adults	38	0.00	0.38	8	32
4	Scarf Stane	Adults	67	0.00	0.67	3	7
5	East of Ollaberry	10-15	36	0.05	0.45	11	3
		15-21	22	0.01	0.33	9	11
		21-26	7	0.00	0.07	14	5
		26-35	11	0.00	0.11	9	11
		Adults	13	0.00	0.13	15	22
6	Grunn Taing	Adults	67	<0.01	1.44	18	20
7	Tivaka Taing	Adults	86	0.07	2.05	22	8
8	Noust of Burraland	Adults	88	0.11	2.19	16	13
9	Mavis Grind	10-15	100	0.46	1.33	3	1
		15-21	63	0.27	1.13	8	11
		21-26	57	<0.01	0.86	7	11
		26-35	50	0.01	0.90	10	9
		Adults	87	0.17	2.4	15	23
10	Voxter Ness	Adults	56	0.02	1.25	16	14
11	Northward	Adults	86	0.31	2.73	22	13
12	Kames	10-15	NA	NA	NA	0	0
		15-21	50	1.10	1.00	12	6
		21-26	70	0.23	1.70	10	10
		26-35	70	0.15	1.70	10	11
		Adults	88	0.17	2.25	16	17
13	Skaw Taing	Adults	70	0.07	1.6	20	20
14	Grunna Taing	Adults	19	0.00	0.19	16	22
15	Orfassary	Adults	22	<0.01	0.26	23	17
16	Samphrey/The Helliach	Adults	7	<0.01	0.14	14	18
17	Uynarey	Adults	23	<0.01	0.27	22	18
18	Little Roe	Adults	46	<0.01	0.62	13	18
19	The Brough	Adults	4	<0.01	0.08	24	15
22	Sweinna Stack	Adults	6	0.00	0.06	17	20

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 taken from Bailey and Davies (1991), Harding *et al.* (1997), Minchin and Davies (2000), Gubbins et al (2005, 2008), Gubbins (2010) and the present survey.

Site	1987	1990	1991	1993	1995	1997	1999	2001	2004	2007	2009	2011
1	-	-	*J	*J	*J	*J	*J	*J	*J	*J	*J	*J
2	-	-	*	*	*	*	*	*	*	*	*	*
3	*	*	*J	*J	*J	*J	*J	*J	*J	*J	*J	*J
4	*	*	*	*	*	*	*	*	*	*	*	*
5	*	*J	*J	*J	*J	*J	*J	*J	*J	*J	*J	*J
6	*	*J	*	*	*	*	*	*	*	*	*	*
7	*	*	*	*	*	*	*	*	*	*	*	*
8	*	*J	*	*	*	*	*	*	*	*	*	*
9	*	*J	*J	*J	*J	*J	*J	*J	*J	*J	*J	*J
10	*	*	*	*	*	*	*	*	*	*	*	*
11	*	*J	*	*	*	*	*	*	*	*	*	*
12	*	*J	*	*J	*J	*	*J	*J	*J	*J	*J	*J
13	*	*	*	*	*	*	*	*	*	*	*	*
14	-	-	*	*	*	*	*	*	*	*	*	*
15	-	-	*	*	*	*	*	*	*	*	*	*
16	-	-	*	*	*	*	*	*	*	*	*	*
17	*	*	*	*	*	*	*	*	*	*	*	*
18	*	*	*	*	*	*	*	*	*	*	*	*
19	-	-	*	*	*	*	*	*	*	-	*	*
20	-	-	*	*	*	*	*	*	*	-	*	-
21	-	-	-	-	-	*J	*	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	*

Table 3

Data from surveys undertaken in 1987-2011. Numbers of toothed dogwhelk (*Nucella lapillus*) individuals, percentage of females (%F) and percentage of sterile females (%FS) at each site.

- = No sampling; 0 = No sterile females found.

SITE	SITE NAME	1987			1990			1991			1993			1995		
		TOTAL	%F	%FS	TOTAL	%F	%FS	TOTAL	%F	%FS	TOTAL	%F	%FS	TOTAL	%F	%FS
1	Easterwick	-	-	-	-	-	-	48	60	0	40	45	0	41	56	0
2	Burgo Taing	-	-	-	-	-	-	40	73	0	40	43	0	41	20	0
3	Billia Skerry	41	54	0	41	56	0	40	50	0	40	43	0	40	48	0
4	Scarf Stane	40	63	0	41	46	0	38	45	0	40	40	19	40	43	0
5	East of Ollaberry	40	50	0	42	55	5	37	62	0	40	50	5	40	38	0
6	Grunn Taing	40	45	0	40	58	0	39	49	0	36	42	0	40	60	13
7	Tivaka Taing	40	45	22	39	41	71	39	44	29	38	42	19	40	30	25
8	Noust of Burraland/ Blanches Geo	40	35	21	28	32	33	38	30	91	40	33	15	40	43	59
9	Mavis Grind	40	48	21	43	49	55	29	28	63	26	15	50	40	43	35
10	Voxter Ness	30	57	65	40	75	77	39	26	60	40	25	60	40	35	57
11	Northward	40	40	44	36	28	30	40	28	91	41	32	77	40	25	40
12	The Kames	38	42	93	40	50	95	39	44	100	40	30	92	40	30	83
13	Skaw Taing	40	50	0	37	43	69	39	44	35	40	45	62	40	33	39
14	Moss Bank/ Grunna Taing	-	-	-	-	-	-	40	50	15	40	33	0	40	33	0
15	Orfasay	-	-	-	-	-	-	40	48	0	40	45	0	40	58	0
16	Samphrey/The Helliack	-	-	-	-	-	-	40	48	0	40	38	0	40	60	0
17	Uynarey	34	56	0	40	53	0	40	53	0	40	50	0	40	48	0
18	Little Roe	38	55	0	42	60	4	39	54	14	38	63	13	40	40	6
19	Brough	-	-	-	-	-	-	40	53	0	40	28	0	41	46	0
20	Norther Geo	-	-	-	-	-	-	40	43	0	40	23	0	38	63	0
21	Breiwick	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3 (Continued)

SITE	SITE NAME	1997			1999			2001			2004			2007		
		TOTAL	%F	%FS	TOTAL	%F	%FS	TOTAL	%F	%FS	TOTAL	%F	%FS	TOTAL	%F	%FS
1	Easterwick	40	40	0	40	45	0	40	60	0	39	56	0	40	65	0
2	Burgo Taing	40	63	0	40	40	0	40	50	0	40	63	0	40	50	0
3	Billia Skerry	40	58	0	40	50	0	40	43	0	40	35	0	39	38	0
4	Scarf Stane	40	53	0	40	45	6	39	44	59	38	37	7	40	58	0
5	East of Ollaberry	38	40	0	40	48	0	40	38	0	39	59	0	40	50	0
6	Grunn Taing	39	33	0	40	58	0	40	48	0	39	62	0	40	45	0
7	Tivaka Taing	39	54	10	40	65	10	40	48	0	39	72	0	40	48	0
8	Noust of Burraland/ Blanches Geo	40	43	24	40	55	9	40	40	25	39	46	6	40	68	11
9	Mavis Grind	40	28	27	40	20	13	40	30	42	39	46	22	40	23	11
10	Voxter Ness	40	38	7	40	25	0	40	53	5	40	53	10	40	23	0
11	Northward	40	35	7	40	35	0	40	23	0	40	43	18	37	35	8
12	The Kames	23	13	67	40	40	19	40	50	25	37	41	33	40	48	21
13	Skaw Taing	40	48	16	40	48	0	40	43	29	39	39	0	40	38	0
14	Moss Bank/ Grunna Taing	40	40	0	41	41	0	40	40	0	40	60	0	40	30	0
15	Orfasay	40	60	0	40	58	0	40	40	0	40	60	0	38	63	0
16	Samphrey/ The Helliack	40	38	0	40	45	0	40	35	0	40	38	0	40	50	0
17	Uynarey	40	45	0	40	40	0	40	45	0	39	46	0	40	43	0
18	Little Roe	40	38	0	40	45	0	39	41	6	42	57	0	40	45	0
19	Brough	40	35	0	40	45	0	40	48	0	39	46	0	-	-	-
20	Norther Geo	40	58	0	40	48	0	40	58	0	40	63	0	-	-	-
21	Breiwick	20	30	50	40	43	12	-	-	-	-	-	-	-	-	-

Table 3 (Continued)

SITE	SITE NAME	2009			2011		
		TOTAL	%F	%FS	TOTAL	%F	%FS
1	Easterwick	40	55	0	40	70	0
2	Burgo Taing	40	65	0	38	76	0
3	Billia Skerry	40	58	0	40	20	0
4	Scarf Stane	40	50	0	10	30	0
5	East of Ollaberry	40	53	0	37	41	0
6	Grunn Taing	40	43	0	38	47	0
7	Tivaka Taing	38	58	0	30	73	0
8	Noust of Burraland/ Blanches Geo	39	49	0	29	55	0
9	Mavis Grind	40	40	0	38	39	0
10	Voxter Ness	39	31	0	30	53	0
11	Northward	39	56	0	35	63	0
12	The Kames	40	35	0	33	48	0
13	Skaw Taing	40	43	0	40	50	0
14	Moss Bank/ Grunna Taing	39	44	0	38	42	0
15	Orfasay	39	38	0	40	58	0
16	Samphrey/ The Helliack	40	45	0	32	44	0
17	Uynarey	40	53	0	40	55	0
18	Little Roe	40	48	0	31	42	0
19	Brough	38	58	0	39	62	0
20	Norther Geo	39	64	0	-	-	-
21	Breiwick	-	-	-	-	-	-
22	Sweinna Stack	-	-	-	37	46	0

Table 4

RPSI and VDSI in adult dogwhelks (*Nucella lapillus*) from populations in Sullom Voe and Yell Sound surveyed between 1987 and 2011.

J = sites at which juvenile/subadult surveys were carried out; - = No sampling.

RPSI

SITE NO	SITE NAME	1987	1990	1991	1993	1995	1997	1999	2001	2004	2007	2009	2011
1 J	Easterwick	-	-	0.00	0.00	0.00	0.00	0.00	1.43	<0.01	<0.01	0.00	<0.01
2	Burgo Taing	-	-	3.37	<0.01	<0.01	0.02	<0.01	0.03	<0.01	<0.01	<0.01	<0.01
3 J	Billia Skerry	0.64	1.45	0.24	0.06	0.02	0.02	0.05	0.16	0.27	<0.01	0.13	0.00
4	Scarf Stane	2.16	1.67	3.76	4.38	2.69	15.24	22.29	28.81	8.69	0.14	<0.01	0.00
5 J	East of Ollaberry	2.41	7.51	3.53	0.31	0.23	0.94	0.39	0.09	0.12	<0.01	<0.01	0.00
6	Grunn Taing	12.71	13.52	15.00	4.92	7.33	7.18	4.69	6.20	4.62	0.95	0.00	<0.01
7	Tivaka Taing	58.85	34.19	23.72	14.06	20.34	19.90	21.52	14.21	10.55	3.45	0.54	0.07
8	Noust of Burraland	54.50	45.59	50.75	39.39	21.44	21.88	24.26	18.06	11.00	1.73	0.41	0.11
9 J	Mavis Grind	40.91	30.24	30.15	23.19	11.63	24.11	21.33	28.61	20.33	4.29	1.08	0.17
10	Voxter Ness	58.54	39.59	41.32	32.38	27.65	28.05	24.27	27.65	12.63	2.69	0.01	0.02
11	Northward	34.03	30.54	42.57	31.37	26.70	36.70	40.26	30.71	14.73	7.86	0.31	0.31
12 J	The Kames	56.78	69.44	54.93	37.49	31.32	73.12	35.65	34.03	16.99	0.90	0.26	0.17
13	Skaw Taing	42.46	32.34	45.00	18.26	20.59	27.16	20.02	23.61	14.43	2.59	0.26	0.07
14	Moss Bank/ Grunna Taing	-	-	5.04	0.18	0.37	0.76	0.64	0.50	0.07	0.01	0.67	0.00
15	Orfassary	-	-	0.54	0.05	0.09	0.01	0.59	0.02	<0.01	<0.01	<0.01	<0.01
16	Samphrey/ The Helliack	-	-	1.30	<0.01	0.01	0.02	<0.01	0.00	<0.01	<0.01	<0.01	<0.01
17	Uynarey	0.99	1.25	0.18	0.01	0.02	0.11	0.03	0.02	0.02	<0.01	<0.01	<0.01
18	Little Roe	13.46	9.69	18.89	14.10	5.30	12.00	5.81	8.91	3.76	1.62	0.03	<0.01
19	The Brough	-	-	0.63	<0.01	<0.01	0.00	<0.01	0.00	0.01	-	0.01	<0.01
20	Norther Geo	-	-	0.13	0.01	0.00	0.00	0.00	0.00	0.00	-	0.00	-
21	Breiwick	-	-	-	-	-	38.89	33.51	-	-	-	-	-
22	Sweinna Stack	-	-	-	-	-	-	-	-	-	-	-	0.00

Table 4 (Continued)

VDSI

SITE NO.	SITE NAME	1987	1990	1991	1993	1995	1997	1999	2001	2004	2007	2009	2011
1 J	Easterwick	-	-	0.26	0.05	0.04	0.06	0.33	0.17	0.36	0.15	0.46	0.21
2	Burgo Taing	-	-	1.72	1.13	1.00	0.92	1.125	0.25	0.28	0.50	0.58	0.31
3 J	Billia Skerry	2.32	2.35	2.30	2.06	1.11	1.04	1.25	1.76	1.79	1.20	1.50	0.38
4	Scarf Stane	3.44	3.42	3.53	3.75	3.82	3.67	4.06	4.59	4.07	2.56	0.95	0.67
5 J	East of Ollaberry	3.21	3.95	3.39	2.55	2.47	2.33	2.68	1.60	1.57	0.70	0.38	0.13
6	Grunn Taing	4.00	4.00	4.00	3.73	4.13	4.00	4.00	4.00	3.46	3.50	0.59	1.44
7	Tivaka Taing	4.22	4.93	4.41	4.19	4.25	4.09	4.00	4.00	4.00	3.58	2.64	2.05
8	Noust of Burraland	4.21	4.33	5.00	4.15	4.65	4.24	4.09	4.31	4.05	4.00	3.53	2.19
9 J	Mavis Grind	4.26	4.64	4.75	4.50	4.35	4.27	4.125	4.42	4.25	4.11	3.67	2.4
10	Voxter Ness	4.71	4.83	4.80	4.60	4.57	4.07	4.00	4.05	4.10	3.78	1.30	1.25
11	Northward	4.44	4.87	5.18	4.77	4.40	4.07	4.07	4.33	4.18	4.08	3.14	2.73
12 J	The Kames	5.27	5.33	5.59	5.08	5.17	4.67	4.19	4.25	4.33	3.89	3.00	2.25
13	Skaw Taing	4.00	4.69	4.41	4.61	4.31	4.16	4.00	4.29	4.00	3.33	2.77	1.60
14	Moss Bank/ Grunna Taing	-	-	4.05	1.77	2.46	2.13	2.65	1.88	1.47	1.08	3.24	0.19
15	Orfassary	-	-	2.74	1.78	1.04	0.88	1.65	0.81	1.12	0.83	0.40	0.26
16	Samphrey/ The Helliack	-	-	2.32	0.53	0.63	0.87	0.72	0.43	0.40	0.20	0.33	0.14
17	Uynarey	2.58	2.86	2.05	1.20	0.90	1.56	1.375	0.78	1.17	0.82	0.38	0.27
18	Little Roe	4.00	4.04	4.14	4.13	4.06	3.93	3.94	2.19	3.63	3.56	1.95	0.62
19	The Brough	-	-	2.57	1.09	1.16	0.43	0.83	0.61	0.89	-	0.38	0.08
20	Norther Geo	-	-	1.35	0.56	0.00	0.30	0.43	0.17	0.08	-	0.20	-
21	Breiwick	-	-	-	-	-	4.50	4.10	-	-	-	-	-
22	Sweinna Stack	-	-	-	-	-	-	-	-	-	-	-	0.06

Table 5

Oslo and Paris Commission biological effects assessment criteria for imposex in *Nucella lapillus*, based on VDSI (OSPAR, 2004) and amended to show which classes exceed Background Assessment Criteria (BAC) and Environmental Assessment Criteria (EAC).

Assessment class	*Nucella* VDSI	Effects and impacts
A (<BAC)	VDSI = <0.3	The level of imposex in the more sensitive gastropod species is close to zero (0 - ~30% of females have imposex) indicating exposure to TBT concentrations close to zero, which is the objective in the OSPAR strategy of hazardous substances.
B (>BAC <EAC)	VDSI = 0.3 - <2.0	The level of imposex in the more sensitive gastropod species (~30 - ~100 % of the females have imposex) indicates exposure to TBT concentrations below the EAC derived for TBT. E.g. adverse effects in the more sensitive taxa of the ecosystem caused by long-term exposure to TBT are predicted to be unlikely to occur.
C (>EAC)	VDSI = 2.0 - <4.0	The level of imposex in the more sensitive gastropod species indicates exposure to TBT concentrations higher than the EAC derived for TBT. E.g. there is a risk of adverse effects, such as reduced growth and recruitment, in the more sensitive taxa of the ecosystem caused by long-term exposure to TBT.
D (>EAC)	VDSI = 4.0 - 5.0	The reproductive capacity in the populations of the more sensitive gastropod species, such as *Nucella lapillus*, is affected as a result of the presence of sterile females, but some reproductively capable females remain. E.g. there is evidence of adverse effects, which can be directly associated with the exposure to TBT.
E (>EAC)	VDSI = > 5.0	Populations of the more sensitive gastropod species, such as *Nucella lapillus*, are unable to reproduce. The majority, if not all females within the population have been sterilized.
F (>EAC)	VDSI = -	The populations of the more sensitive gastropod species, such as *Nucella lapillus* and *Ocinebrina aciculata*, are absent/expired.

Table 6

Temporal changes in OSPAR imposex classes at sites in Sullom Voe and Yell Sound. See Table 5 for key to OSPAR classes (A: VDSI<0.3; E: VDSI>5.0).

Site	1987	1990	1991	1993	1995	1997	1999	2001	2004	2007	2009	2011
1	-	-	A	A	A	A	B	A	B	A	B	A
2	-	-	B	B	B	B	B	A	A	B	B	B
3	C	C	C	C	B	B	B	B	B	B	B	B
4	C	C	C	C	C	C	D	D	D	C	B	B
5	C	C	C	C	C	C	C	B	B	B	B	A
6	D	D	D	C	D	D	D	D	C	C	B	B
7	D	D	D	D	D	D	D	D	D	C	C	C
8	D	D	D	D	D	D	D	D	D	D	C	C
9	D	D	D	D	D	D	D	D	D	D	C	C
10	D	D	D	D	D	D	D	D	D	C	B	B
11	D	D	E	D	D	D	D	D	D	D	C	C
12	E	E	E	E	E	D	D	D	D	C	C	C
13	D	D	D	D	D	D	D	D	D	C	C	B
14	-	-	D	B	C	C	C	B	B	B	C	A
15	-	-	C	B	B	B	B	B	B	B	B	A
16	-	-	C	B	B	B	B	B	B	A	B	A
17	C	C	C	B	B	B	B	B	B	B	B	A
18	D	D	D	D	D	C	C	C	C	C	B	B
19	-	-	C	B	B	B	B	B	B	-	B	A
20	-	-	B	B	A	A	B	A	A	-	A	-
22	-	-	-	-	-	-	-	-	-	-	-	A

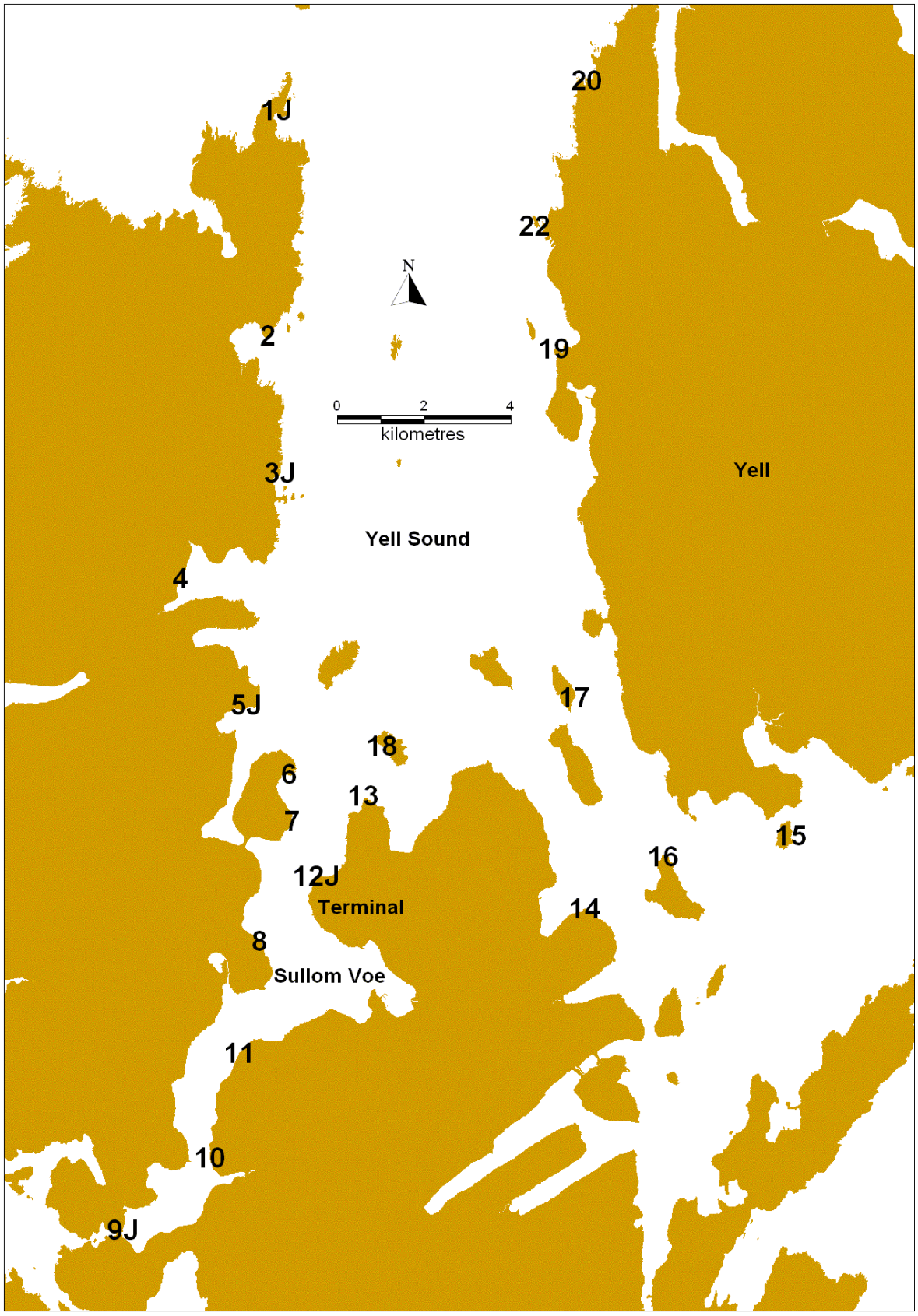


Figure 1: Dogwhelk sampling sites in Sullom Voe and Yell Sound. (**J** Indicates sites where untoothed adults, sub-adults and juvenile size classes were sampled).

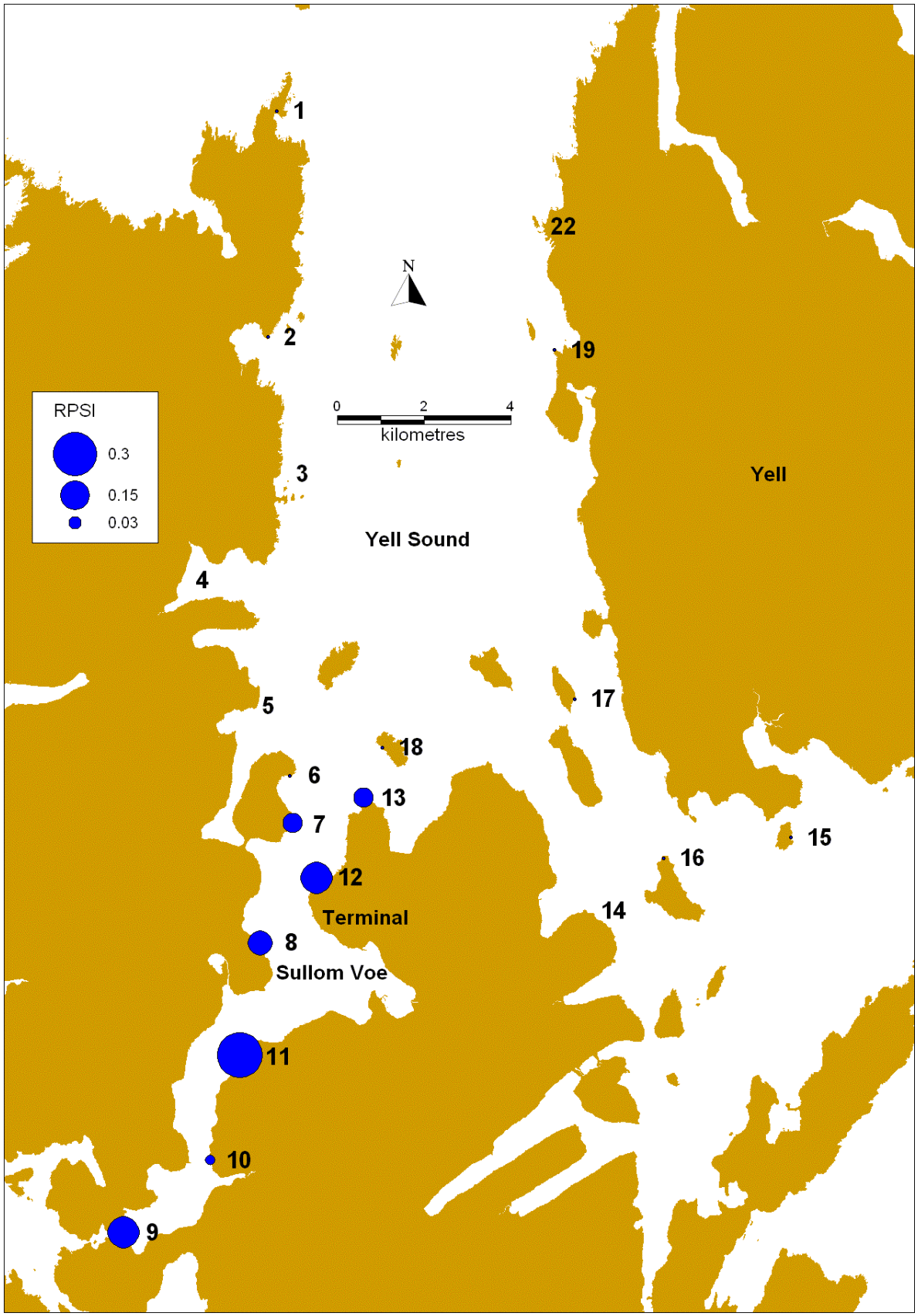


Figure 2: RPSI in toothed adult dogwhelks (*Nucella lapillus*) from populations in Sullom Voe and Yell Sound sampled during the 2011 survey.

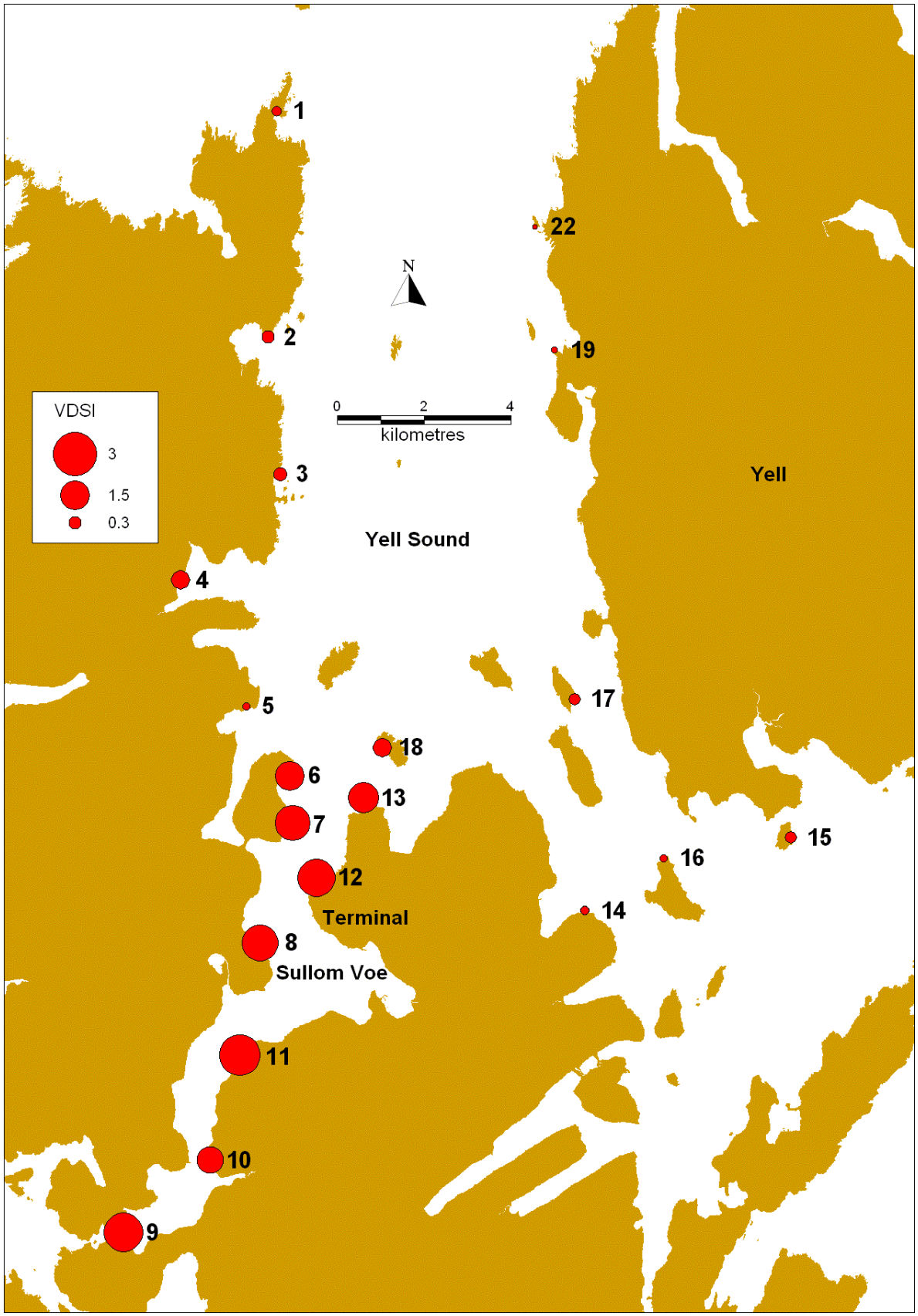


Figure 3: VDSI in toothed adult dogwhelks (*Nucella lapillus*) from populations in Sullom Voe and Yell Sound sampled during the 2011 survey.

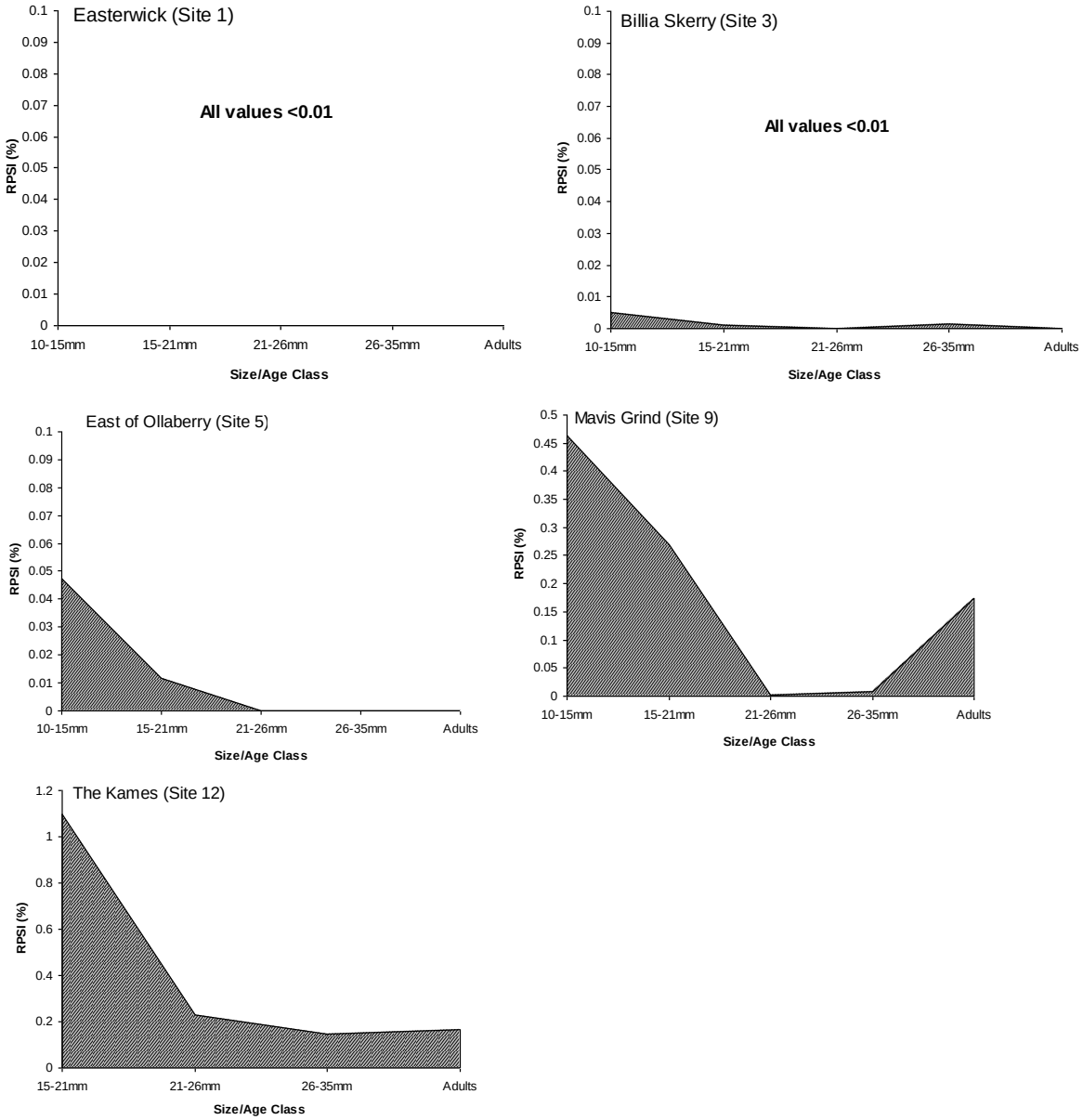


Figure 4: Relative penis size (RPSI) values for all the size/age classes of dogwhelks in the juvenile, sub-adult and untoothed adult survey 2011.

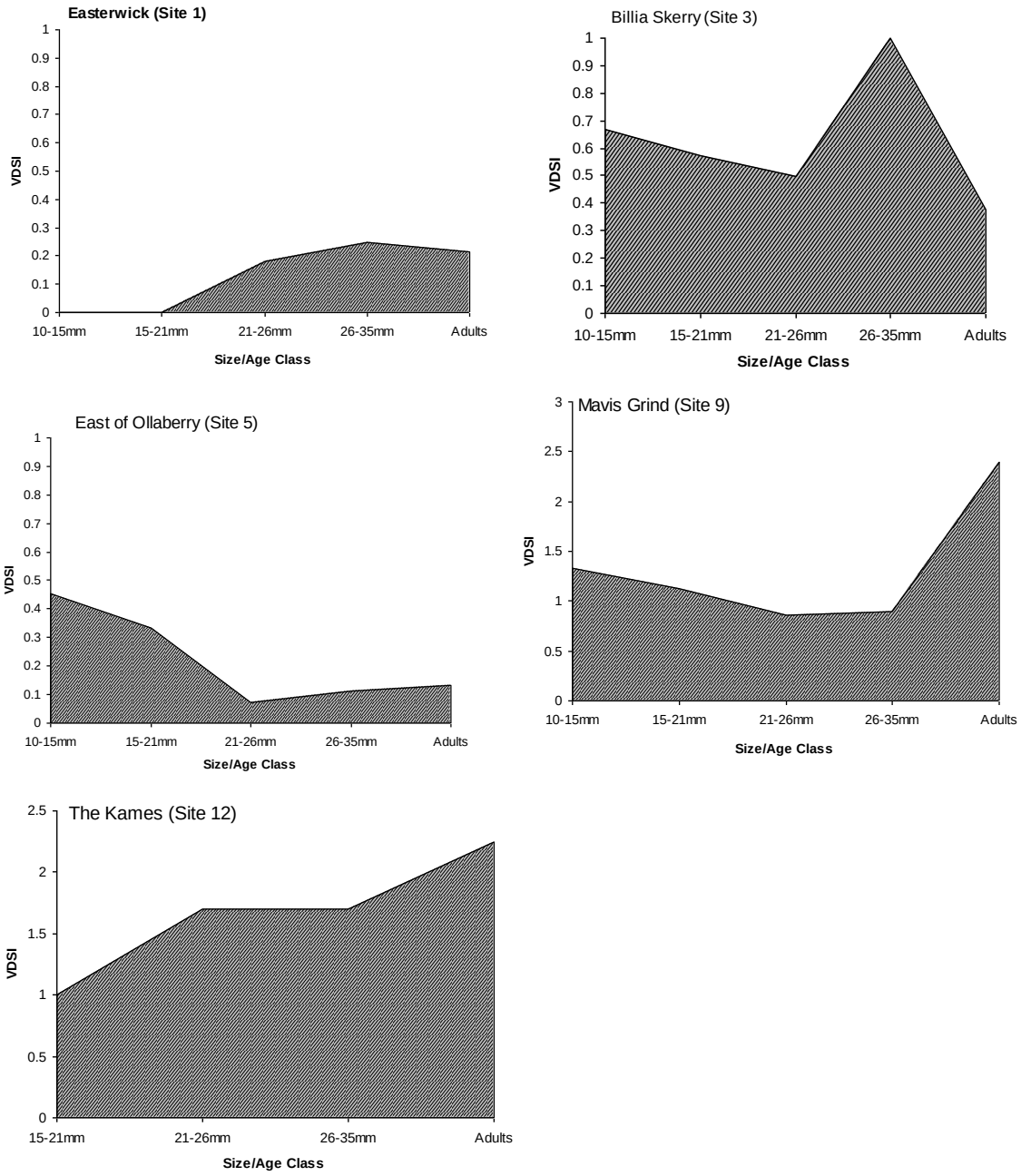
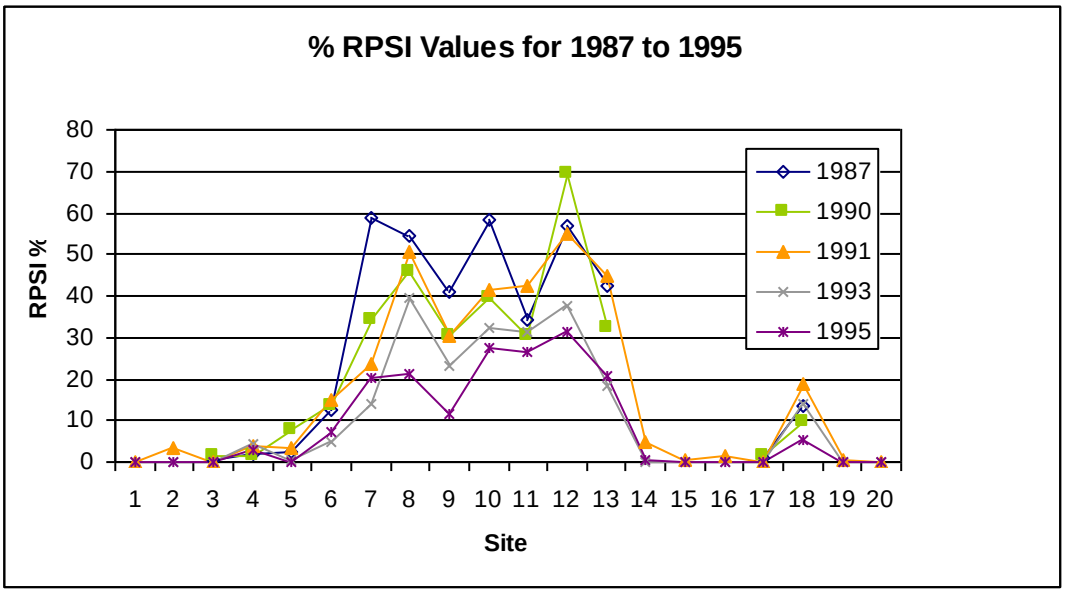


Figure 5: Vas Deferens Sequence Index (VDSI) values for all the size/age classes of dogwhelks in the juvenile, sub-adult and untoothed adult survey 2011.



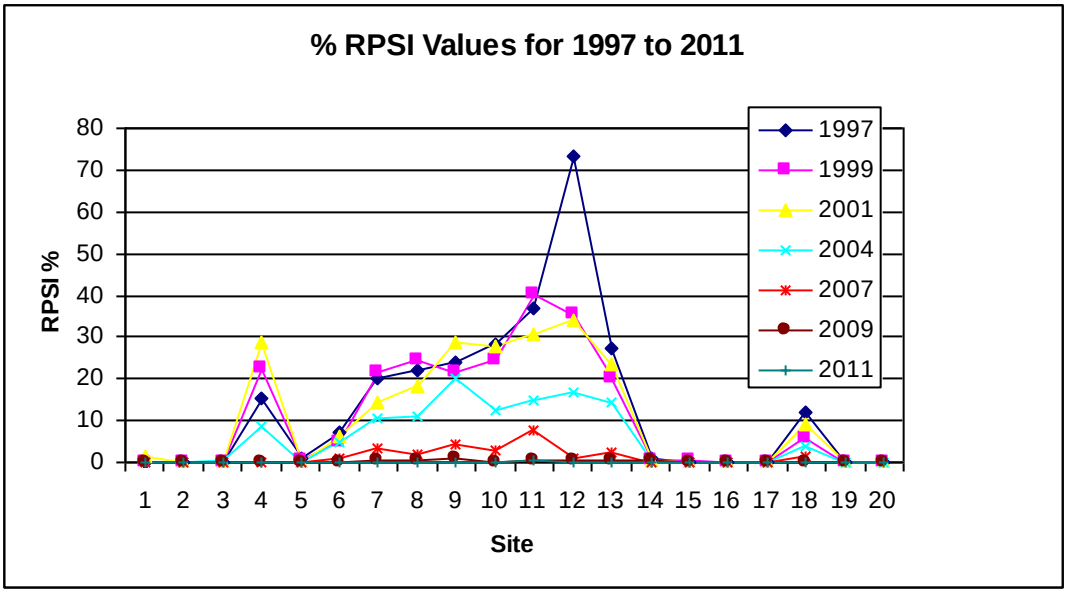
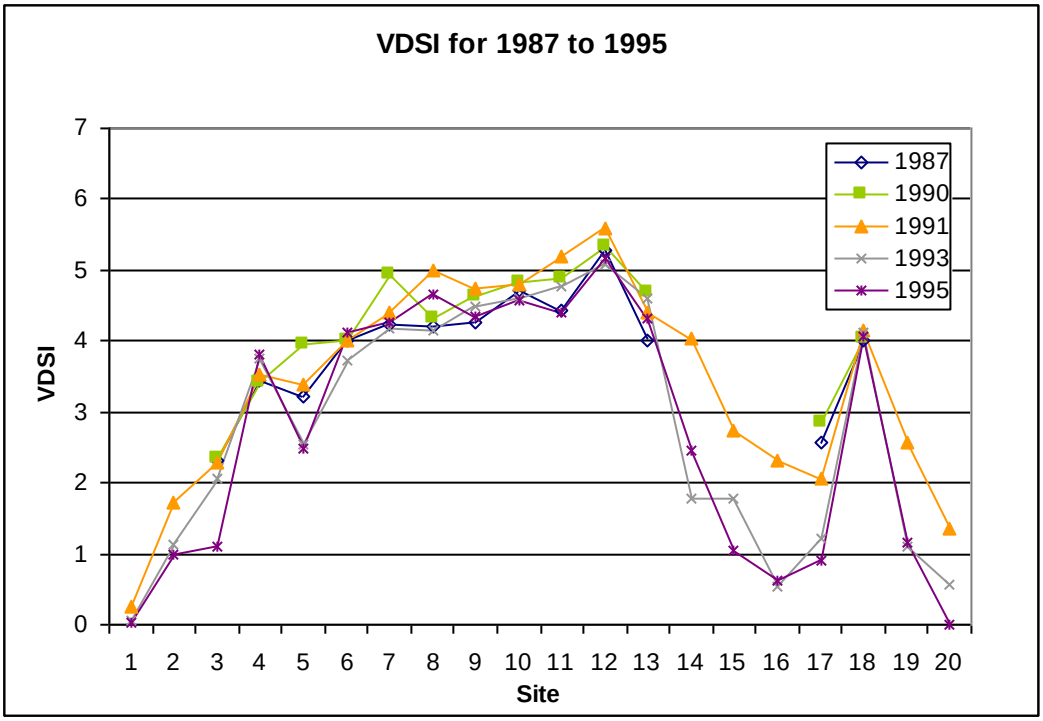


Figure 6: Relative penis Size Index (RPSI %) values of adult dogwhelk (*Nucella lapillus*) populations sampled at Sullom Voe (sites 7-12) and Yell Sound between 1987 and 2011.



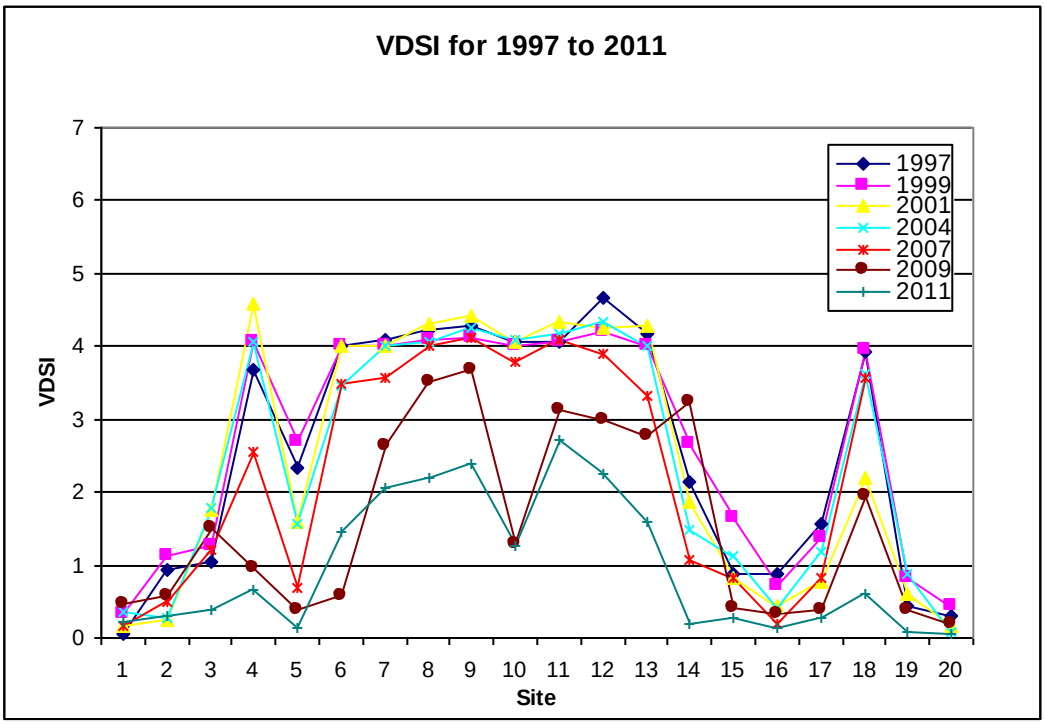


Figure 7: Vas Deferens Sequence Index (VDSI) values of adult dogwhelk (*Nucella lapillus*) populations sampled at Sullom Voe (sites 7-12) and Yell Sound between 1987 and 2011.

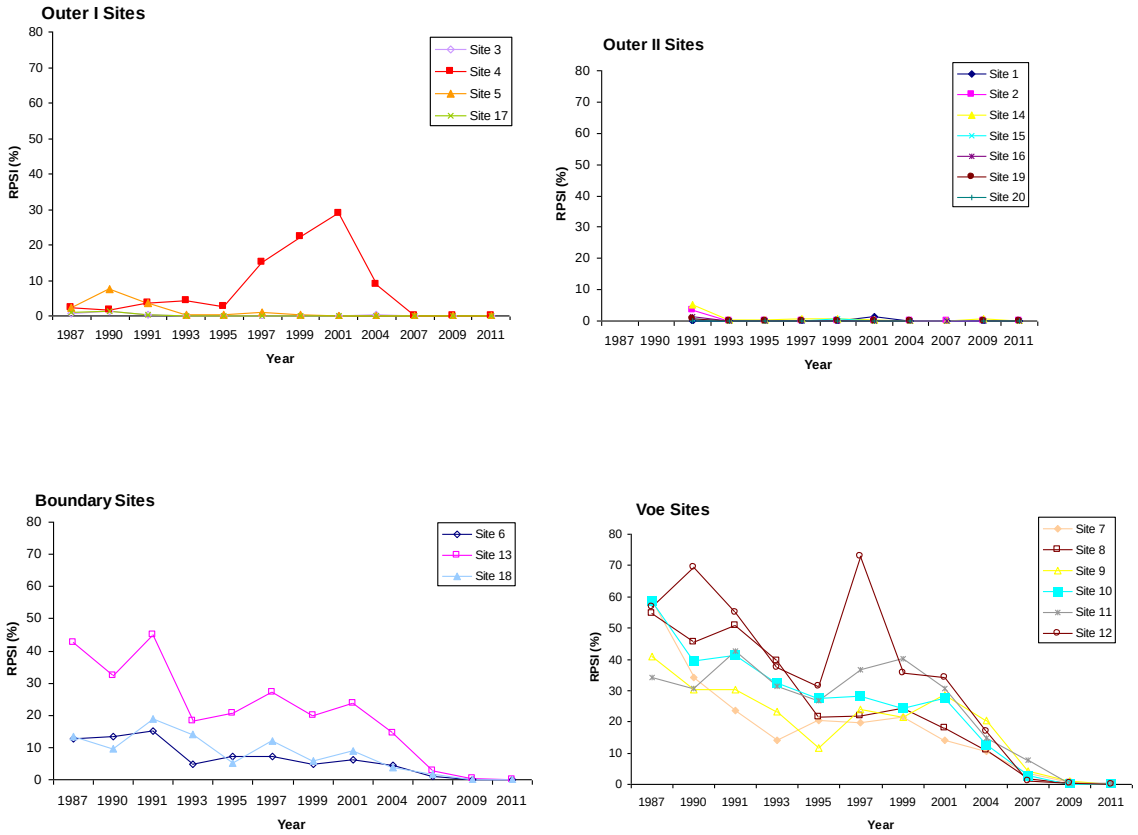


Figure 8: Relative penis Size Index (RPSI) values for adult populations in the surveys from 1987-2011 shown by geographical grouping.

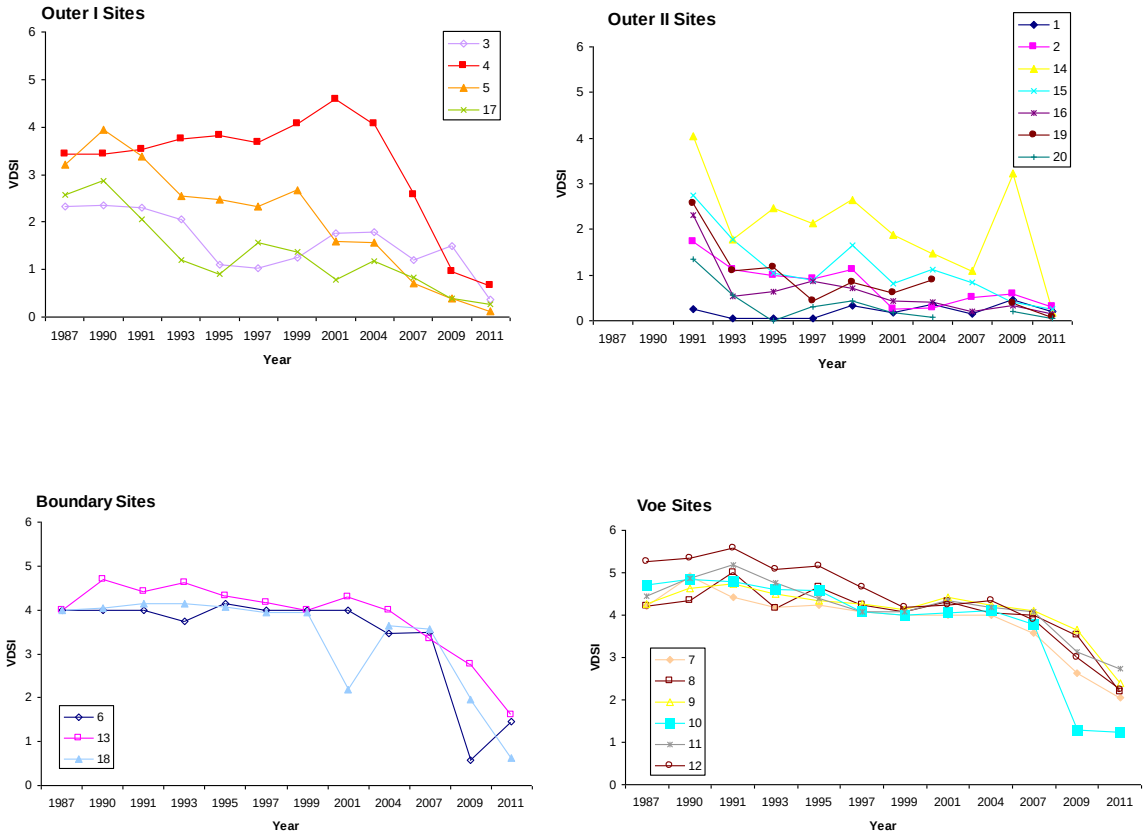


Figure 9: Vas Deferens Sequence Index (VDSI) values for adult populations in the surveys from 1987-2011 shown by geographical grouping.

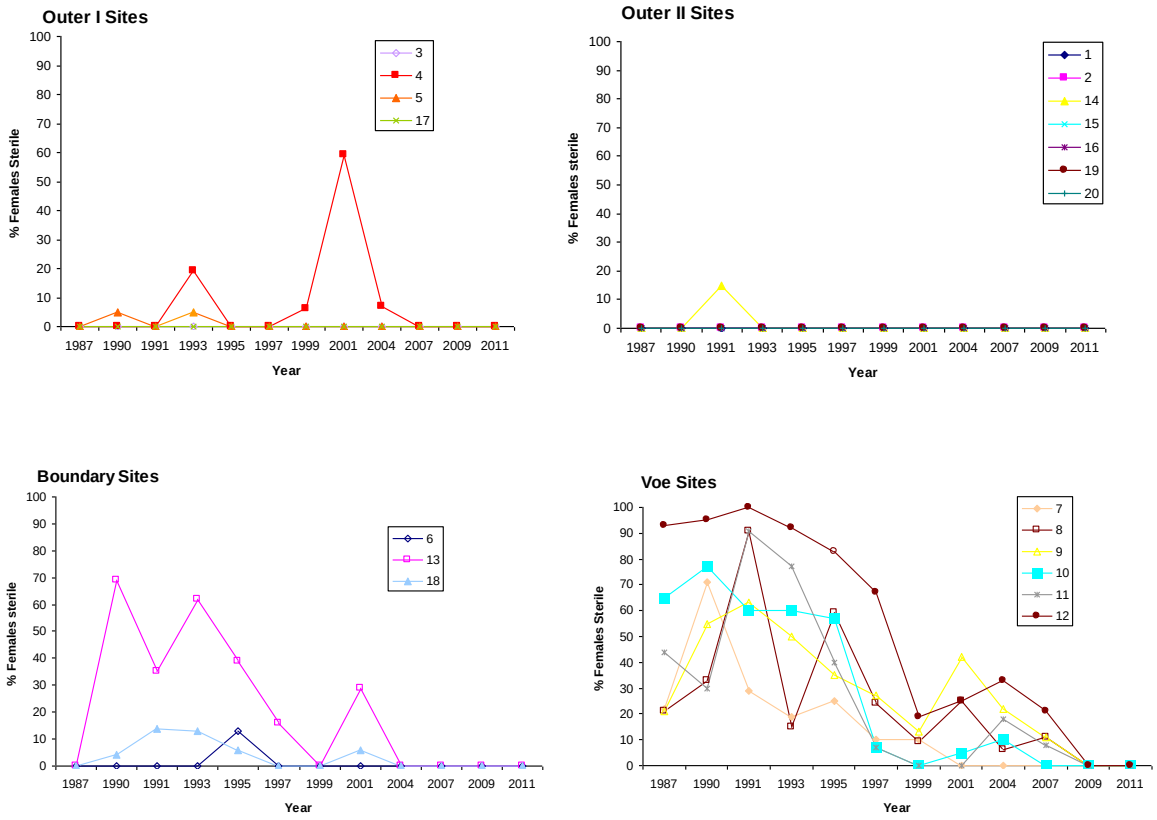


Figure 10: The percentage of the adult female populations sampled which were sterile in the surveys from 1987-2011, shown by geographical grouping.

Figure 11: Assessment of VDSI data from adult dogwhelks (*Nucella lapillus*) sampled from sites around Sullom Voe and Yell Sound in 2011. Data are presented in accordance with OSPAR assessment classes (See Table 5).

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