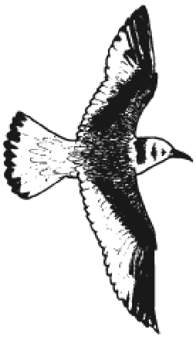
SOTEAG

Surveys of dogwhelks, *Nucella lapillus* in the vicinity of Sullom Voe 2018

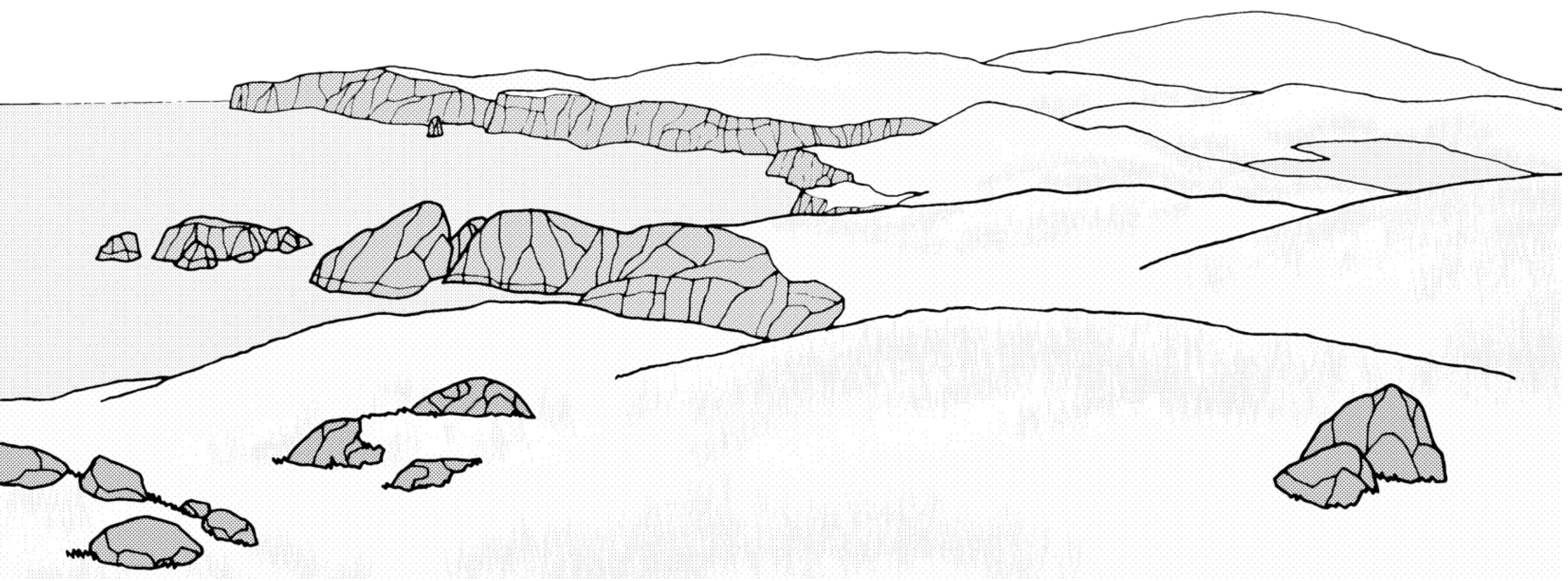


A report to the Shetland Oil Terminal Environmental Advisory Group

by

Aquatic Survey and Monitoring Ltd

& Marine Scotland



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Surveys of dogwhelks *Nucella lapillus* in the vicinity of Sullom Voe, Shetland, August 2018

A report for SOTEAG

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Data access

Summary

This report presents the 2018 results of a dogwhelk *Nucella lapillus* monitoring programme carried out by Aquatic Survey & Monitoring Ltd. (ASML) and the Marine Scotland Science (MSS) Marine Laboratory, as part of the rocky shore monitoring programme commissioned by Shetland Oil Terminal Environmental Advisory Group (SOTEAG), and funded by the Sullom Voe Association. The dogwhelk programme has been running since 1991 and has confirmed that shipping associated with the oil terminal has been the source of tributyltin (TBT) contamination to the area. This contamination has affected dogwhelk populations in Sullom Voe and Yell Sound. The recorded history of this decline began in 1987, when imposex surveys found that 94.5% of females sampled at sites in the immediate vicinity of the terminals had blocked reproductive tracts. The SOTEAG rocky shore monitoring surveys in 1990 highlighted the low abundances of juvenile dogwhelks at many sites in Sullom Voe.

The dogwhelk monitoring surveys are in two parts:

- analysis of imposex in samples of adult and juvenile dogwhelks by laboratory dissection; and
- analysis of dogwhelk population structure from size/frequency data collected in the field

Twenty sites in Sullom Voe and Yell Sound were surveyed and sampled in August 2018. At each site, a timed search for dogwhelks was carried out and all specimens collected were measured and their age class noted. These data were used to produce size/frequency histograms and summary population statistics, and were compared with the data from the previous surveys, at 2 or 3 year intervals between 1991 and 2015.

Dogwhelks for imposex analysis were collected from the same twenty sites and transported to the MSS Marine Laboratory in Aberdeen. Adult dogwhelks were collected from all sites, and juvenile dogwhelks were collected from five of the twenty sites. Dissection and measurement of these animals enabled the calculation of values for the incidence of imposex occurrence (%), Relative Penis Size Index (RPSI) and Vas Deferens Sequence Index (VDSI) at each site. Results of the present survey were compared to the previous imposex surveys (1987 to 2015) and assessed against the Oslo and Paris Commission (OSPAR) assessment criteria.

The degree of imposex (RPSI and VDSI measurements) in adult and juvenile dogwhelks from sites within Sullom Voe in 2018 show that these sites continue to be more impacted by tri-butyl tin (TBT) than populations at sites in Yell Sound, but that this difference is no longer statistically significant. As TBT inputs to the Voe have ceased following the International Maritime Organisation (IMO) ban on use on large vessels in 2008, the continued

development of imposex in juveniles is likely due to reservoirs of residual concentrations in sub-tidal sediments that are known to be present in the area of the terminal. Throughout Sullom Voe, RPSI and VDSI values in adults (RPSI <0.01-0.04%; VDSI 0.27- 0.78) were generally slightly lower than the values in the 2015 survey. The RPSI values of populations outside the Voe (RPSI 0.00-0.01%), in the well flushed waters of Yell Sound, were slightly lower overall than at sites within the Voe. As in previous surveys, the degree of imposex in populations in Yell Sound tends to decrease with distance from Sullom Voe. VDSI at sites in Yell Sound and the boundary sites were generally lower (0.00-0.17) than at sites inside the Voe, however, there were three sites located in the Yell Sound which had VDSI values above those from Sullom Voe sites (0.79-1.00).

No sterile female dogwhelks were recorded from any site and the presence of juveniles and eggs at all sites confirmed that all populations had the capacity to reproduce. RPSI and VDSI levels decreased at most sites, but six sites showed a small increase in levels. None of those increases was considered notable and they likely represent inherent variability rather than a change in environmental conditions. RPSI levels at all sites remained close to zero with no substantial changes. Changes in VDSI resulted in changes in OSPAR Classification for four sites, all of which are now classified as A or B, which means that all are below the Environmental Assessment Criteria (EAC).

The population data again confirm that juveniles are being produced at all sites and show that adult population structure is close to normal distribution at many of the Sullom Voe sites, as well as most of the Yell Sound sites. However, temporal analysis of adult and juvenile dogwhelk abundances shows a statistically significant decline at a number of sites in both Sullom Voe and Yell Sound. The cause is not clear but observations in 2018 suggest that an increasing dominance of fucoid algae at many sites is a major factor.

Since the last dogwhelk survey in 2015 there has been continued evidence of dogwhelk migration back to the shores between the Sullom Voe terminal jetties. The populations there are still small, but increasing.

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.

Contents

1 Introduction

During the late 1980s and in 1990, SOTEAG-funded monitoring of rocky shore communities in Sullom Voe (Moore, 1990) showed that dogwhelk *Nucella lapillus* populations were declining. This observation was supported by work carried out for the Department of the Environment on imposex[1] (Bailey and Davies, 1989). Concern about the declining trend of Sullom Voe dogwhelk populations, attributed to shipping associated with the oil terminal, led to an expansion of the rocky shore monitoring programme in 1991, to include more detailed studies on those populations and the levels of imposex.

Results from the 1991 survey (Taylor *et al.* 1992) showed that dogwhelks were completely absent from the terminal area, and that at the Kames (the closest site to the terminal where dogwhelk populations could then be found) the degree of imposex was higher than at any other site. All populations within Sullom Voe had high degrees of imposex, and juveniles or eggs were rare or absent at most sites in the Voe. In Yell Sound, there was a decrease in the level of dogwhelk imposex with increasing distance from Sullom Voe. The furthest sites, at the top of Yell Sound, had imposex levels similar to the background levels described from other studies. Population structure appeared normal in most populations outside the Voe, with large numbers of juveniles at all sites. Comparison of levels of imposex in 1991 with those found in 1987 and 1990 (Bailey and Davies, 1991) showed that there had been a progressive decline in the reproductive capacity of female dogwhelks in Sullom Voe.

SOTEAG therefore initiated a regular monitoring programme, with repeat surveys at intervals of two or three years. The survey reports are available from SOTEAG (www.soteag.org.uk). The programme now represents 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.

The primary input of TBT contamination to the Voe was from antifoulants on tankers, with some limited inputs from other smaller craft and structures until 1986. There have been increasing reductions in the use of TBT anti-fouling paints since 1986 and it has been an offence since 1st January 2008 for any ship visiting an EU port to have TBT on its hull (EC Regulation 782/2003 on the Prohibition of Organotin Compounds on Ships, which implements IMO Convention on the Control of Harmful Anti-Fouling Systems on Ships 2001). TBT inputs to the area should therefore have reduced to zero.

The monitoring programme has described a gradual decrease in levels of imposex, an increase in production of juvenile dogwhelks and improvements

in population structure at the Sullom Voe sites (Moore and Gubbins 2015, Gubbins *et al.* 2010). In 2009 there were no sterile females in any of the samples, for the first time since 1987; and there has been a gradual migration of dogwhelks back towards the terminal. The latter is evident in data from the associated annual rocky shore transect monitoring programme, showing that a small and increasing population was becoming re-established between the jetties (Moore and Mercer 2018). However, the 2015 dogwhelk survey results showed that imposex levels were still higher within Sullom Voe than sites in Yell Sound and that imposex was continuing to develop in juvenile dogwhelks; indicating that TBT contamination was still present. Gubbins *et al.* 2012 showed that samples of Sullom Voe seabed sediments contained TBT, with highest concentrations (up to 69 ng/g dw) at locations close to the terminal jetties and in the upper basin. The concentrations of TBT were in excess of environmental quality standards given in the Water Framework Directive (0.02 ng/g) but were below the action limit used for dredge spoil disposal licensing (100 ng/g).

This report describes the results of a dogwhelk monitoring survey carried out in August 2018 and compares them with the results of previous surveys in the programme.

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[1] A condition in some female dogwhelks (and some other gastropods), which develop male sexual characteristics resulting from exposure to tri-butyl tin (TBT, an additive in some anti-fouling paints). In severe cases the condition can result in sterility and death. See Gibbs *et al* 1987.

2 Methods

The methodology used in this survey was the same as used in previous surveys. The following description provides relevant details for interpretation of the results. Additional details are given in previous reports (e.g. Moore and Gubbins 2015).

The survey and methodology are in two parts:

a) analysis of imposex in samples of adult and juvenile dogwhelks by laboratory dissection; and

b) analysis of dogwhelk population structure from size/frequency data collected in the field.

Fieldwork for both parts was carried out between the 8th and 17th August 2018. A related monitoring survey on rocky shore transects was also carried out in that period (Moore and Mercer, 2018). A field log is given in Appendix 1

2.1 Survey site locations

Dogwhelk populations were surveyed at the same suite of 20 sites as in previous surveys (Figure 1 and Table 1). However, since 2011 there has been one change in site location for sampling of dogwhelks for imposex analysis. At Norther Geo (site 20), the density of adult (toothed) dogwhelks in the vicinity of the site became too low for sustainable sampling. A replacement site at Sweinna Stack (site 22), half way between sites 20 and 19, was therefore established in 2011. Since then, the population study site in Norther Geo was surveyed as usual (without removing any dogwhelks) but sampling for imposex analysis was transferred to the Sweinna Stack site.

Table 1 Survey sites. Mins is the period used for the population study collections. Area: YS = Yell Sound (separated into I & II), SV = Sullom Voe, B = Boundary sites. Asterisks (*) indicate sites where juveniles were collected for imposex analyses. Where two survey dates are given for a site, the population survey and the sampling were carried out on different days (see text for explanation). #No samples were taken from Site 20 for imposex analysis, but a population study was carried out (see text for explanation).

	Site name	Longitude	Latitude	Survey date	Mins	Area
1*	Easterwick	-1.31467	60.6283	09/08/18	5	YSII
2	Burgo Taing	-1.31915	60.5833	09/08/18 & 16/08/18	3	YSII
3*	Billia Skerry	-1.31467	60.5554	09/08/18	5	YSI
4	Scarf Stane	-1.35679	60.5332	09/08/18 & 11/08/18	10	YSI
5*	East of Ollaberry	-1.32868	60.5069	09/08/18	5	YSI
6	Grunn Taing	-1.31209	60.4929	08/08/18	5	B
7	Tivaka Taing	-1.31077	60.4832	08/08/18	2	SV
8	Noust of Burraland	-1.32506	60.4585	08/08/18	5	SV
9*	Mavis Grind	-1.38357	60.3989	17/08/18 & 19/08/18	5	SV
10	Voxter Ness	-1.34674	60.4136	14/08/18 & 19/08/18	5	SV
11	Northward	-1.33387	60.4354	13/08/18 & 19/08/18	4	SV
12*	The Kames	-1.30126	60.4718	12/08/18 & 19/08/18	5	SV
13	Skaw Taing	-1.28005	60.4877	08/08/18	5	B
14	Mossbank	-1.18893	60.4644	17/08/18	5	YSII
15	Orfasay	-1.10213	60.479	17/08/18	5	YSII
16	Samphrey	-1.15565	60.4751	17/08/18	5	YSII

17	Uynarey	-1.19196	60.5082	10/08/18 & 17/08/18	4	YSI
18	Little Roe	-1.2731	60.4985	09/08/18 & 10/08/18	5	B
19	The Brough	-1.19897	60.5803	17/08/18	2	YSII
20[#]	Norther Geo	-1.18365	60.6356	17/08/18	5	YSII
22	Sweinna Stack	-1.2064	60.6058	17/08/18	n/a	YSII

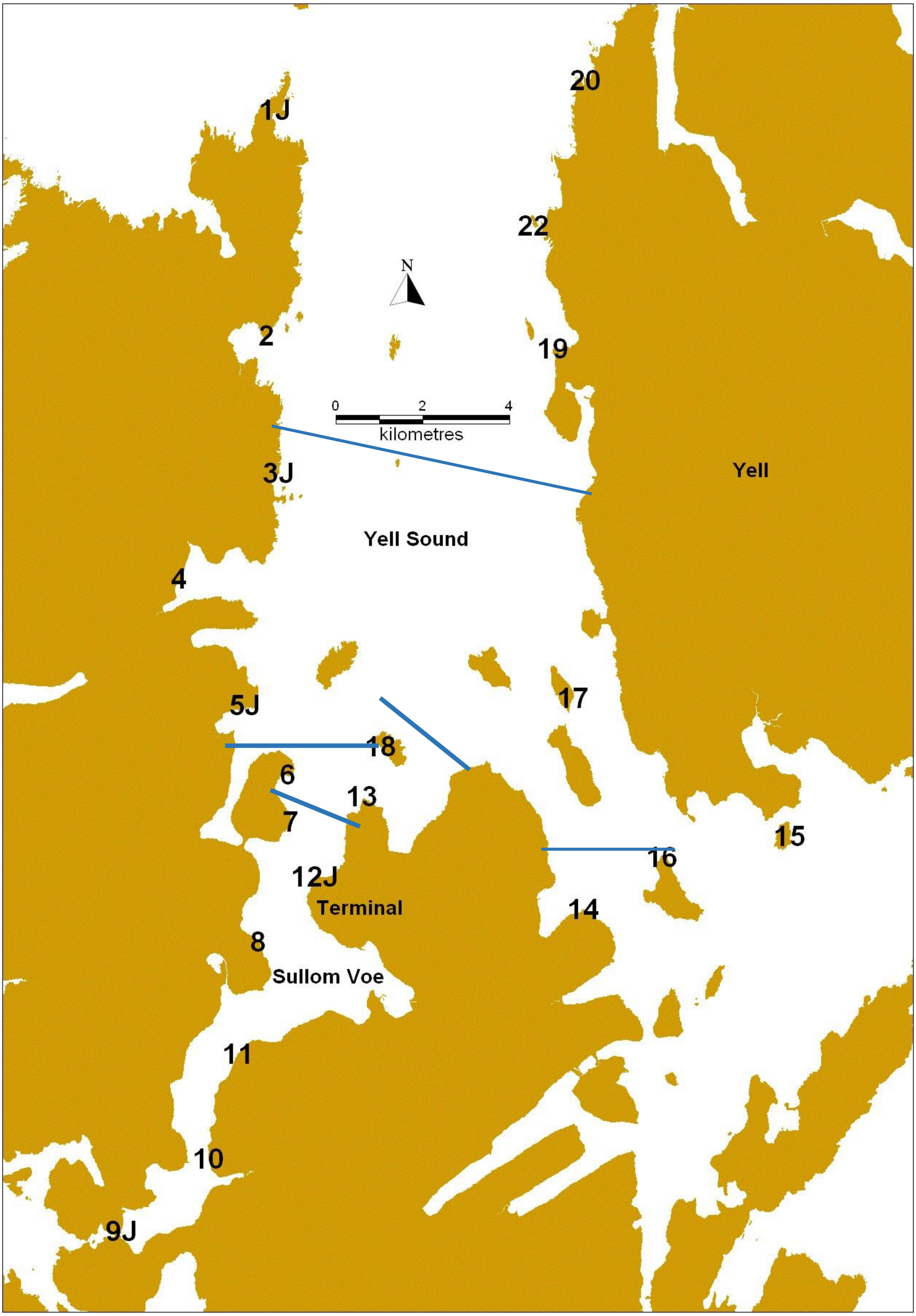


*Figure 1 Dogwhelk sampling sites in Sullom Voe and Yell Sound. (**J** indicates sites where untoothed adults, sub-adults and juvenile size classes were also sampled). Blue lines demarcate sites used for data analysis: Yell Sound (Inner & Outer), Sullom Voe and Boundary sites.*

2.2 Collecting population study data

At each site, a timed search for dogwhelks was carried out within a defined collection area (established in 1991) – typically an area of bedrock around 4m x 4m, relocated using annotated photographs on a laminated site location sheet. Additional site specific protocols are also given on the sheet. The standard duration of search at most sites is five minutes, but for some sites where dogwhelks are typically abundant or sparse the standard time is lower or higher (see Table 1). Two surveyors, would carry out the search, one collecting dogwhelks on the open rock surface, the other, armed with a pair of forceps, collecting dogwhelks from crevices. Most of the juveniles are found in the crevices.

The shell height of every specimen collected during the search was measured to the nearest millimetre using vernier calipers (see Figure 2). Age was determined by examination of shell edge thickness and classified according to observations by Moore (1936): juveniles and first year specimens have a thin shell edge and are normally in the range 4 to 15mm; second year sub adults have a thicker edge and are normally 15 to 21mm; adults of three or more years are normally more than 21mm and normally have a thick edge which also develops teeth on the inside lip in mature adults.

Measurement was always carried out on-site, immediately after collection; then the dogwhelks were returned to the sampling area.

2.3 Sampling dogwhelks for imposex analysis

Samples for imposex analysis were taken from the same sites, but as this sampling was necessarily destructive, the sampling area was located a short distance (at least 10m and up to 50m) away from the population study area. The adult sampling required 40 mature adult dogwhelks (identified by thickened shell rim and the presence of teeth) to be taken from each site. Additionally, samples of juveniles were taken at five sites (see Table 1); with 20 dogwhelks from each of the following size classes 10-15mm, 15-21mm, 21-26mm and 26-35mm.

All dogwhelks collected for laboratory analyses were kept alive in clean seawater overnight and cool, dry conditions during the day. Within two days of collection, the live specimens were flown down to Aberdeen and transferred to suitable aquaria at the MSS Marine Laboratory in Aberdeen.

2.4 Laboratory analysis of imposex

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

2.4.1 Determination of the Relative Penis Size Index (RPSI)

A correlation exists between the weight (or volume) of the penis in the dogwhelk, and the cube of its length (Bryan *et al.*, 1986). An indication of the extent of imposex development in a population may, therefore, be obtained by comparing the volume of penises in males and females. By expressing the mean volume of the female penises as a percentage of the mean volume of the penises in males in the same population, a ratio is obtained (RPSI, Gibbs *et al.*, 1987). Comparison with ratios obtained from other populations provides a gradient of RPSI values, reflecting a gradient of imposex development.

The RPSI was calculated from penis length measurements of 40 adult dogwhelks, using the equation shown:

$$\frac{\textit{mean female penis length}^{3}}{\textit{mean male penis length}^{3}} \times 100\%$$

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.

Figure 2 Photographs to illustrate dogwhelks feeding on barnacles, egg capsules., range of sizes (6mm to 35mm), crevice habitat, timed search at Mavis Grind and measuring with calipers.

2.4.2 Determination of the Vas Deferens Sequence Index (VDSI)

The development of imposex may be divided into six stages, depending upon the developmental state of both the penis and vas deferens in the female (Gibbs *et al.*, 1987). By stage 5 the vas deferens tissue proliferates over the opening of the vulva, rendering the female sterile since she can no longer release egg capsules. In the final stage (stage 6), the capsule gland ruptures, causing premature death of the female. Each of the six stages of imposex is known as a Vas Deferens Stage (VDS), and calculation of the mean VDS for a group of females provides the VDSI. This, together with the percentage of sterile females in the sample, is widely used to compare the reproductive competency of different populations.

The VDS was determined through dissection and the mean VDS calculated to provide an estimate of the VDSI of the population. The percentage of sterile females was also calculated.

2.4.3 OSPAR assessment criteria

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 Environmental 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 2. This includes the derivation of Background Assessment Criteria (BAC) at VDSI 0.3 and Environmental Assessment Criteria at VDSI 2 therefore Class A is below the BAC, class B above BAC but below EAC and classes C-F above the EAC. Failure of the EAC level may be used by the UK (and other OSPAR Contracting Parties) as an indicator for Descriptor 8 (effects of contaminants) of the Marine Strategy Framework Directive.

Table 2 Oslo and Paris Commission biological effects assessment criteria for imposex in Nucella lapillus*, based on VDSI (OSPAR, 2004).*

Assessment class	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.

2.5 Data analysis

Much of the data analysis is based on a classification of the sites into four groups: Yell Sound A (mid Sound, 4 sites), Yell Sound B (outer Sound, 8 sites), Sullom Voe (6 sites) and Boundary sites (3 sites) (see Figure 1 and Table 1). This classification is simplified further for analysis of the population study data, with all of the Yell Sound and Boundary sites combined.

Analysis of variance (ANOVA) at the 95% confidence level, with Tukey's pair-wise comparisons (Minitab 17) was used to assess significant differences in VDSI between the different site categories.

The size/frequency data from the population study were used to produce size/frequency histograms (Appendix 2) and summary population statistics. Statistical analysis of the data was carried out with the features available in Excel.

3 Results

3.1 Laboratory studies on degree of imposex

Table 3 gives the results of the imposex analysis from all sites and samples. Figure 3 and Figure 4 show the geographic distribution of RPSI and VDSI respectively, from the adult dogwhelks.

Table 3 Results of the 2018 survey of imposex in dogwhelks in Sullom Voe and Yell Sound. Dogwhelk size categories, % Incidence of imposex occurrence, % RPSI, % VDSI, No. of Females and Males in sample.

Site No	Name	Size (mm)	% Incidence	% RPSI	VDSI	No. Females	No. Males
1	Easterwick	10-15	0	0.00	0.00	16	3
		15-21	0	0.00	0.00	6	14
		21-26	0	0.00	0.00	6	13
		26-35	0	0.00	0.00	10	10
		Adults	0	0.00	0.00	21	18
2	Burgo Taing	Adults	8	0.00	0.08	24	15
3	Billia Skerry	10-15	13	0.00	0.13	8	12
		15-21	36	0.00	0.36	11	9
		21-26	10	<0.01	0.20	10	10
		26-35	11	0.00	0.11	9	11
		Adults	58	0.01	1.00	19	21
4	Scarf Stane	Adults	6	0.00	0.06	17	15
5	East of Ollaberry	10-15	0	0.00	0.00	11	8
		15-21	9	0.00	0.09	11	9
		21-26	30	0.00	0.30	10	8
		26-35	0	0.00	0.00	11	9
		Adults	6	0.00	0.06	17	23
6	Grunn Taing	Adults	37	<0.01	0.79	19	20
7	Tivaka Taing	Adults	57	<0.01	0.78	23	17
8	Noust of Burraland	Adults	38	0.04	0.71	21	18
9	Mavis Grind	10-15	9	0.01	0.18	11	5
		15-21	0	0.00	0.00	9	9
		21-26	0	0.00	0.00	11	6
		26-35	11	<0.01	0.22	9	10
		Adults	20	<0.01	0.27	15	24
10	Voxter Ness	Adults	38	<0.01	0.62	21	19
11	Northward	Adults	35	0.01	0.59	17	20
12	Kames	10-15	0	0.00	0.00	8	9
		15-21	13	<0.01	0.25	8	11
		21-26	42	0.03	0.58	12	6
		26-35	0	0.00	0.00	11	7
		Adults	28	<0.01	0.56	18	21
13	Skaw Taing	Adults	6	0.00	0.06	16	21
14	Mossbank	Adults	8	<0.01	0.17	12	28
15	Orfasay	Adults	50	<0.01	0.95	20	20
16	Samphrey	Adults	12	0.00	0.12	17	22
17	Uynarey	Adults	6	0.00	0.06	16	24
18	Little Roe	Adults	0	0.00	0.00	15	24
19	The Brough	Adults	14	0.00	0.14	22	18
22	Sweinna Stack	Adults	0	0.00	0.00	18	21

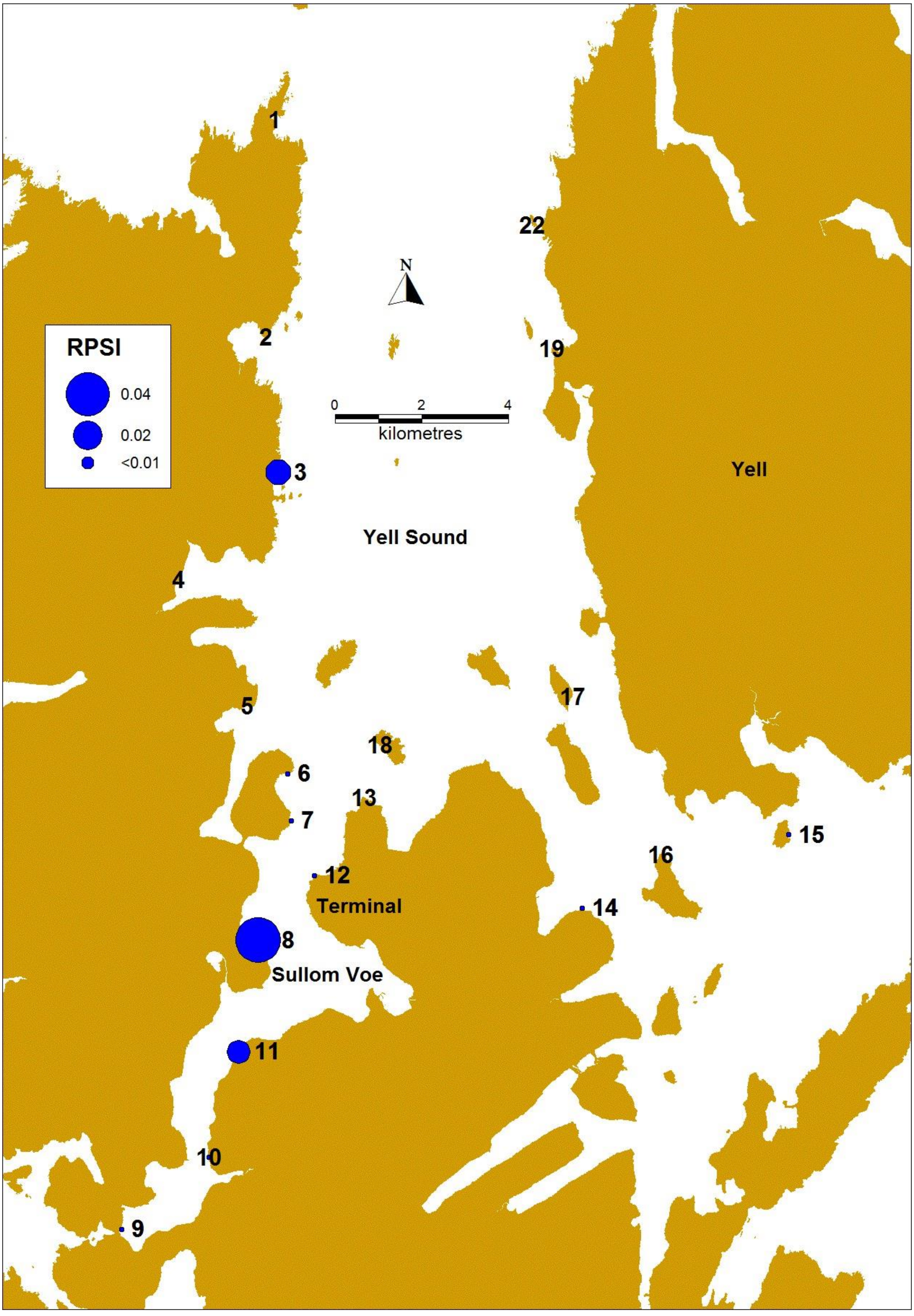


Figure 3 *RPSIs in toothed adult dogwhelks (<u>Nucella lapillus</u>) from populations in Sullom Voe and Yell Sound sampled during the 2018 survey.*

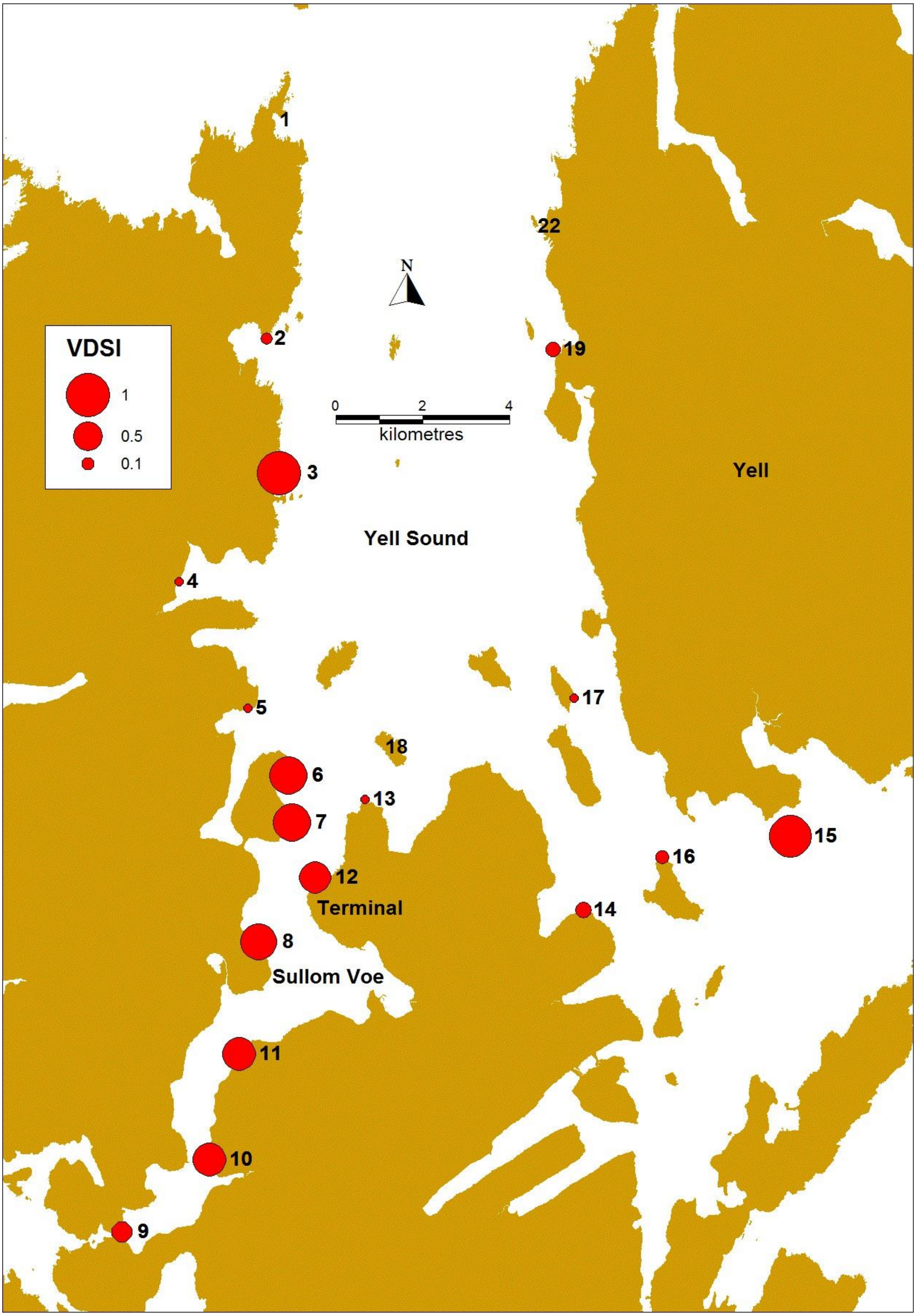


Figure 4 *VDSIs in toothed adult dogwhelks (Nucella lapillus) from populations in Sullom Voe and Yell Sound sampled during the 2018 survey.*

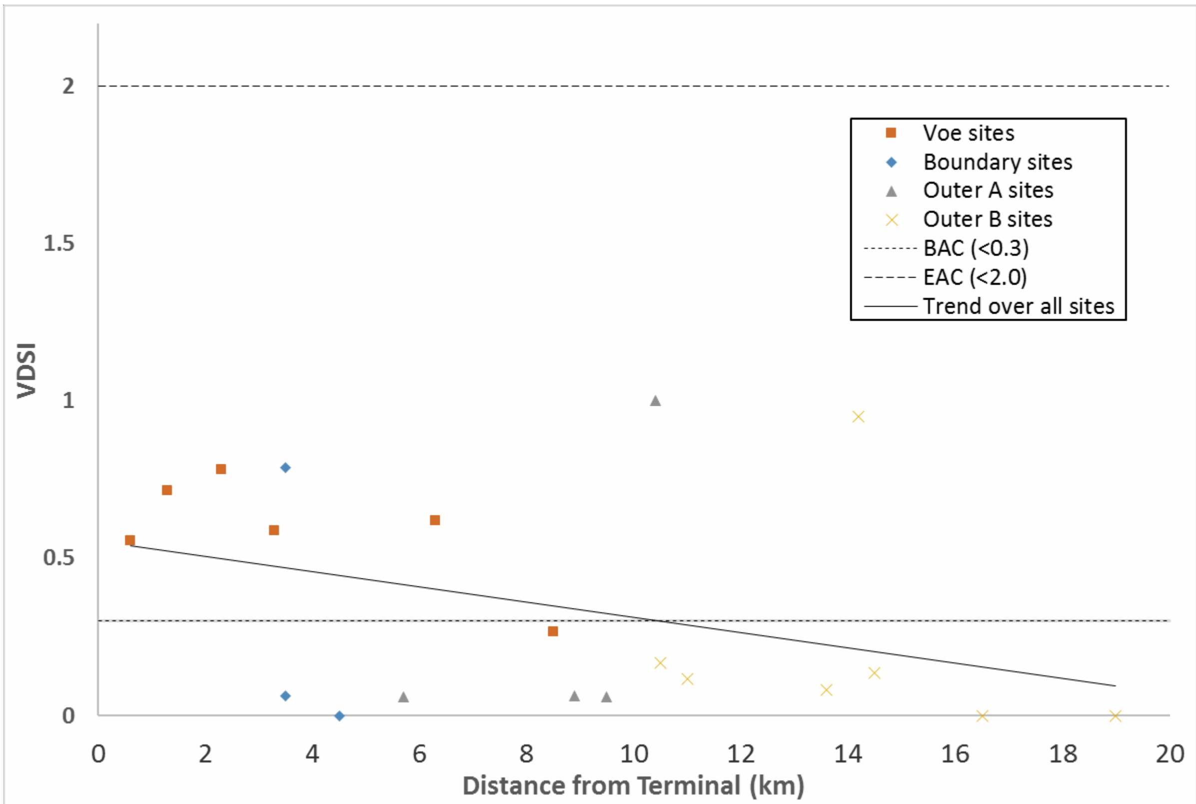
3.1.1 Toothed adult survey

RPSI values from sites sampled in 2018 within Sullom Voe ranged from <0.01 to 0.04%. The RPSI values of populations outside the Voe in Yell Sound (A and B) and at the Boundary sites ranged from 0.00-0.01%. The highest RPSI value from the toothed adult populations was found in Sullom Voe, just south of the terminal at Noust of Burraland (0.04%, Table 3, site 8).

The VDSI values ranged from 0.27 to 0.78 (Table 3) at sites within Sullom Voe. The highest VDSI scores from the 2018 survey were found in populations from the Yell Sound sites: at Billia Skerry (site 3, Table 3, Figure 4 VDSI 1.00); and at Orfasay (site 15, Table 3, Figure 4, VDSI 0.95). All other sites in Yell Sound have VDSI <0.2. The VDSI from the Boundary sites ranged from 0.06 to 0.79.

In previous surveys, the degree of imposex in populations has decreased with distance from Sullom Voe. This trend is still clear in the VDSI data from all sites in 2018 (Figure 5) however, statistically there was no significant difference in VDSI between sites within Sullom Voe, Boundary sites and Yell Sound (A and B) (p>0.05) (Figure 6).

There was no evidence of sterility (VDS > 4) in any of the populations sampled



in 2018 (Table 4).

Figure 5 2018 VDSI values in adult dogwhelks Nucella lapillus shown by geographic groupings and distance from terminal. The Background Assessment Criteria (BAC) and Environmental Assessment Criteria (EAC) are also shown.

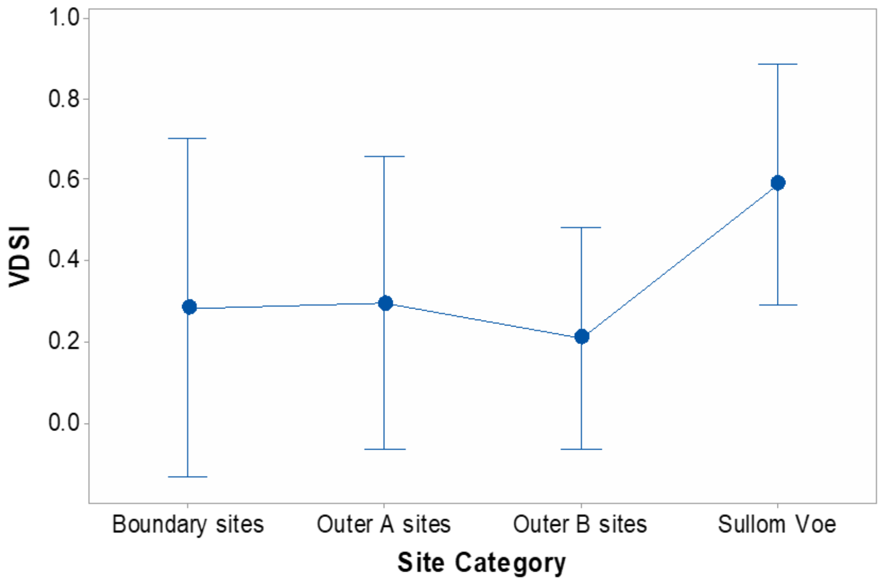


Figure 6 Comparison of average VDSI values (2018) in adult dogwhelks from geographic grouping in Sullom Voe and Yell Sound.

3.1.2 Untoothed 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 3, Figure 1; sites marked with a J).

Imposex was not detected in any of the age classes at the Easterwick site (Table 3, site 1). The highest level of imposex was observed in untoothed adults from a site inside Sullom Voe, the Kames (Table 3, site 12, 21-26 mm, 0.03% RPSI, 0.58 VDSI). The highest level of imposex in the Yell Sound was from sub-adults at Billia Skerry (Table 3, site 3, 15-21 mm, 0.00% RPSI, 0.36 VDSI) and untoothed adults at East of Ollaberry (Table 3, site 5, 21-26 mm, RPSI 0.00%, VDSI 0.30). All other populations sampled had VDSI <0.3.

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.

3.1.3 Comparison with previous surveys: Adults

A summary of the results of all surveys for sites 1-22 is given in Table 4, Table 5 and Table 6. 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 7 for RPSI, Figure 8 for VDSI and Figure 9 for the incidence of sterile females.

The RPSI and VDSI values for the populations of adults 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 2011-2018. 2018 values remain low.

Changes in VDSI between 2001 and 2007 were smaller than the changes in RPSI, but since 2007 show a marked decrease that continues to 2018 for most sites. In 2009, all sites within Sullom Voe show VDSI
<4.00, showing that populations appear to be no longer reproductively impaired. This remains the case in 2018. In 2018, VDSI has decreased since 2015 at most sites in Sullom Voe and the Yell Sound except

3, 5, 6, 7, 14, 16 where small increases from already low levels were observed (Figure 8). These are thought more likely to represent inherent variability rather than a change in environmental conditions. RPSI has also decreased or remained at very low levels since 2015. In 2015, a single adult female was recorded as sterile (VDS 5) at site 11 (Northward), leading to an increase in RPSI and VDSI for that site. In 2018, this site has returned to the previously low values recorded from 2009 to 2013. There has been a steady increase in VDSI from site 3 (Billia Skerry) since 2011 however levels still remain low.

While the overall trend of imposex in dogwhelk populations in the surveyed area has been downwards, we are starting to see a cessation of this trend with a number of sites reporting no further decreases in imposex indicators. This may be due to the fact that previous declines were due to massive changes in TBT inputs associated with changes in shipping density and paint usage. Under the present status, imposex levels are reflecting the local residual environmental concentrations and may not be expected to decline so rapidly.

The incidence of female sterility at each site from each sampling survey from 1987 – 2018 is shown in Figure 9. The proportion of sterile females at all sites decreased to 0% for the first time in 2009 and was maintained to 2013. In 2015 a single sterile female was recorded at Northward (site 11) representing an incidence rate of 7% for this site. There was no evidence of sterility in any of the populations sampled in 2018.

Table 4 The numbers of toothed animals and the percentage of females obtained from the surveys in 1987, 1991, 2015 and 2018. 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. Data from other surveys have been tabulated in previous reports.

Site	Site name	1987			1991			2015			2018		
		Total	%F	%FS	Total	%F	%FS	Total	%F	%FS	Total	%F	%FS
1	Easterwick	-	-	-	48	60	0	40	55	0	39	54	0
2	Burgo Taing	-	-	-	40	73	0	40	40	0	39	62	0
3	Billia Skerry	41	54	0	40	50	0	40	53	0	40	48	0
4	Scarf Stane	40	63	0	38	45	0	39	67	0	32	53	0
5	East of Ollaberry	40	50	0	37	62	0	40	45	0	40	43	0
6	Grunn Taing	40	45	0	39	49	0	40	48	0	39	49	0
7	Tivaka Taing	40	45	22	39	44	29	39	59	0	40	58	0
8	Noust of Burraland	40	35	21	38	29	91	36	44	0	39	54	0
9	Mavis Grind	40	48	21	29	28	63	36	47	0	39	38	0
10	Voxter Ness	30	57	65	39	26	60	40	33	0	40	53	0
11	Northward	40	40	44	40	28	91	38	37	7	37	46	0
12	The Kames	38	42	93	39	44	100	39	41	0	39	46	0
13	Skaw Taing	40	50	0	39	44	35	39	56	0	37	43	0
14	Mossbank	-	-	-	40	50	15	39	41	0	40	30	0
15	Orfasay	-	-	-	40	48	0	39	51	0	40	50	0
16	Samphrey	-	-	-	40	48	0	40	48	0	39	44	0
17	Uynarey	34	56	0	40	53	0	40	38	0	40	40	0

18	Little Roe	38	55	0	39	54	14	39	28	0	39	38	0
19	Brough	-	-	-	40	53	0	38	55	0	40	55	0
20	Norther Geo	-	-	-	40	43	0	-	-	-	-	-	-
22	Sweinna Stack	-	-	-	-	-	-	39	62	0	39	46	0

Table 5 RPSI in adult dogwhelks, all surveys (except 93 & 99, to make space) (- No sample taken).

Site No	Site name	1987	1990	1991	1995	1997	2001	2004	2007	2009	2011	2013	2015	2018
1	Easterwick	-	-	0.00	0.00	0.00	1.43	<0.01	<0.01	0.00	<0.01	0.00	0.00	0.00
2	Burgo Taing	-	-	3.37	<0.01	0.02	0.03	<0.01	<0.01	<0.01	<0.01	0.00	<0.01	0.00
3	Billia Skerry	0.64	1.45	0.24	0.02	0.02	0.16	0.27	<0.01	0.13	0.00	0.00	0.00	0.01
4	Scarf Stane	2.16	1.67	3.76	2.69	15.24	28.81	8.69	0.14	<0.01	0.00	0.04	0.00	0.00
5	East of Ollaberry	2.41	7.51	3.53	0.23	0.94	0.09	0.12	<0.01	<0.01	0.00	0.00	0.00	0.00
6	Grunn Taing	12.71	13.52	15.00	7.33	7.18	6.2	4.62	0.95	0.00	<0.01	<0.01	<0.01	<0.01
7	Tivaka Taing	58.85	34.19	23.72	20.34	19.90	14.21	10.55	3.45	0.54	0.07	<0.01	<0.01	<0.01
8	Noust of Burraland	54.50	45.59	50.75	21.44	21.88	18.06	11.00	1.73	0.41	0.11	0.13	0.06	0.04
9	Mavis Grind	40.91	30.24	30.15	11.63	24.11	28.61	20.33	4.29	1.08	0.17	0.01	0.04	<0.01
10	Voxter Ness	58.54	39.59	41.32	27.65	28.05	27.65	12.63	2.69	0.01	0.02	0.01	<0.01	<0.01
11	Northward	34.03	30.54	42.57	26.70	36.70	30.71	14.73	7.86	0.31	0.31	0.04	0.37	0.01
12	The Kames	56.78	69.44	54.93	31.32	73.12	34.03	16.99	0.90	0.26	0.17	0.30	0.03	<0.01
13	Skaw Taing	42.46	32.34	45.00	20.59	27.16	23.61	14.43	2.59	0.26	0.07	<0.01	<0.01	0.00
14	Mossbank	-	-	5.04	0.37	0.76	0.5	0.07	0.01	0.67	0.00	0.00	0.00	<0.01
15	Orfasay	-	-	0.54	0.09	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01
16	Samphrey	-	-	1.30	0.01	0.02	0	<0.01	<0.01	<0.01	<0.01	0.00	0.00	0.00
17	Uynarey	0.99	1.25	0.18	0.02	0.11	0.02	0.02	<0.01	<0.01	<0.01	0.00	<0.01	0.00
18	Little Roe	13.46	9.69	18.89	5.30	12.00	8.91	3.76	1.62	0.03	<0.01	<0.01	0.00	0.00
19	The Brough	-	-	0.63	<0.01	0.00	0	0.01	-	0.01	<0.01	0.00	<0.01	0.00
20	Norther Geo	-	-	0.13	0.00	0.00	0	0.00	-	0.00	-	-	-	-
22	Sweinna Stack	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00

Table 6 VDSI in adult dogwhelks, all surveys (except 93 & 99, to make space) (- No sample taken).

Site No	Site name	1987	1990	1991	1995	1997	2001	2004	2007	2009	2011	2013	2015	2018
1	Easterwick	-	-	0.26	0.04	0.06	0.17	0.36	0.15	0.46	0.21	0.00	0.00	0.00
2	Burgo Taing	-	-	1.72	1.00	0.92	0.25	0.28	0.50	0.58	0.31	0.00	0.75	0.08
3	Billia Skerry	2.32	2.35	2.30	1.11	1.04	1.76	1.79	1.20	1.50	0.38	0.55	0.67	1.00
4	Scarf Stane	3.44	3.42	3.53	3.82	3.67	4.59	4.07	2.56	0.95	0.67	0.15	0.08	0.06
5	East of Ollaberry	3.21	3.95	3.39	2.47	2.33	1.6	1.57	0.70	0.38	0.13	0.05	0.00	0.06
6	Grunn Taing	4.00	4.00	4.00	4.13	4.00	4.00	3.46	3.50	0.59	1.44	0.85	0.47	0.79
7	Tivaka Taing	4.22	4.93	4.41	4.25	4.09	4.00	4.00	3.58	2.64	2.05	0.79	0.70	0.78
8	Noust of Burraland	4.21	4.33	5.00	4.65	4.24	4.31	4.05	4.00	3.53	2.19	1.74	1.63	0.71
9	Mavis Grind	4.26	4.64	4.75	4.35	4.27	4.42	4.25	4.11	3.67	2.40	1.05	1.65	0.27
10	Voxter Ness	4.71	4.83	4.80	4.57	4.07	4.05	4.10	3.78	1.30	1.25	1.23	1.00	0.62
11	Northward	4.44	4.87	5.18	4.40	4.07	4.33	4.18	4.08	3.14	2.73	1.40	2.36	0.59
12	The Kames	5.27	5.33	5.59	5.17	4.67	4.25	4.33	3.89	3.00	2.25	2.00	1.81	0.56
13	Skaw Taing	4.00	4.69	4.41	4.31	4.16	4.29	4.00	3.33	2.77	1.60	0.44	0.77	0.06
14	Mossbank	-	-	4.05	2.46	2.13	1.88	1.47	1.08	3.24	0.19	0.00	0.00	0.17
15	Orfasay	-	-	2.74	1.04	0.88	0.81	1.12	0.83	0.40	0.26	0.54	1.60	0.95
16	Samphrey	-	-	2.32	0.63	0.87	0.43	0.40	0.20	0.33	0.14	0.38	0.00	0.12
17	Uynarey	2.58	2.86	2.05	0.90	1.56	0.78	1.17	0.82	0.38	0.27	0.05	0.20	0.06
18	Little Roe	4.00	4.04	4.14	4.06	3.93	2.19	3.63	3.56	1.95	0.62	0.50	0.00	0.00
19	The Brough	-	-	2.57	1.16	0.43	0.61	0.89	-	0.38	0.08	0.08	0.19	0.14
20	Norther Geo	-	-	1.35	0.00	0.30	0.17	0.08	-	0.20	-	-	-	-
22	Sweinna Stack	-	-	-	-	-	-	-	-	-	0.06	0.00	0.00	0.00

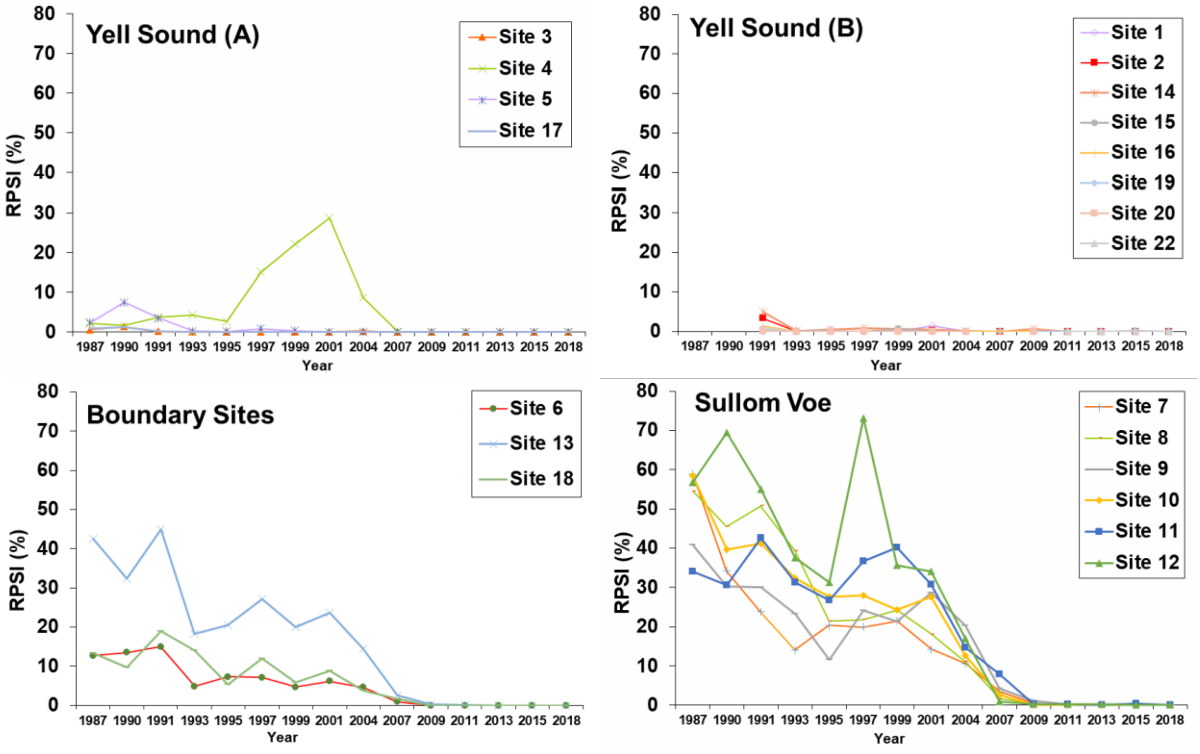


Figure 7 RPSI values for dogwhelk populations in the surveys from 1987-2018 shown by geographical groupings.

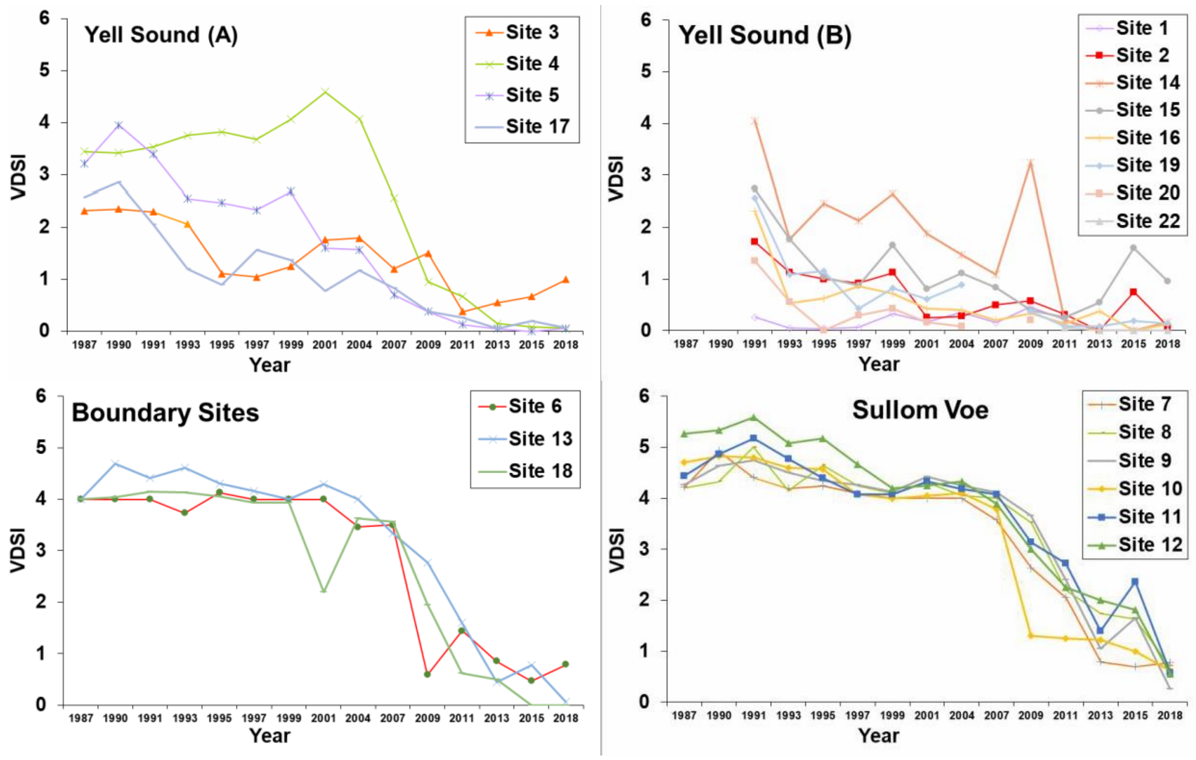


Figure 8 VDSI values for dogwhelk populations in the surveys from 1987-2018 shown by geographical groupings.

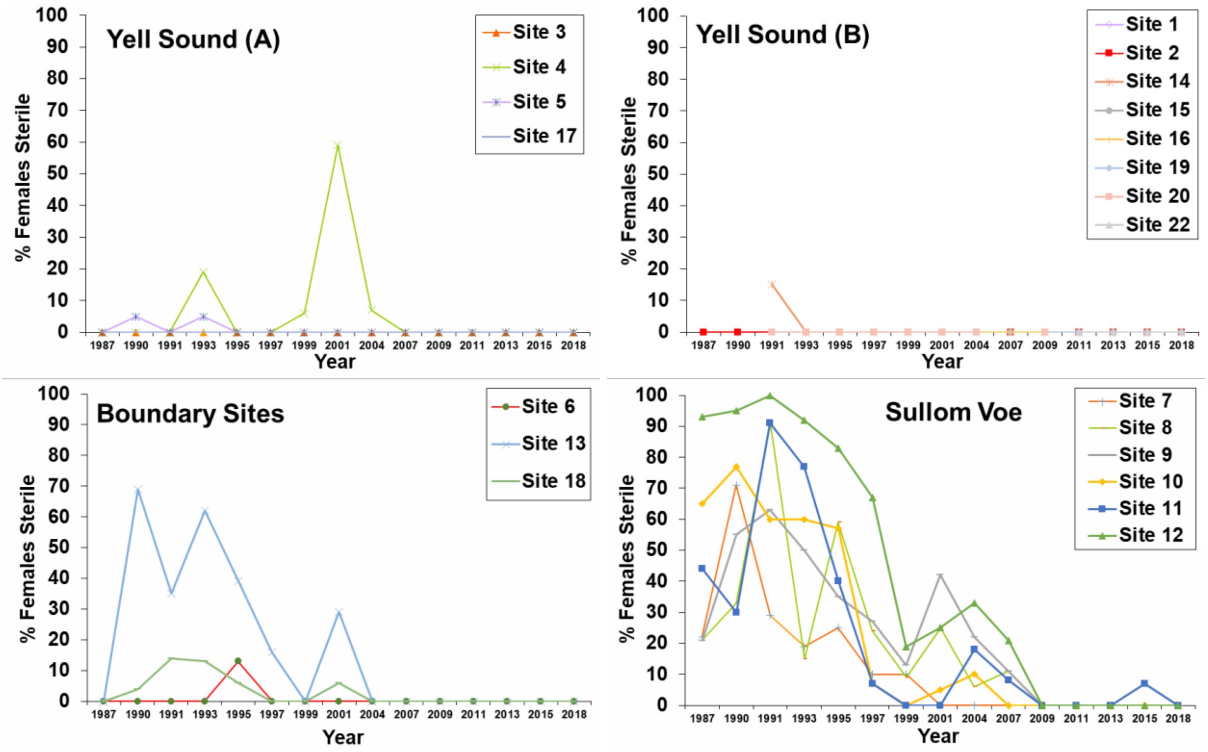


Figure 9 The percentage of sterile female dogwhelks (<u>Nucella lapillus</u>) sampled in the surveys from 1987-2018.

3.2 Population structure studies

The population data are strongly influenced by site specific characteristics, so direct comparisons between sites are mostly inappropriate. Some comparisons between larger areas, e.g. Sullom Voe and Yell Sound, can be ... gwhelks in the more ... 10).

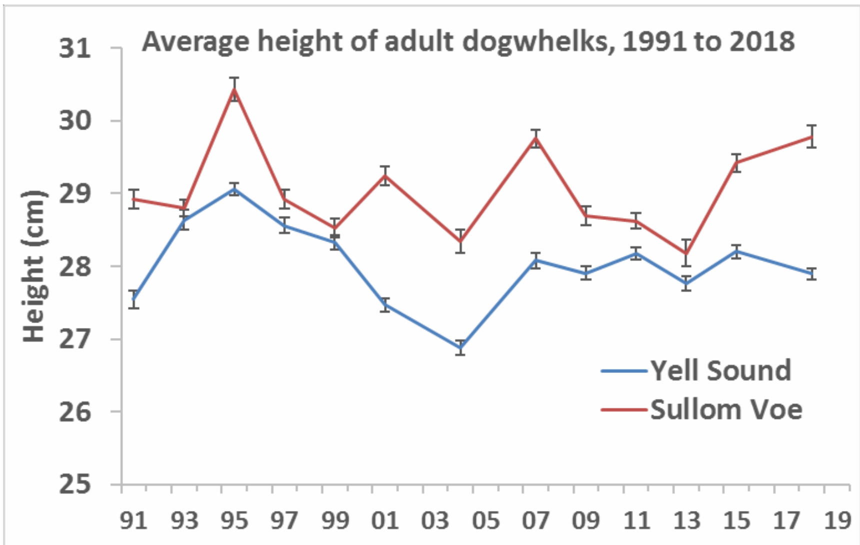


Figure 10 Average height of adult (toothed) dogwhelks, averaged across all sites in Sullom Voe and Yell Sound, ± standard error

Populations in Sullom Voe that were severely affected by the impact of tributyltin in the late 1980s and early 1990s were characterised by low juvenile abundances, large minimum shell heights, abnormal size-class

distributions and fluctuating size-class distributions. Size-class distributions at some sites showed adult sizes that were skewed towards the larger individuals, suggesting that recruitment of young

animals has been reduced and the population was dominated by old survivors. However, skewed distributions can also be due to site specific characteristics that favour particular size classes (e.g. sites with few crevices may have fewer juveniles), so interpretation needs to be cautious. Nevertheless, the characteristics described above were consistent with an impact on the reproductive capacity of the dogwhelk populations in Sullom Voe and appeared to correlate well with the levels of imposex in dogwhelks collected from those sites.

The monitoring programme has described improvements in some, but not all, of the population characteristics listed above compared to the 1991 baseline.

3.2.1 Descriptions and changes at individual sites

Results are presented in Appendix 2 in the form of histograms. Histograms from 2015 and 2018 are plotted side-by-side for easy comparison. Histograms for 1993 to 2013 are printed in previous reports. Table 7 summarises the population data from 2018 and compares it with data from 2015. Note that analysis of the juveniles has been confined to individuals with shell height <16mm. Figure 11a to Figure 11d plot the fluctuations in abundance of dogwhelks (all sizes) for selected sites. Figure 12a to Figure 12d plot the fluctuations in juvenile dogwhelk abundances.

Table 7 Comparison of summary data from July 2015 and August 2018. No./min (all dogwhelks) and Juvs/min (juveniles, <16mm) are the number of individuals collected per minute. Mean and Min are the mean and minimum shell heights of dogwhelks from the whole population. Median is the median shell height of the toothed adult population only.

	2015					2018				
Site	**No./min**	**Juvs/min**	**Mean**	**Median**	**Min**	**No./min**	**Juvs/min**	**Mean**	**Median**	**Min**
1	34.4	1.2	23.0	24	13	34.0	2.8	22.7	24	11
2	57.3	1.7	29.0	30	10	51.0	2.3	27.4	29	6
3	40.6	0.0	26.8	27	16	43.8	1.0	25.5	27	11
4	3.6	0.6	20.9	24	12	6.4	1.6	21.1	29	10
5	12.2	0.8	28.2	30	9	15.2	1.6	27.2	30	10
6	17.0	0.6	26.8	29	10	13.6	0.8	26.7	30	7
7	56.5	1.5	27.6	30	8	49.5	12.0	23.6	29	6
8	22.4	0.0	26.3	27	18	19.8	1.6	25.3	27	10
9	14.2	1.4	26.1	30	11	11.8	0.6	26.6	32	9
10	22.0	0.6	28.8	31	14	12.0	0.0	29.6	30	16
11	19.8	1.5	26.8	30	9	24.5	1.5	27.8	30	8
12	29.6	0.2	28.9	30	15	18.6	0.8	29.6	31	8
13	42.8	2.2	27.2	29	11	37.0	1.2	28.0	29	9
14	28.8	0.4	31.6	32	12	32.2	0.6	29.5	31	9
15	34.8	0.2	24.9	25	15	42.6	1.4	24.9	26	9
16	35.0	0.4	27.3	29	13	27.6	1.2	26.6	29	6
17	41.8	1.0	26.3	28	12	39.2	2.0	25.4	28	10
18	38.2	1.2	28.4	30	11	42.4	0.4	28.8	29	10
19	56.5	1.5	23.4	24	12	39.5	0.0	23.7	24	17
20	6.0	2.4	17.1	21	10	5.2	0.6	18.6	-	11

The lowest dogwhelk abundances (<10/minute, all ages) were recorded at Norther Geo (site 20) and Scarf Stane (site 4) (Table 7). Both of those sites are in Yell Sound where we expect very little influence of TBT from tanker traffic, but other site characteristics have caused the dogwhelk populations to decline (see Figure 11b).

The highest dogwhelk abundances (>40/minute, all ages) were recorded at Burgo Taing (site 2), Billia Skerry (site 3), Tivaka Taing (site 7), Orfasay (site 15) and Little Roe (site 18). Most of those sites are also within Yell Sound, but Tivaka Taing is on Gluss Isle, just within Sullom Voe. The characteristics

of that site appear to be particularly good for dogwhelks and the recorded abundance has been
>35/minute in every survey (see Figure 11a).

The lowest abundances of juveniles (<0.5/minute, <16mm) were recorded at Voxter Ness (site 10), Little Roe (site 18) and The Brough (site 19) (Table 7). Of those, the only site within Sullom Voe is Voxter Ness. Juvenile abundances have varied considerably over the course of the programme at all of those sites, but an apparent decline at Little Roe is notable (see Figure 12c).

The highest abundances of juveniles (>5/minute, <16mm) were recorded at Tivaka Taing (site 7), within Sullom Voe. As mentioned above, the characteristics of that site appear to be particularly good for dogwhelks, but the 12 juveniles / minute recorded in 2018 is still not as high as that recorded in 1991 (18/minute).

Samples collected in 2018 from most, but not all, of the population study sites contained a wide range of ages and sizes, from juveniles through to toothed adults. The size distribution histogram for most samples showed a well-defined peak of adult (toothed) dogwhelks, approximately bell shaped, an adult size range of 8-10mm and a tail of younger dogwhelks. Samples which diverged notably from those characteristics and those which have shown notable changes in structure and/or abundance in recent surveys include:

<u>Scarf Stane (4)</u>. This site was highlighted in previous reports because of an unexplained rise in the levels of imposex between 1997 and 2001; the only site in the region to show a statistically significant increase in VDSI and RPSI. The size class structure of juveniles and adults showed considerable variation over that period, but the relatively high numbers of juveniles did not indicate severe reproductive stress. Imposex levels have since declined and have been effectively at background levels since 2013. However, the dogwhelk population continued to fluctuate and abundance (Figure 11b) has been <10/minute since 2007. As explained in previous reports, this is likely due to a change in the overall community at the site, which has been characterised by a dense sward of *Fucus vesiculosus* and relatively low densities of barnacles (dogwhelk prey) since 2009. In 2018 only 32 dogwhelks (24 adults, 8 juveniles) were collected from the sampling area in the allocated 5 minute search time. It is unlikely that imposex is having any further impact at the site.

<u>East of Ollaberry (5)</u>. This site was characterised by a good sized population with at least moderate numbers of juveniles up to 2013. Imposex data show a decline in levels which fell to background levels by 2011. However, the population showed a downward trend in abundances (adults and juveniles)

between 2011 1nd 2015. Abundances were still low in .2018 (Figure 11). An explanation is not known.

Grunn Taing (6). This site shows a similar pattern to site 5 (above), with background levels of imposex since 2013 but a relatively recent decline in abundances (Figure 11c). Juvenile abundances, however, have shown a downward trend for many years and were still low in 2018 (Figure 12c). Like Scarf Stane (above), the decline is likely due to increased fucoid algae cover and reduced barnacle abundance (clearly shown in photos).

Mavis Grind (9). The population at Mavis Grind showed notable increases in juveniles and a rapid increase in adults, up to 2001 (Figure 11a). However, in 2004 and subsequent surveys the population progressively decreased and is now similar to the size it was in the early 1990s. This decline contrasts with the improvements in levels of imposex and the good availability of juveniles in the area of boulder shore 10 to 20m north of the population study area.

Voxter Ness (10). Dogwhelk abundances showed a notable increase at this site between 1991 and 1995, but then progressively declined to very low abundance in 2004 (Figure 11a). Subsequent recovery has been limited and abundances are still low, possibly due to increased fucoid cover and relatively small numbers of crevices for juveniles. Juvenile abundances have usually been fairly low.

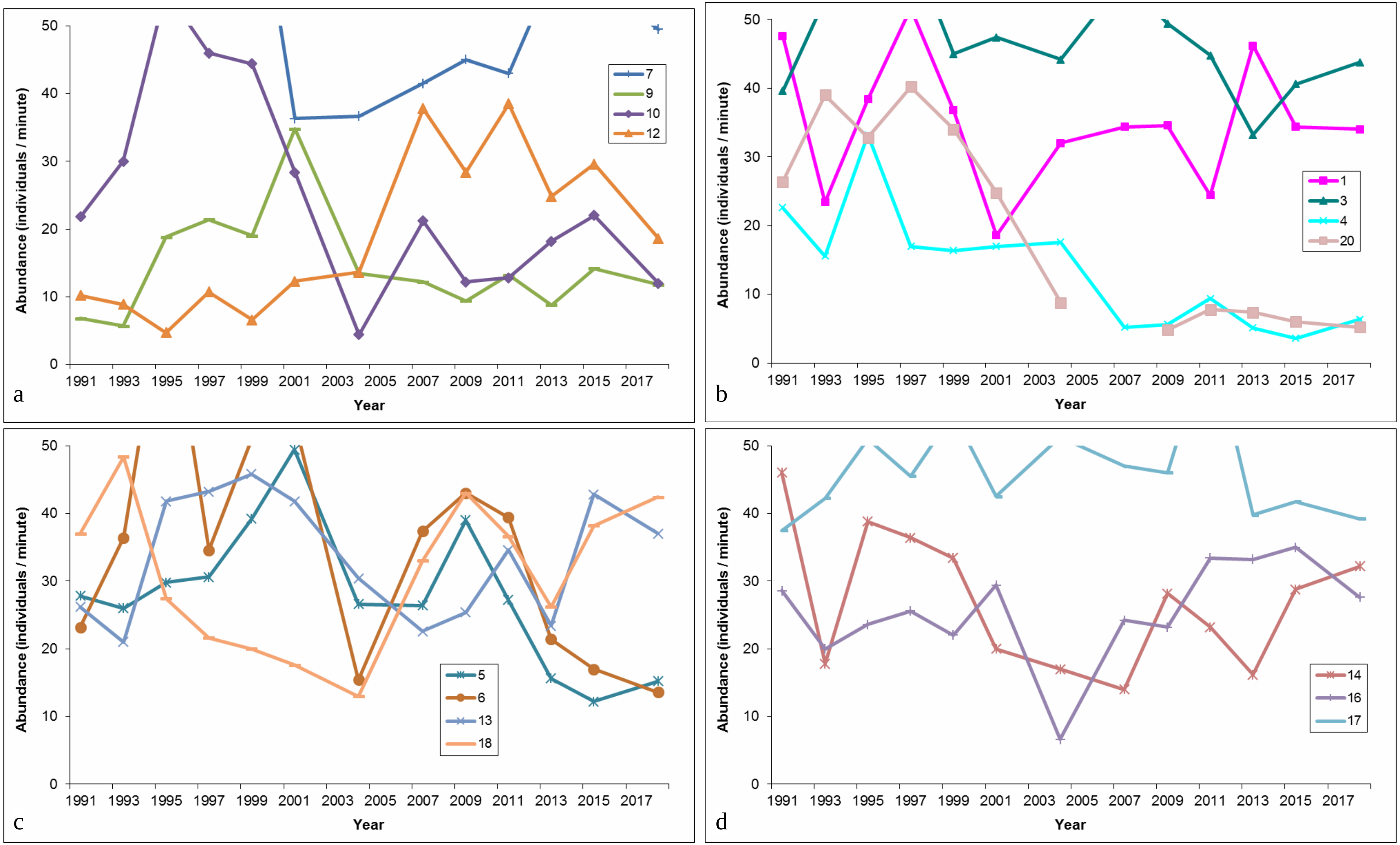


Figure 11 Temporal changes in abundance of dogwhelks (all sizes) at selected sites in regional groupings: a) Sullom Voe, b) North Yell Sound, c) Sullom Voe entrance, d) South east Yell Sound. Graphs cut-off at 50 / minute where pick-up rate in large populations is biased by the collectors speed.

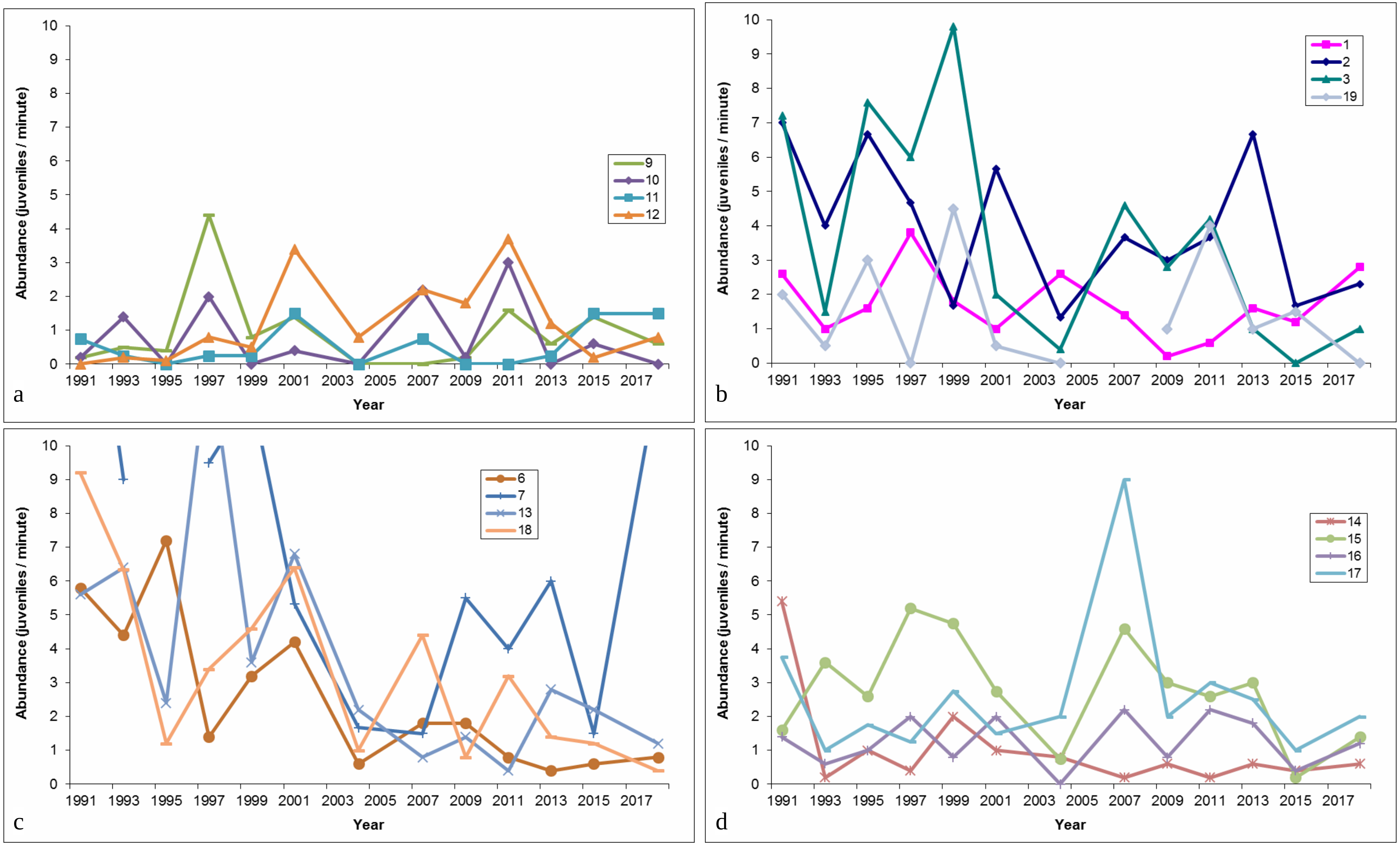


Figure 12 Temporal changes in abundance of juvenile dogwhelks at selected sites in regional groupings: a) Sullom Voe, b) North Yell Sound, c) Sullom Voe entrance, d) South east Yell Sound.

<u>Northward (11)</u>. The 2013 report highlighted the progressive reduction in numbers of adults since 2007 and suggested that the population may be failing. However, abundances have subsequently improved, though not yet to the levels recorded in 1991.

<u>The Kames (12)</u>. This site is of particular interest, because of its proximity to the terminal, because it was the site where high levels of imposex first became apparent and because juvenile production was apparently non-existent there in 1991. The population demonstrated the greatest progressive increase over the course of the monitoring programme up to 2007 (Figure 11), as levels of imposex gradually reduced. The population then appeared to stabilise until 2011 but then began a decline, particularly in abundance of juveniles. In 2018 the juvenile abundances within the population study area were back to the levels recorded in the early 1990s. Once again this is thought to be due to an increase in fucoid cover, which dominated much of the upward facing bedrock in the population study area in 2018. Imposex is certainly not implicated as there were no signs of sterility in any of the female dogwhelks collected at the site and juvenile dogwhelks were plentiful amongst the low shore boulders to the south of the population study area.

<u>Orfasay (15)</u>. Population abundances appeared to be on a downward trend since their peak in 2004, but they are still relatively high compared to many sites. Juvenile abundances in 2015 were the lowest ever recorded there, but there was some recovery in 2018 (Figure 12d). The unexpected rise in imposex levels in 2015, which was still present in 2018 (see Table 6 and Figure 8), could be the cause, but that would not explain the decline since 2004 it could just be another ecological effect.

<u>Little Roe (18)</u>. A progressive decline in juveniles, though with some considerable fluctuations (Figure 12c) has been shown at this site. Adult populations have also fluctuated, but without the overall trend of reduced numbers. Like many other sites, there as been a notable increase in fucoid algal cover over the course of the programme and these may have reduced the habitat suitable for juveniles.

<u>The Brough (19)</u>. The relatively low abundances of juveniles often collected from this site may be an artefact of the very high densities of adults, which also tend to fill the numerous crevices, making it difficult to get to the juveniles that tend to hide at the back. The fluctuations in juvenile abundances may therefore be due to differences in collection technique.

<u>Norther Geo (20)</u>. This site is very isolated at the back of a geo that is extremely exposed to wave action from the north. After some considerable

searching no other significant populations have been found within a distance of more than 1 kilometre. Since 2004, the population has been fairly small and in 2018 only 26 dogwhelks were found in the defined survey area (Figure 11b). Nevertheless, the population appears to remain viable, with numerous juveniles in a range of ages and sizes.

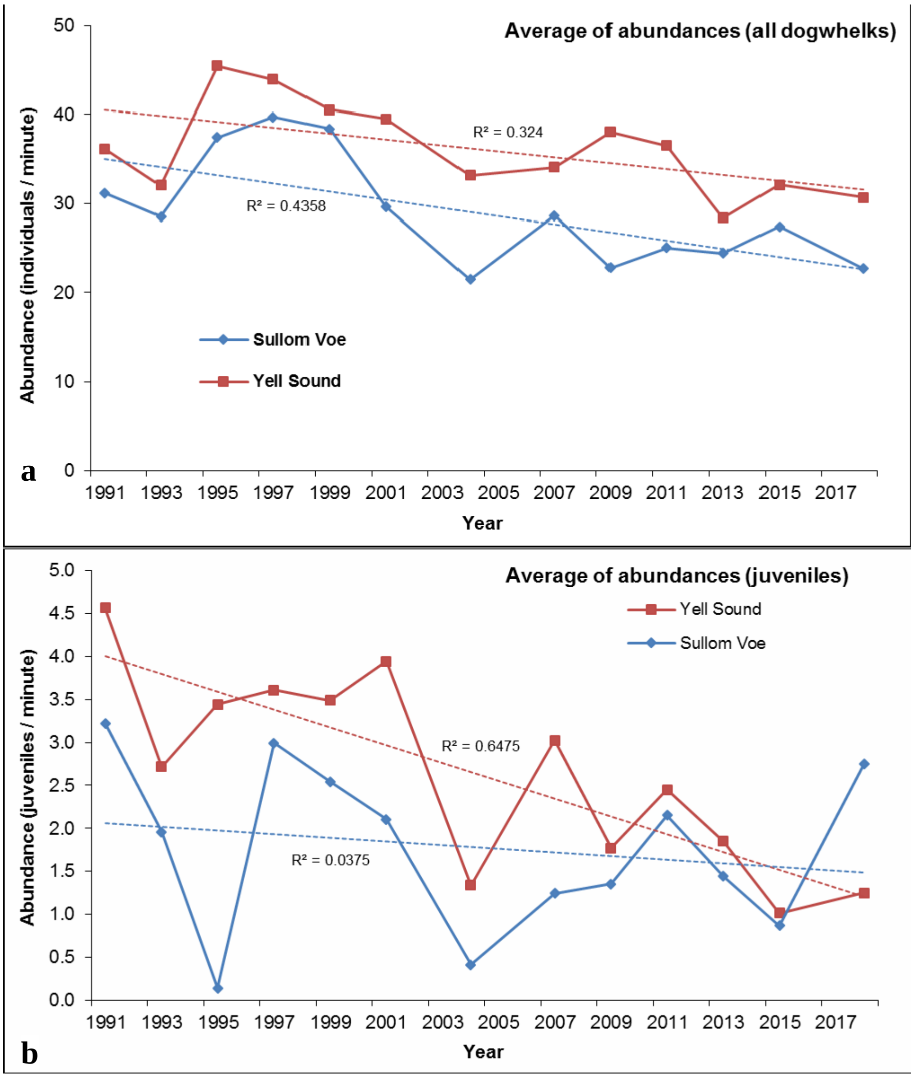
3.2.2 Descriptions and changes by region

Imposex data strongly suggests that dogwhelks within Sullom Voe were exposed to considerable reproductive stress which has gradually reduced. The population studies have described a slow recovery process at the worst affected sites, especially The Kames (site 12), from the very poor conditions at the time of the first survey in 1991. However, notable changes have occurred since 2007 and it is apparent from Section 3.2.1 that other ecological factors are also influencing the dogwhelk populations. In 2011 it was concluded that it may now be difficult to distinguish any further improvements in population structure that are due to the declining imposex at Voe sites.

The evidence from individual sites suggests a downward trend in populations at a number of sites over the last few years. Juvenile abundances in particular have declined at a number of sites. Calculations of average abundance in 2018 across all Sullom Voe sites (7 to 12) gives a value of 22.7 dogwhelks per minute and 30.7 per minute across all sites in Yell Sound. Those values are low compared to most of the previous surveys (see Figure 13a). The average abundance values for juveniles were 2.8 per minute

and 1.3 per minute, respectively. The latter is also low compared to most previous surveys and this was the first survey when there was a lower average value for juveniles abundance in Yell Sound compared to Sullom Voe (see Figure 13b) (Note, however, that this was at least partly due to the large numbers of juveniles at Tivaka Taing, site 7).

Figure 13a includes trendlines (linear regression) to show the apparent gradual decline in average dogwhelk abundances at Sullom Voe sites and Yell Sound sites. Both lines are statistically significant (P = 0.014 and 0.042 respectively). Figure 13b includes the equivalent trendlines for juvenile



dogwhelk abundances, which show an insignificant regression for Sullom Voe (P = 0.53), but a very statistically significant regression for Yell Sound (P = 0.0009).

Figure 13 Temporal changes in average abundance of a) dogwhelks (all sizes) and b) juvenile dogwhelks (<16mm) collected from all Sullom Voe sites (7 to 12) and all Yell Sound sites (1 to 6, 13 to 20). Trend lines are included. See text for details.

Further inspection of the data to look for any other regional patterns finds no clear patterns. Figure 14 plots, for each site, the differential in mean height between 2018 and the mean heights averaged over all the previous surveys.

Again, there were no apparent geographic trends related to distance from the terminal or any other environmental factor.

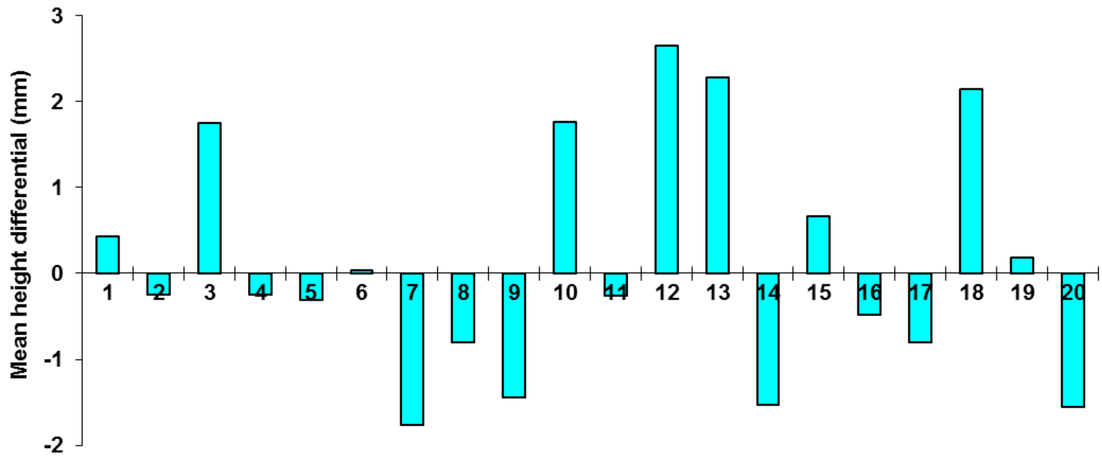


Figure 14 Mean height of dogwhelks in 2018 calculated as the differential to the average of mean heights (1991 to 2015), at the 20 monitoring sites

Another indicator of improved juvenile production, and hence of reproductive capacity of the dogwhelk populations, is the ratio of juvenile to adult numbers (Table 8). Comparisons of ratios between 2015 and 2018 data show mostly small increases, indicating a small improvement since the last survey, but the ratios are generally low.

Table 8 Comparison of juveniles (<16mm) / toothed adults ratio from population studies in 1995, 1997, 2004, 2007, 2009, 2011, 2013, 2015 and 2018..

Site	1991	1997	2004	2007	2009	2011	2013	2015	2018
1	0.07	0.23	0.19	0.06	0.01	0.04	0.07	0.05	0.12
2	0.34	0.16	0.03	0.11	0.11	0.10	0.24	0.04	0.06
3	0.46	0.27	0.02	0.18	0.07	0.17	0.07	0.00	0.04
4	1.44	0.7	0.59	0.30	6.50	10.50	0.58	0.50	2.00
5	0.07	0.11	0.13	0.17	0.16	0.11	0.11	0.09	0.18
6	0.73	0.06	0.06	0.10	0.05	0.03	0.05	0.05	0.11
7	0.46	0.35	0.07	0.09	0.18	0.21	0.63	0.04	0.51
8	0.02	0.04	0.00	0.08	0.04	0.05	0.05	0.00	0.23
9	0.04	0.85	0.00	0.00	0.08	0.42	0.21	0.20	0.75
10	0.02	0.19	0.00	0.55	0.05	0.83	0.00	0.04	0.00
11	0.04	0.03	0.00	0.03	0.00	0.00	0.09	0.26	0.19
12	0	1.43	0.20	0.10	0.11	0.17	0.12	0.01	0.06
13	0.4	0.69	0.11	0.08	0.09	0.02	0.27	0.07	0.04
14	0.18	0.02	0.09	0.02	0.03	0.01	0.06	0.02	0.03
15	0.06	0.37	0.01	0.11	0.09	0.10	0.08	0.01	0.04
16	0.07	0.18	0.00	0.28	0.07	0.16	0.10	0.02	0.09
17	0.21	0.06	0.07	0.44	0.11	0.08	0.12	0.04	0.08
18	0.52	0.29	0.16	0.41	0.03	0.15	0.13	0.05	0.01
19	0.06	0	0.00	-	0.02	0.10	0.05	0.05	0.00
20	0.33	0.25	0.17	-	0.43	3.67	1.40	4.00	na

4 Discussion and conclusions

4.1 Assessment of imposex data against OSPAR assessment criteria

Changes in VDSI from the 2018 survey resulted in improvements in OSPAR Classification for 4 sites across the surveyed area (Table 9). These included changes at 2 sites inside the Voe: site 9 (Mavis Grind) which recorded a drop in VDSI to below 0.3 for the first time and changing to a class A; and site 11 (Northward) which changed from class C to class B. One boundary site (site 13 Skaw Taing) also decreased from class B to A as did one of the Yell Sound sites (site 2 Burgo Taing). The overall assessment status has changed little since 2013 however for the first time since implementation of this survey, all sites are classed as below the EAC (i.e. OSPAR class A or B) (Figure 15).

Table 9 Temporal changes in OSPAR imposex classes at sites in Sullom Voe and Yell Sound. See Table 7 for key to OSPAR classes (A: VDSI<0.3; E: VDSI>5.0). Dist = distance by sea from Sullom Voe terminal (km).

Site	Dist	1987	1990	1991	1993	1995	1997	1999	2001	2004	2007	2009	2011	2013	2015	2018
1	19.0	-	-	A	A	A	A	B	A	B	A	B	A	A	A	A
2	13.6	-	-	B	B	B	B	B	A	A	B	B	B	A	B	A
3	10.4	C	C	C	C	B	B	B	B	B	B	B	B	B	B	B
4	9.5	C	C	C	C	C	C	D	D	D	C	B	B	A	A	A
5	5.7	C	C	C	C	C	C	C	B	B	B	B	A	A	A	A
6	3.5	D	D	D	C	D	D	D	D	C	C	B	B	B	B	B
7	2.3	D	D	D	D	D	D	D	D	D	C	C	C	B	B	B
8	1.3	D	D	D	D	D	D	D	D	D	D	C	C	B	B	B
9	8.5	D	D	D	D	D	D	D	D	D	D	C	C	B	B	A
10	6.3	D	D	D	D	D	D	D	D	D	C	B	B	B	B	B
11	3.3	D	D	E	D	D	D	D	D	D	D	C	C	B	C	B
12	0.6	E	E	E	E	E	D	D	D	D	C	C	C	C	B	B
13	3.5	D	D	D	D	D	D	D	D	D	C	C	B	B	B	A
14	10.5	-	-	D	B	C	C	C	B	B	B	C	A	A	A	A
15	14.2	-	-	C	B	B	B	B	B	B	B	B	A	B	B	B
16	11.0	-	-	C	B	B	B	B	B	B	A	B	A	B	A	A
17	8.9	C	C	C	B	B	B	B	B	B	B	B	A	A	A	A
18	4.5	D	D	D	D	D	C	C	C	C	C	B	B	B	A	A
19	14.5	-	-	C	B	B	B	B	B	B	-	B	A	A	A	A
20	20.6	-	-	B	B	A	A	B	A	A	-	A	-	-	-	-
22	16.5	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A

4.2 Reproductive capacity of Sullom Voe and Yell Sound dogwhelks

The degree of imposex in toothed adults from sites within Sullom Voe in 2018 show that these sites are no longer significantly more impacted by TBT than populations at sites in Yell Sound. The imposex indicators (RPSI and VDSI) in the smaller size classes at sites both within Sullom Voe and the surrounding Yell Sound where these size classes were sampled suggests a continued low exposure of juvenile dogwhelks to TBT across the surveyed area. Given that no new inputs of TBT should be occurring in the area following the International Maritime Organisation (IMO) ban on use of TBT on large vessels in 2008, this continued exposure is likely to arise from

historical contamination in sediments. Concentrations of TBT in sediments throughout Sullom Voe were measured in 2010 (Gubbins *et al.* 2012) and found to be high particularly close to the jetties and in the upper Voe (close to site 9 Mavis Grind). In relation to the latter, however, VDSIs from all size class populations sampled from Mavis Grind in 2018 were below the BAC and close to zero indicating that exposure to TBT was low.

Figure 15 Assessment of VDSI data from adult dogwhelks (Nucella lapillus) sampled from sites around Sullom Voe and Yell Sound in 2018. Data are presented in accordance with OSPAR assessment classes (See Table 2).

In 2009, for the first time since the survey began, there was no evidence of sterility in any of the populations. This continued in 2011 and 2013, but in 2015 a single female from Northward (site 11) was found to be sterile. There was no evidence of sterility in any of the populations sampled in 2018, which included site 11. The VDSI measurements at the sites within the Voe showed that these populations can continue to reproduce. The population data and other observations also shows that juveniles are being produced at all sites within the Voe, but it is now difficult to detect continued improvements in the populations against the large fluctuations that are likely due to other ecological processes.

As in previous surveys, the degree of imposex in populations in Yell Sound still tends to decrease with distance from Sullom Voe, but the differences were not significant. Sites in Yell Sound, furthest from the terminal, show degrees of imposex which continue to reflect those of sites distant from sources of TBT (close to background/zero). For the first time since implementation of this survey, the VDSI values from all sites were below the EAC or close to zero indicating exposure to TBT in the sediment was minimal.

Data from the rocky shore transect monitoring programme (Moore and Mercer 2018) has also continued to show a gradual return of dogwhelk populations to the shores near the terminal. Dogwhelks disappeared from the transect at The Kames in 1991 and then reappeared in 2006. In 2018 they were almost back to the levels typically present before the TBT contamination. Increasing numbers of juvenile dogwhelks have been found under lower shore boulders between Jetties 3 and 4 in recent years and some adults have been recorded on the transect monitoring sites. It is likely that juveniles have been gradually moving south along the lower shore from the populations north of the terminal.

However, temporal analysis of adult and juvenile abundances shows a statistically significant decline at a number of sites in both Sullom Voe and Yell Sound over the course of the monitoring programme, which is obviously the opposite effect expected from improved reproductive capacity. The decline was first reported in 2015 and the cause is still not clear, but observations in 2018 suggest that an increasing dominance of fucoid algae at many sites is a major factor. Ecological factors, like this, complicate the story shown by the imposex data.

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Appendix 1 Field log of rocky shore monitoring surveys in Sullom Voe 7th to 20th August 2018

Survey Team: Jon Moore (JM), ASML, Cosheston, Pembrokeshire Tom Mercer (FB), ASML, Frosterley, Weardale Cait Moore (CM), work experience, Cosheston, Pembrokeshire Kirsten Laurenson (KL), student, St. Andrews University (& Shetland resident)

(Low tide times and heights are for Sullom Voe - Vidlin is approximately 30 minutes later, Burra Voe is approximately 30 minutes earlier. Times are all given as BST).

6 Aug (Mon)

pm JM & CM drive to LHR airport. Flight to Aberdeen airport. Check into Leonardo Hotel.

7 Aug (Tues)

Weather: Showery early on with fresh westerly wind – settled to a calm clear evening.

Low tide:

Date	Time	Ht (m)	Sun	Sunrise	Sunset
Tue 07 Aug	12:40	0.67	Light	05:03	21:07

0530 TM drives to Durham Tees Valley Airport for flight to Aberdeen at 0720

0915 JM, CM, TM meet up at Rotary Terminal - Aberdeen airport.

1030 Flight to Scatsta. Pick up car and lunch at Brae Co-op and go to Brungasta House (self catering house) in Voe to drop off bags.

1400 Drive to Mavis Grind to discuss methods and protocols. Late lunch on shore.

1600 Shop for groceries and return to Brungasta.

1900 Eat in. Relax and prep for the fieldwork.

8 Aug (Wed)

Weather: Dry, mild sun and cloud, with fresh SW wind 3-4

Low tide:

Date	Time	Ht (m)	Sun	Sunrise	Sunset
Wed 08 Aug	13:50	0.57	Light	05:06	21:04

0900 TM and JM drive to SV Terminal for safety induction. CM waits at Pollution Base.

1030 Meet Gillian Connal and return to Pollution Base – discuss survey logistics and pick up PPE. Survey planning.

1230 Drop CM off at Brungasta (not feeling well) and return to Sella Ness.

1300 Change into immersion suits at the Pollution Base and take the Pollution Base RIB Fugla out to survey dogwhelk sites.

1320-1350 Dogwhelk population survey and collection at Tivaka Taing (SVD7)

1415-1430 Dogwhelk population survey and collection at Grunn Taing (SVD6)

1455-1530 Dogwhelk population survey and collection at Skaw Taing (SVD13)

1550-1630 Dogwhelk population survey and collection at Noust of Burraland (SVD8)

1700 Return to Pollution Base – change and return to Brungasta. Store dogwhelks on the shore in front of Brungasta.

1900 Dinner at Frankies fish & chip restaurant. Mussels with blue cheese and bacon …. say no more.

eve Return to Brungasta.

9 Aug (Thu)

Weather: Dry, sunny and fresh SW wind 3-5

Low tide:

Date	Time	Ht (m)	Sun	Sunrise	Sunset
Thu 09 Aug	14:40	0.45	Light		21:02

am	Data entry and diary. JM drives to Lerwick to buy cool boxes
1100	Team drive to Pollution Base at Sella Ness and meet up with KL
1130	Team take Fugla out to survey dogwhelks at sites down the west side Yell Sound.
1240-1330	Dogwhelk population survey and collection at Easterwick (SVD1)
1350	Dogwhelk collection only at Burgo Taing (SVD2)
1430-1520	Dogwhelk population survey and collection at Billia Skerry (SVD3)
1530	Dogwhelk collection only at Scarf Stane (SVD4)
1610-1635	Dogwhelk population survey and collection at East of Ollaberry (SVD5)
1645	Dogwhelk collection only at Little Roe (SVD18)
1700	Return to Sella Ness Pollution Base and then back to Brungasta. Dogwhelks stored on the beach in front of the Holiday cottage.
1900	Dinner at Busta House.
eve	Return to Brungasta. Data entry.

10 Aug (Fri)

Weather: Dry and sunny, but cool N wind 3-5

Low tide:

Date	Time	Ht (m)	Sun	Sunrise	Sunset
Fri 10 Aug	15:30	0.33	Light		21:00

0500	JM moves dogwhelks up the shore – to drain!
0700	TM & JM rise and have breakfast.
0730	JM takes dogwhelk samples to Sella Ness for packaging and onward flight to Aberdeen from Scatsta. Dogwhelks to be collected at Aberdeen by Marine Scotland for imposex analysis by Melanie Roberts.
am	Rest, data entry, photo catalogue and diary.
1200	Leave Brungasta for fieldwork.
1230	TM, JM & CM mobilise at Sella Ness and depart in Fugla for the east coast of Yell.
1345-1500	Survey West Sandwick transect (ST4.7).
1515-1540	Dogwhelk population survey only at Uynarey (SVD17)
1600-1700	Survey Croo Taing transect (ST6.3)
1715-1745	Dogwhelk population survey only at Little Roe (SVD18)
1800	Returned to Sella Ness, then return to Brungasta, via Co-op
eve	Fry-up dinner of sausages, eggs, mushrooms and tomatoes etc. TM writes diary.

11 Aug (Sat)

Weather: Showery at first sunny and cloudy later NW 2-3

Low tide:

Date	Time	Ht (m)	Sun	Sunrise	Sunset
Sat 11 Aug	16:20	0.24	Light		20:57

am	Rest, data entry, photo catalogue and diary.
1315	Met KL at Sella Ness. Take Fugla to Colla Firth.
1400-1420	Dogwhelk population survey only at Scarf Stane (SVD4)
1430-1530	Survey Ola's Ness transect (ST3.10)
1550-1700	Survey Grunn Taing transect (ST4.1)

1715-1755 Survey Gluss Isle East transect (ST3.4)

1800 Return to Sella Ness. Return to Brungasta, via Brae Co-op.

eve Dinner at Brungasta – takeaway from Frankies.

12 Aug (Sun)

Weather: Bright and still early on, with easterly breeze developing later 2-4 , but sunny and dry all day.

Low tide:

Date	Time	Ht (m)	Sun	Sunrise	Sunset
Sun 12 Aug	05:00	0.04	Rising	05:13	
	17:10	0.19	Light		20:55

0430 Up for tea and cereal. Drive to Mavis Grind. Meet KL there.

0515-0655 Survey Mavis Grind transect (ST5.5) and dogwhelk population only (SVD9)

0715 Return to Brungasta.

am/pm Rest, data entry, photo catalogue and diary.

1400 Drive to Sella Ness. Take Fugla to West of Mioness.

1500-1600 Survey West of Mioness transect (ST1.1)

1610-1700 Survey South of Swarta Taing transect (ST3.5)

1715-1805 Survey Roe Clett transect (ST2.3) and take fixed point lichen photos in the upper shore

1810-1850 Dogwhelk population survey only at The Kames (SVD12).

1900 Return to Sella Ness. Return to Brungasta

eve Eat in - chicken salad.

13 Aug (Mon)

Weather: Bright and still early on, with easterly breeze developing later force 2-4 , cloudy and dry all the rest of the day.

Low tide:

Date	Time	Ht (m)	Sun	Sunrise	Sunset
Mon 13 Aug	05:40	0.02	Light	05:15	
	17:50	0.19	Light		20:53

0450 Drive to Lunna and walk to Riven Noust

1530-0700 Survey Riven Noust transect (ST2.9)

0700 Return to the car and back to Brungasta.

am/pm Rest, data entry, photo catalogue and diary.

1400 Team drive to Sella Ness and meet up with KL. Take Fugla to Skaw Taing

1515-1620 Survey South of Skaw Taing transect (ST5.1)

1700-1745 Survey Noust of Burraland transect (ST3.3)

1800-1835 Survey Fugla Ayre transect (ST6.1)

1845-1915 Dogwhelk population survey only at Northward (SVD11)

1915 Return to Sella Ness, then return to Brungasta

eve Dinner at Brungasta - fish pie. Diary and data entry.

14 Aug (Tues)

Weather: Overcast with light southerly breeze, force 2-3 .

Low tide:

Date	Time	Ht (m)	Sun	Sunrise	Sunset
Tue 14 Aug	06:30	0.07	Light	05:18	20:51
	18:30	0.25	Light	05:19	20:50

0445 JM travels to Sella Ness to collect Michael Barnes

0515 Pick up TM and drive to West Lunna Pund south and north

0600-0710	Survey West Lunna Pund south transect (ST5.8). Struggle to find lower station as large rocks appear to have moved!! Re-establish a fifth station E with tape distances, photos and bearings.
0715-0800	Survey West Lunna Pund north transect (ST6.15)
0800	Return to Brungasta. TM takes Michael back to Sella Ness lodgings.
am/pm	Rest, data entry, photo catalogue and diary.
1500	Travel to Sella Ness, refuel car on the way in Brae. Meet Michael Barnes at Sella Ness.
1600-1630	Take Fugla to Orka Voe – brief survey of Orka Voe bund, Magnus pipeline crossing and TOTAL pipeline crossing.
1640-1725	Survey The Kames transect (ST4.3)
1740-1830	Survey the Voxter Ness transect (ST4.6)
1830-1900	Dogwhelk population survey only at Voxter Ness (SVD10).
1940	Return to Sella Ness.
eve	Dinner at Busta House. Return to Brungasta.

15 Aug (Wed)
Weather: Damp and overcast, some drizzle. Light south westerly breeze 3-4.
Low tide:

Date	Time	Ht (m)	Sun	Sunrise	Sunset
Wed 15 Aug	07:10	0.18	Light	05:20	20:49
	19:20	0.36	Light	05:21	20:48

0550	Drive to Vidlin.
0630-0715	Survey Vidlin Ness transect (ST3.8)
0715	Move to Kirkabister
0745-0830	Survey Kirkabister transect (ST6.11)
0830	Return to Brungasta.
am/pm	Rest, data entry, photo catalogue and diary.
1600	Drive to Sella Ness. Meet KL and Michael Barnes. Take Fugla to Scatsta Ness.
1700-1800	Survey Scatsta Ness (uncleared) transect (ST6.13)
1700-1900	Survey Scatsta Ness (cleared) transect (ST6.12)
1900	Return to Sella Ness, then Brungasta, via the Co-op.
eve	Thai takeaway from the Pier Head at Voe

16 Aug (Thurs)
Weather : Bright and sunny, southerly 3-4, 16^{o} C
Low tide:

Date	Time	Ht (m)	Sun	Sunrise	Sunset
Thu 16 Aug	07:50	0.34	Light	05:22	20:47
	20:10	0.51	Light	05:23	20:46

0515	Drive to SVT to meet Gillian Connal. Receive jetty briefing and RA and travel out to Jetty with Gillian overseeing.
0630-0730	Survey Jetty 2 transect (ST6.2)
0730-0820	Survey Jetty 3 transect (ST5.2)
0900	Return to Brungasta via the Co-op and cook 'fry-up' for breakfast.
am/pm	Rest, data entry and write diary.
1600	KL arrives at Brungasta and the team drive to North Roe.
1710-1825	Survey Burgo Taing transect (ST3.12) (top 3 stations), then dogwhelk population only (SVD2).
1830-1900	Survey North Burra Voe transect (ST6.14)
1900-1945	Return to Burgo Taing transect (ST3.12) to complete bottom 2 stations.
2000	Team leave North Roe.

2100 Pick up Chinese takeaway and eat at Brungasta.

17 Aug (Fri)
Weather: Overcast and showery and breezy. South westerly 4-5.
Low tide:

Date	Time	Ht (m)	Sun	Sunrise	Sunset
Fri 17 Aug	08:40	0.51	Light	05:24	
	21:00	0.66	Setting		20:43

0600 Drive to Sella Ness. Change at the base and take Fugla up the east side of Yell Sound to survey dogwhelk sites.

0650 Dogwhelk collection at Sweinna Stack (SVD22)

0720-0735 Dogwhelk population survey only at Norther Geo (SVD20)

0800-0845 Dogwhelk population survey and collection at The Brough (SVD19)

0900 Dogwhelk collection only at Unarey (SVD17)

0920-1015 Dogwhelk population survey and collection at Orfasay (SVD15)

1040-1115 Dogwhelk population survey and collection at The Helliack (Samphrey) (SVD16)

1145 Return to Sella Ness. Speak to Sullom Voe VTS to discuss speed limits around the jetty and in the inner harbour. return to Brungasta.

pm Entered data, QA and photo sorting.

1830 Drive to Mossbank.

1915-1945 Dogwhelk population survey and collection at Grunna Taing (SVD14)

eve Dinner at Moorfield Hotel. Return to Brungasta.

18 Aug (Sat)
Weather: Force 8 gale most of the day.
Low tide:

Date	Time	Ht (m)	Sun	Sunrise	Sunset
Sat 18 Aug	09:30	0.67	Light	05:26	20:42

am/pm Data entry and validation, admin and sleep.

eve Pizza dinner at Brungasta.

19 Aug (Sun)
Weather: Still sunny and very special. Later 3-4 westerly but clear until 1800. Then clouded up from the west.
Low tide:

Date	Time	Ht (m)	Sun	Sunrise	Sunset
Sun 19 Aug	10:40	0.80	Light	05:29	20:40

0810 Drive to Sella Ness. Meet KL and take Fugla to Sullom Voe sites

0900 Dogwhelk collection only at Northward (SVD11)

0930 Dogwhelk collection only at Voxter Ness (SVD10)

1000-1100 Dogwhelk collection only at Mavis Grind (SVD09)

1100-1200 Dogwhelk collection only at The Kames (SVD12). Photograph dogwhelks and Tysties.

1300 Return to Sella Ness. Return to Brungasta.

pm Data entry and validation. Go to Eshaness to get some fresh air.

eve Eat at Frankies. Return to Brungasta to pack.

20 Aug (Mon)
Weather: Still sunny and very special. Later 3-4 westerly but clear until 1800. Then clouded up from the west.

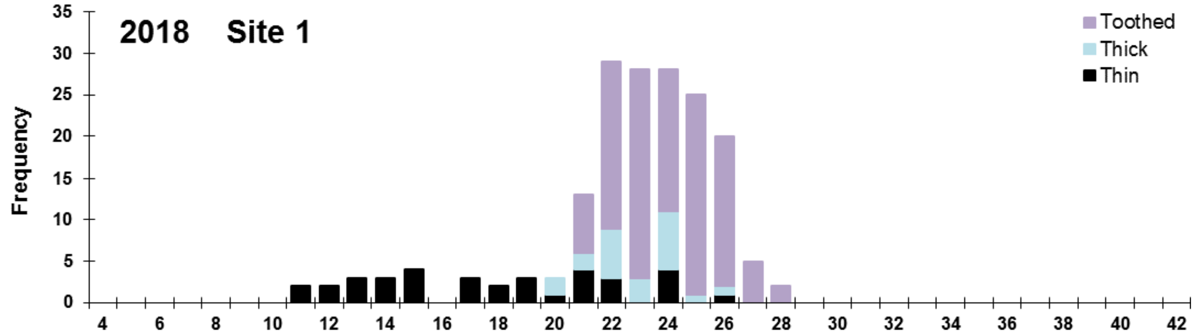
0800 JJM travels to Sella Ness with dogwhelk samples. Packs them up and passes them to Gillian for delivery to Stores and onward flight to Aberdeen.

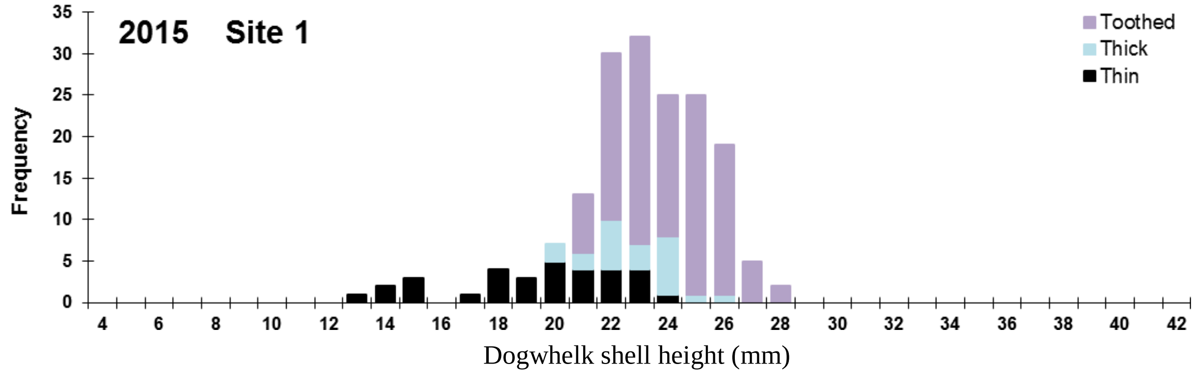
0930 JM returns to Brungasta.

1000 Pack car and drive to Scatsta.
1150 Flight to Aberdeen
1550 JM and CM onward flight to LHR and then taxi to car and on to Pembrokeshire.
1650 Delayed flight to Durham Tees Valley and onward lift to home in Weardale.

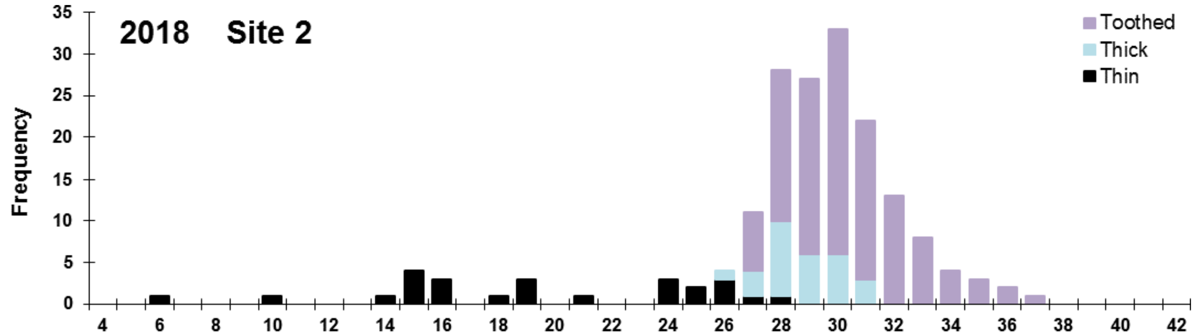
Appendix 2 Size class histograms from 2015 and 2018

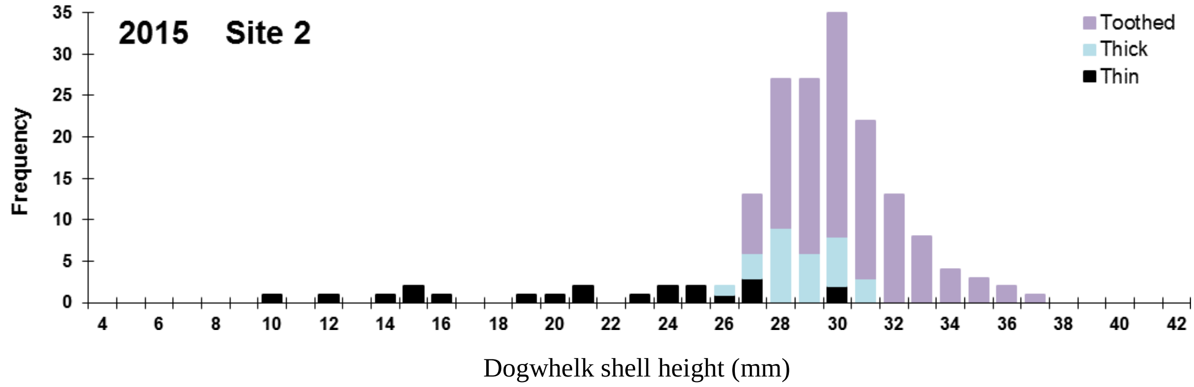
1 Easterwick



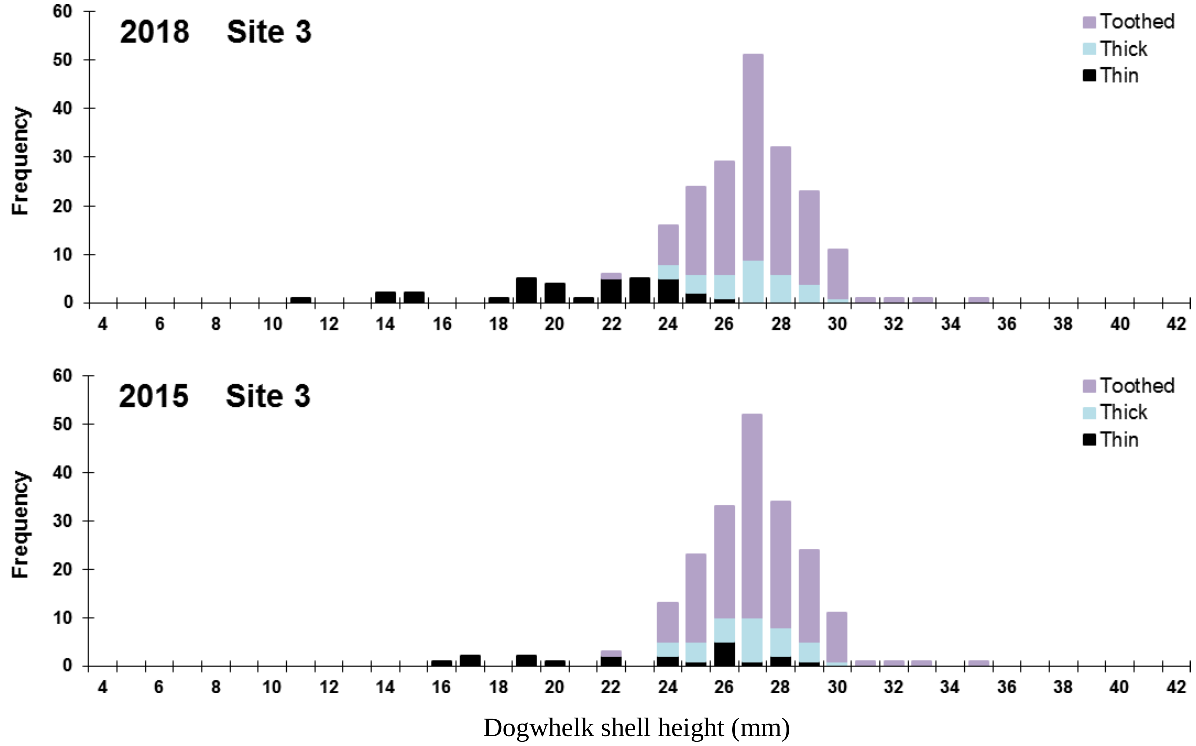


2 Burgo Taing

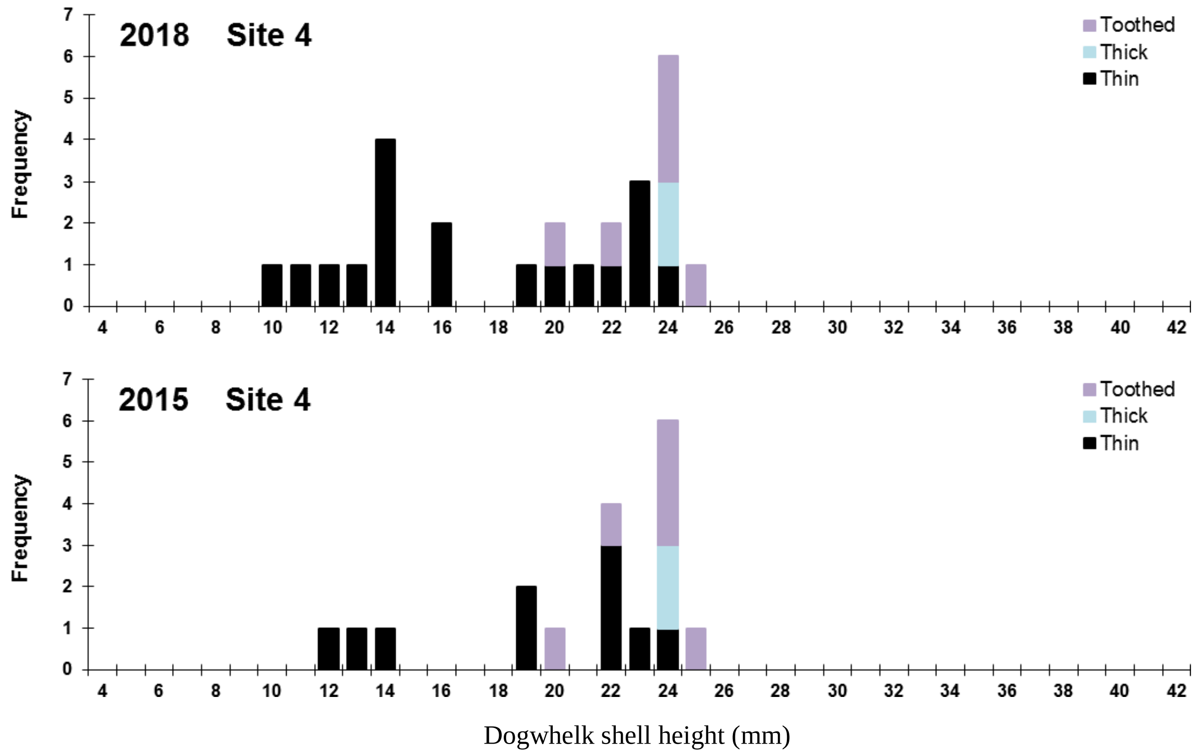




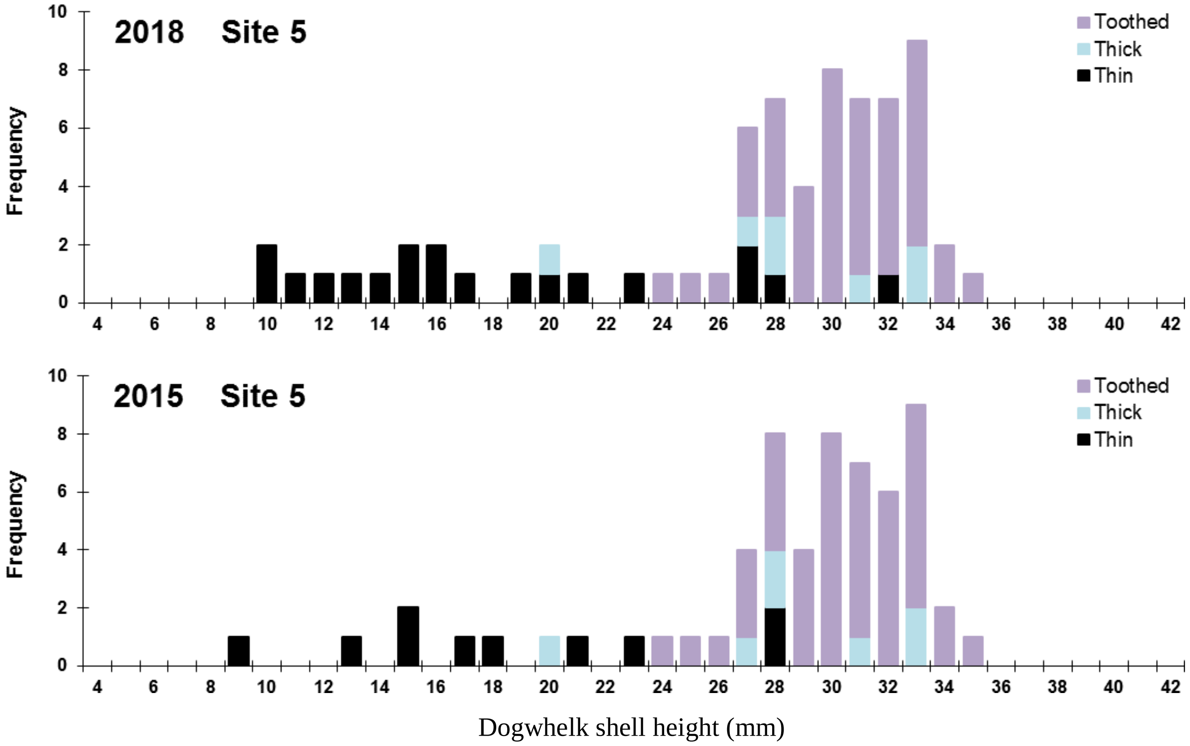
3 Billia Skerry



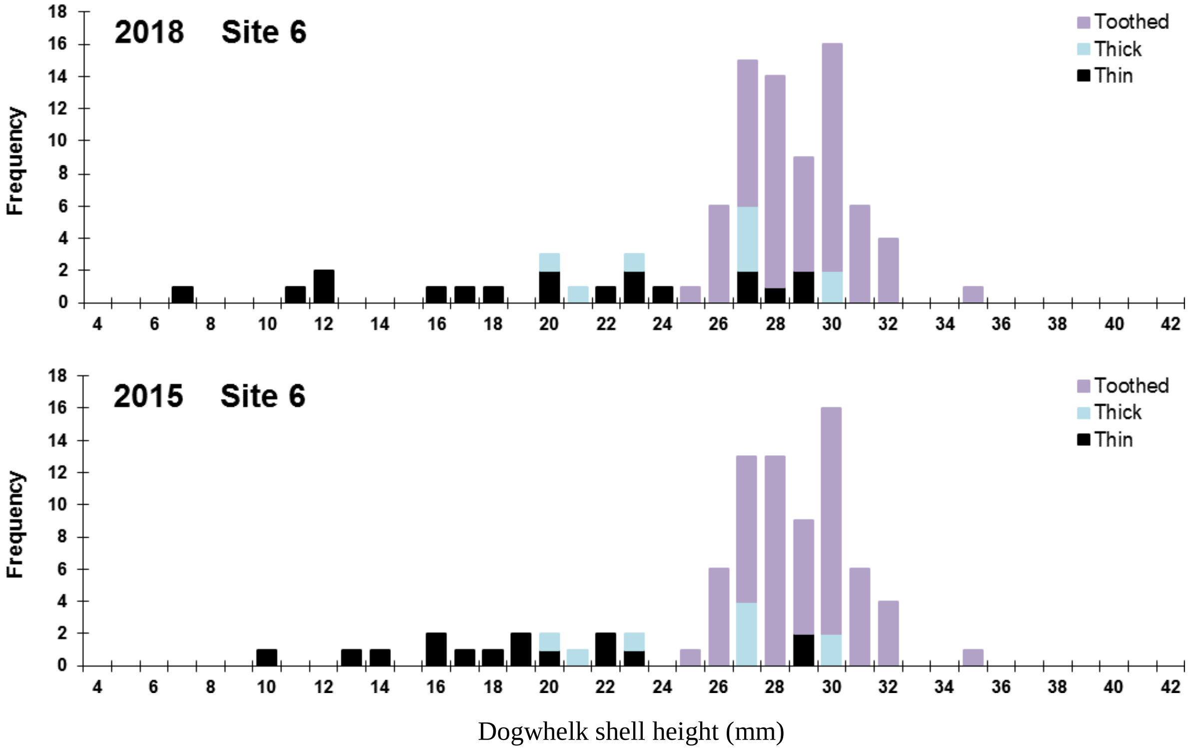
4 Scarf Stane



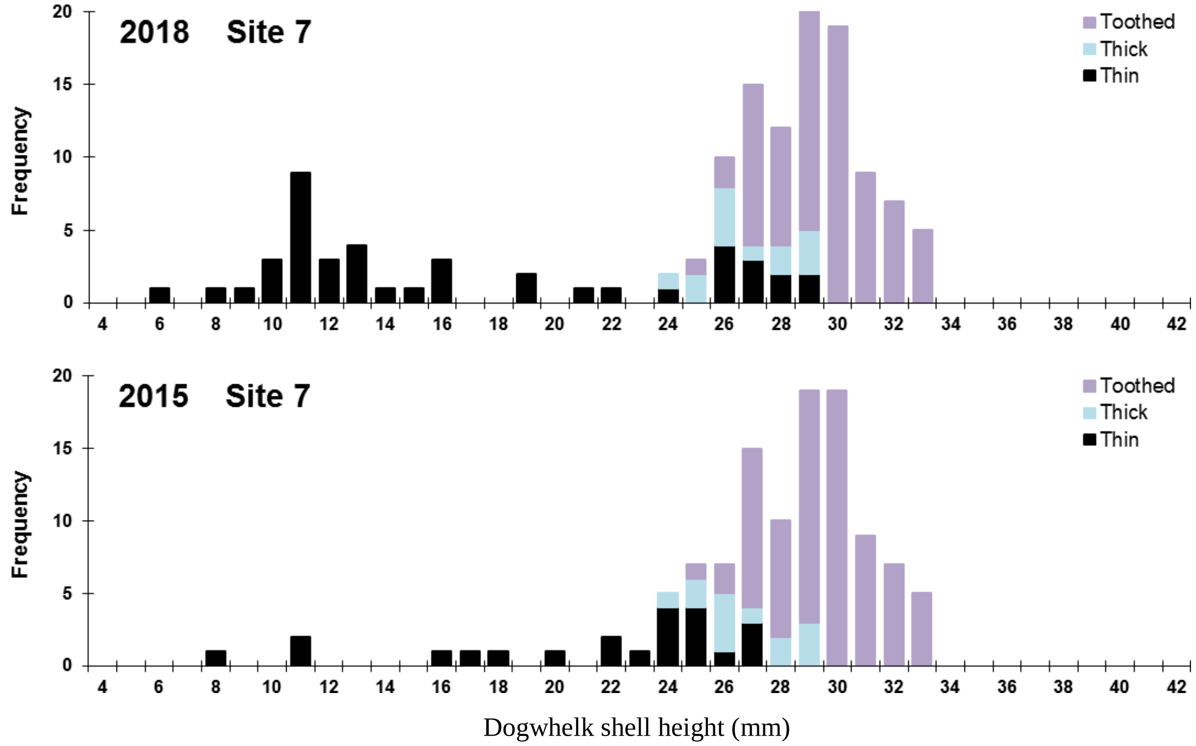
5 East of Ollaberry



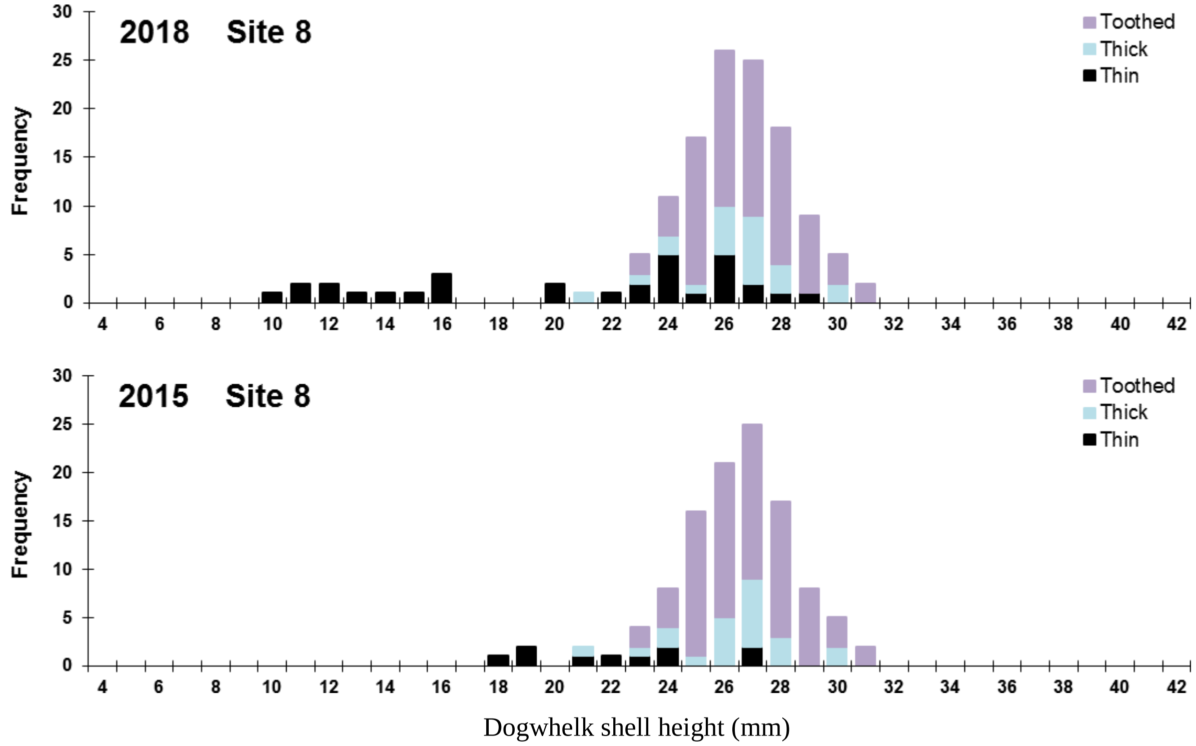
6 Grunn Taing



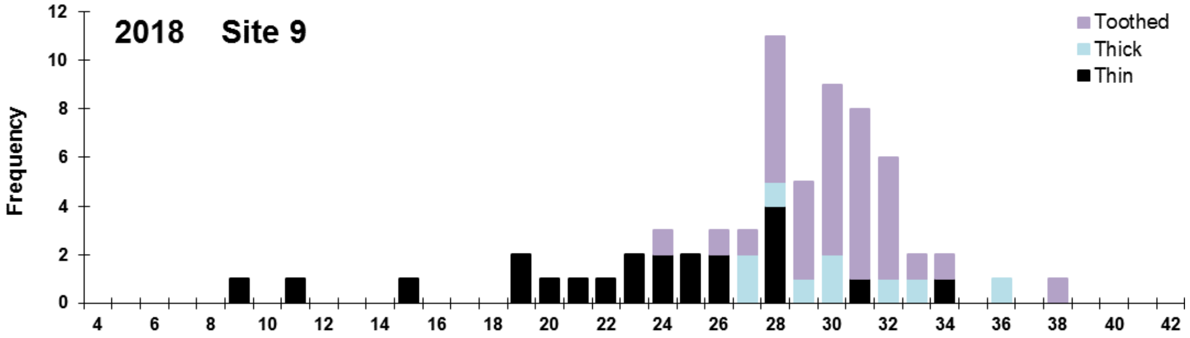
7 Tivaka Taing

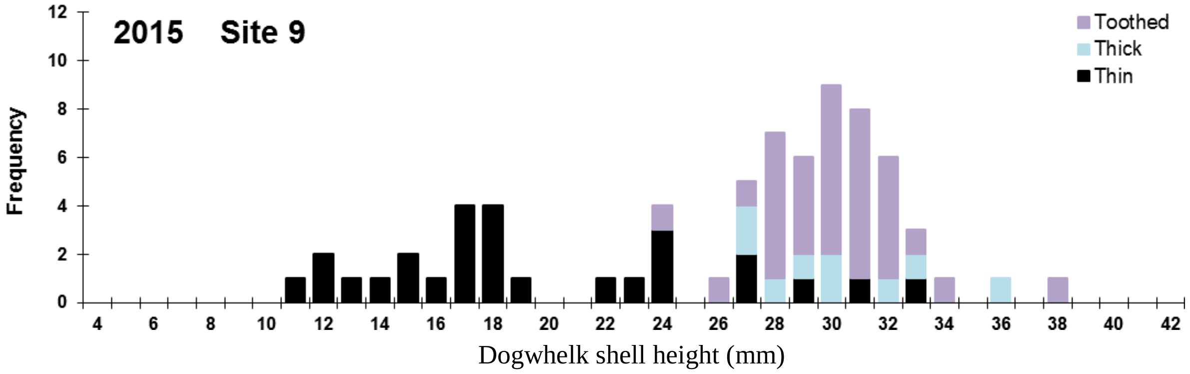


8 Noust of Burraland (Blanches Geo)

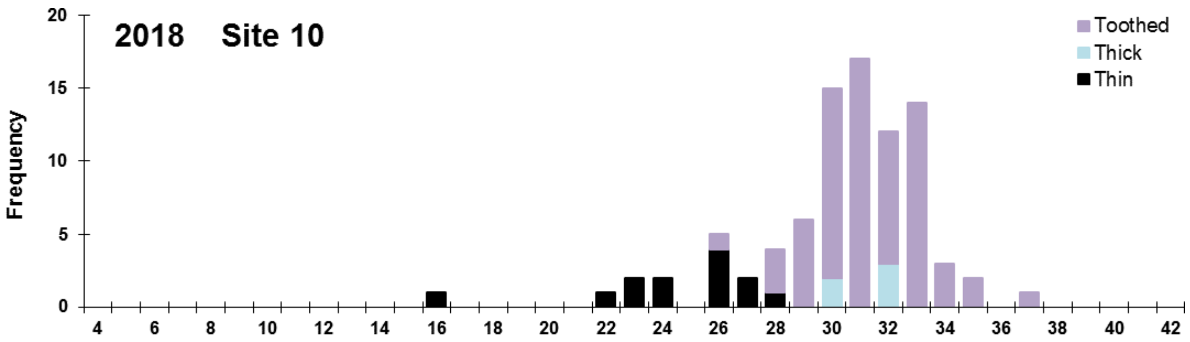


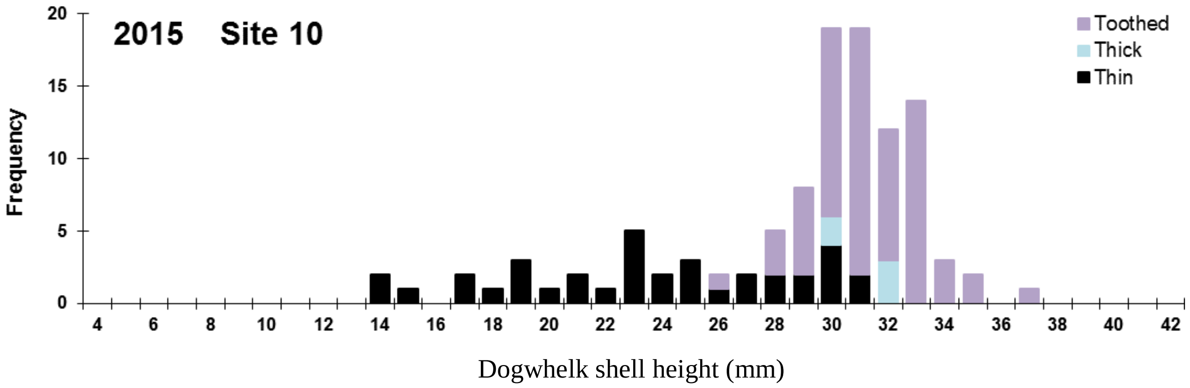
9 Mavis Grind



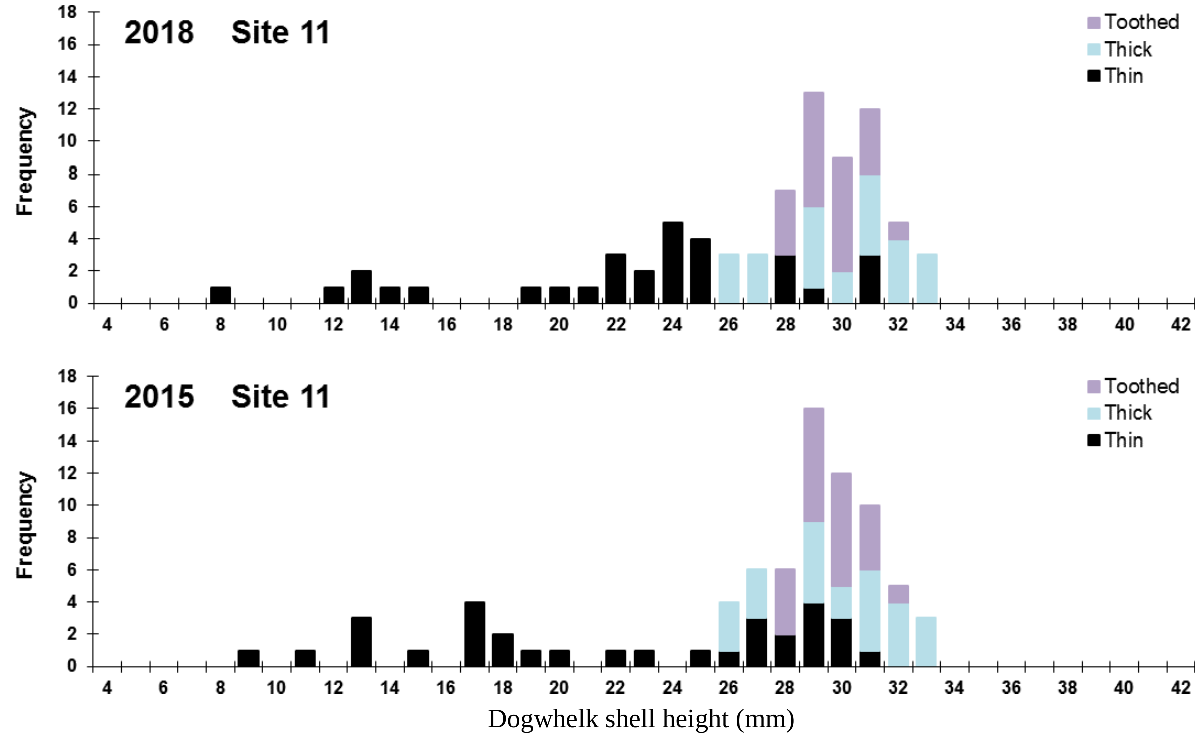


10 Voxter Ness

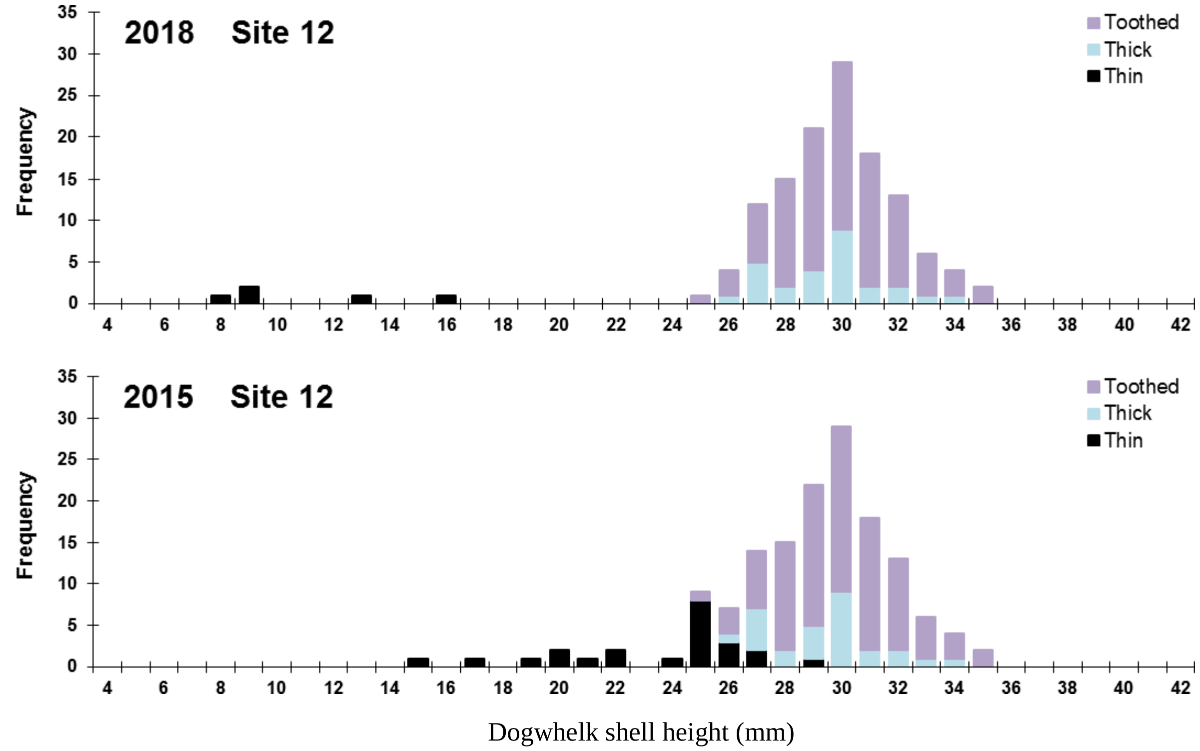




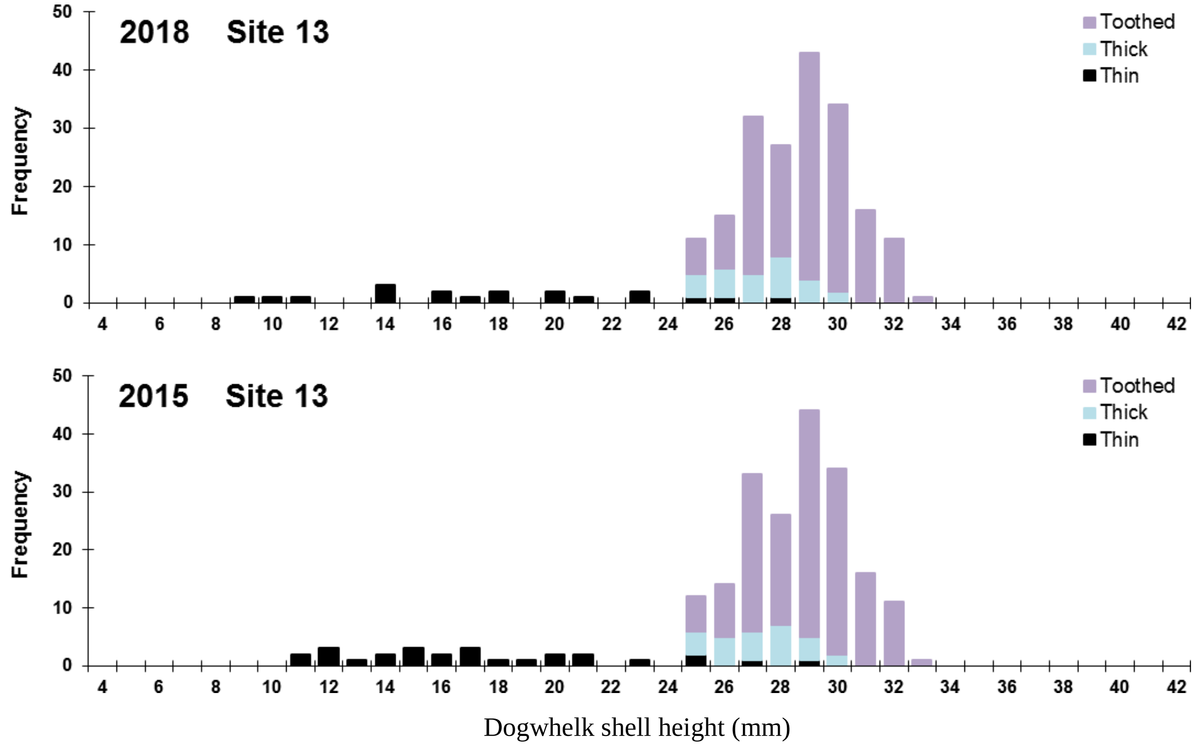
11 Northward



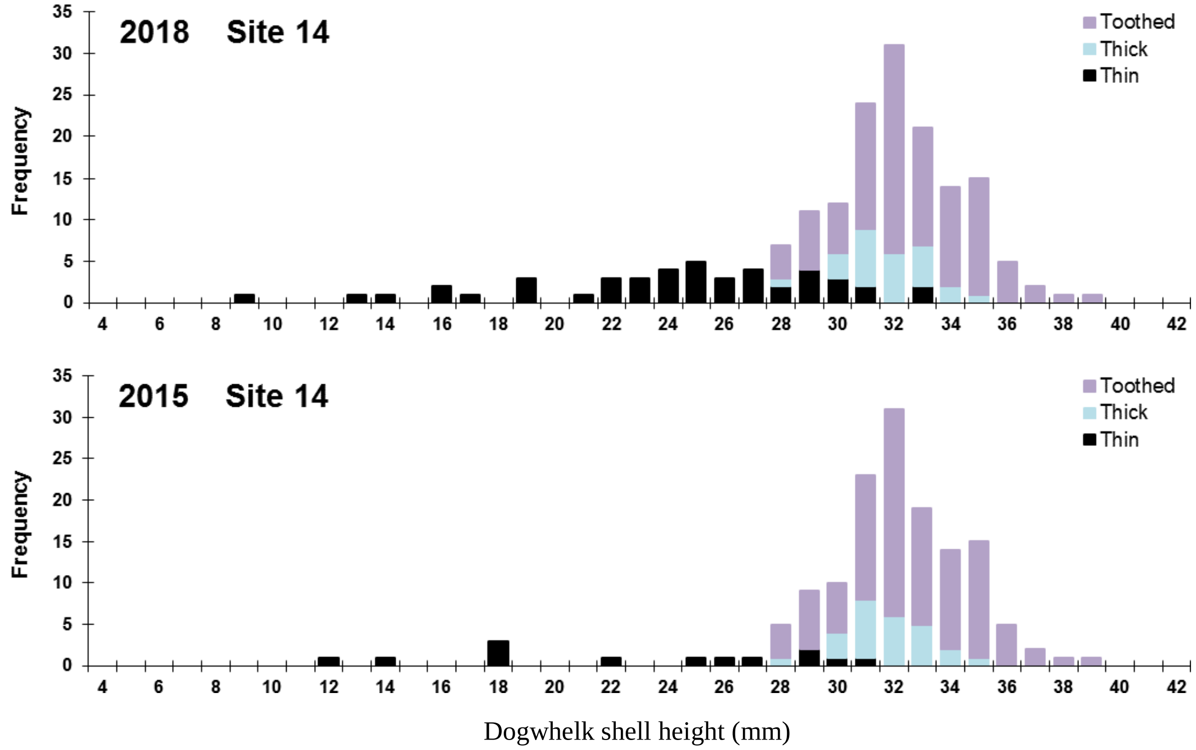
12 The Kames



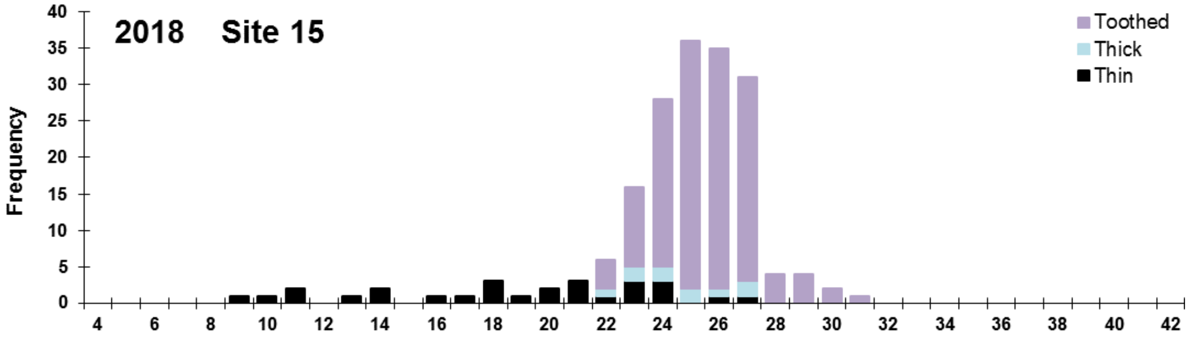
13 Skaw Taing

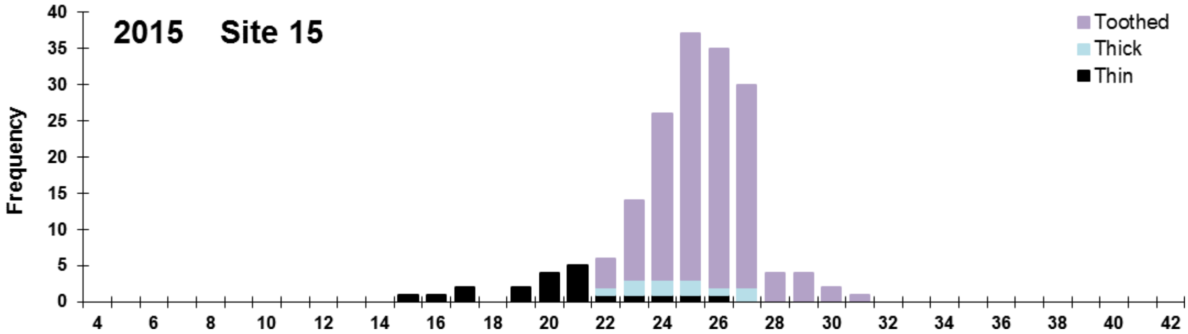


14 Mossbank



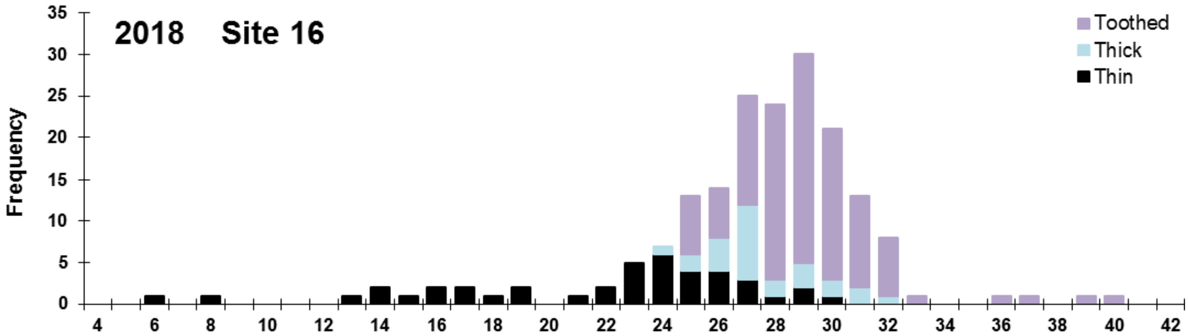
15 Orfasay

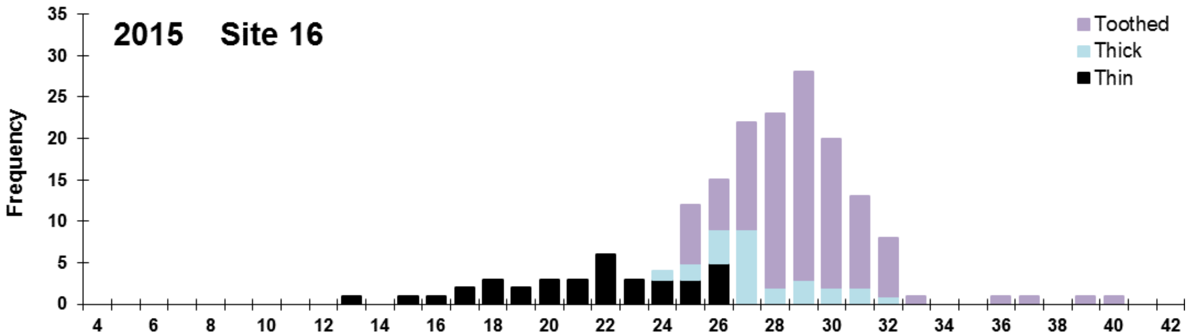




Dogwhelk shell height (mm)

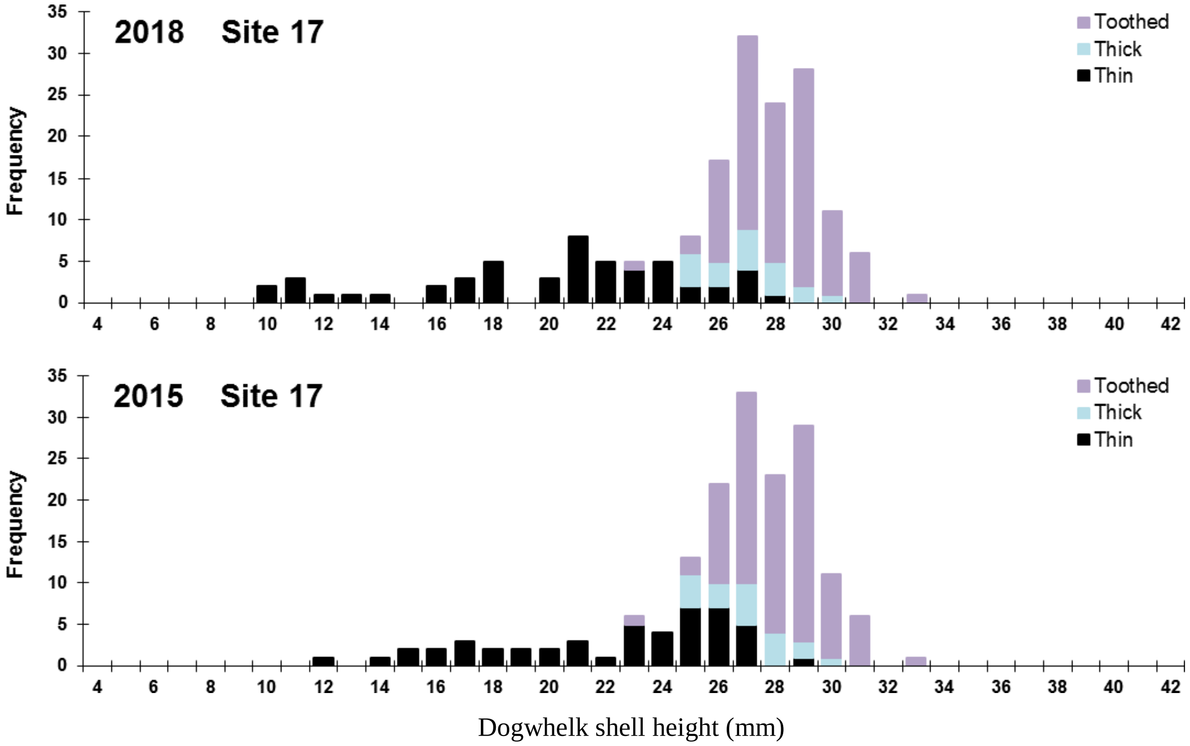
16 Samphrey (The Helliack)



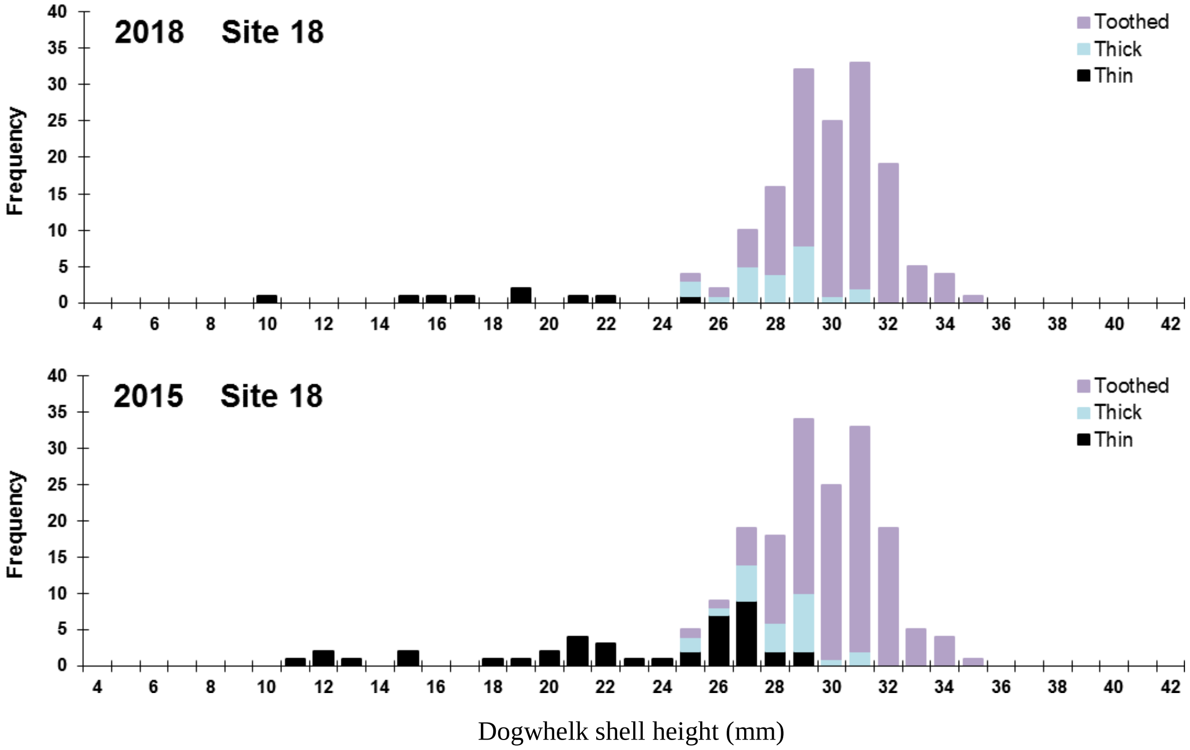


Dogwhelk shell height (mm)

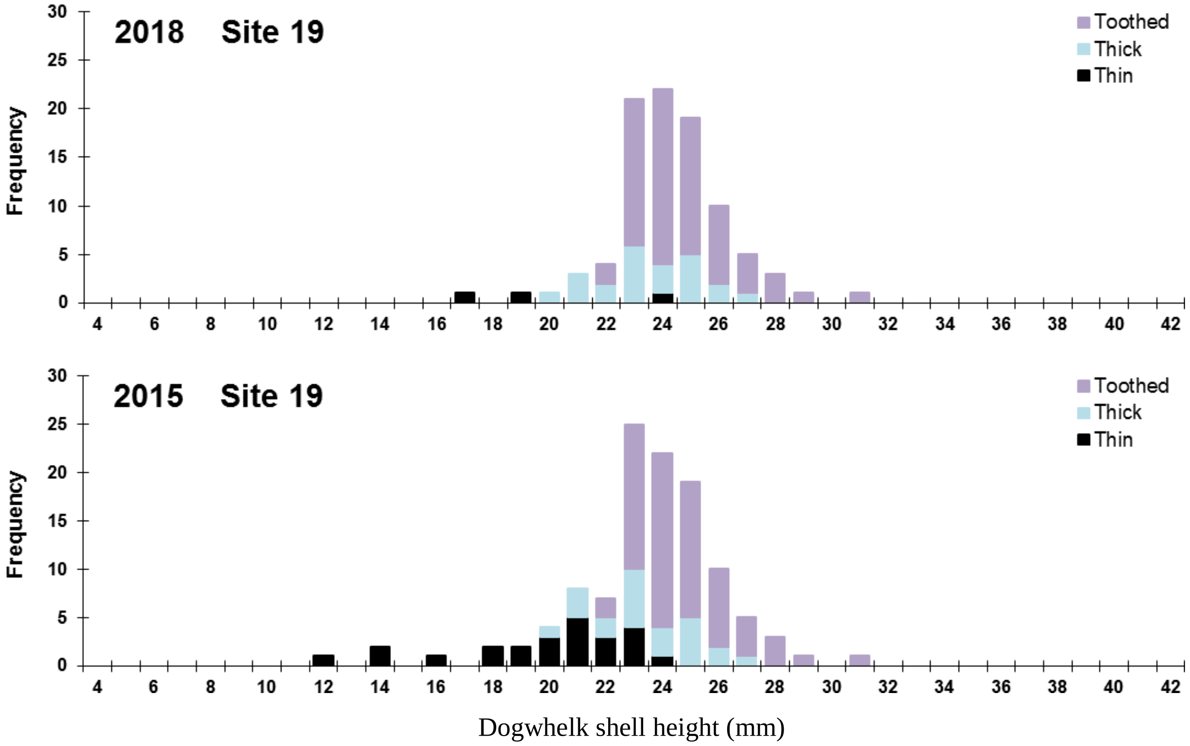
17 Uynarey



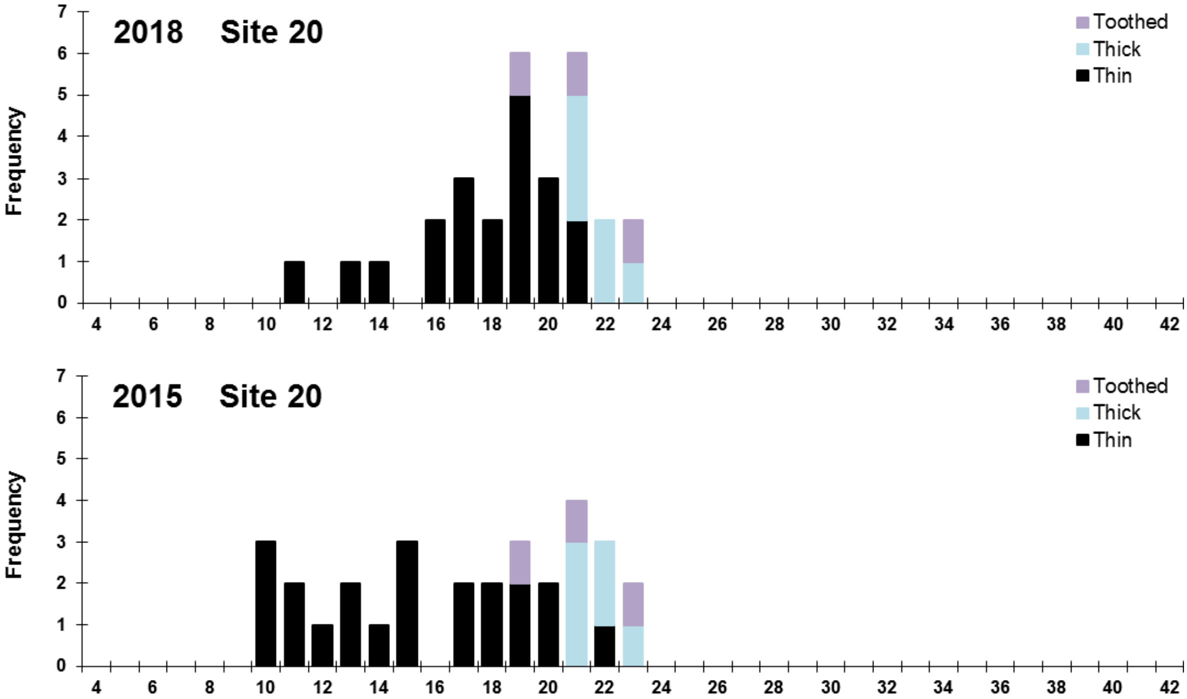
18 Little Roe



19 The Brough



20 Norther Geo



Dogwhelk shell height
(mm)