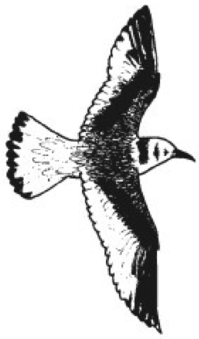
SOTEAG

Survey of dogwhelks, *Nucella lapillus*

in the vicinity of Sullom Voe



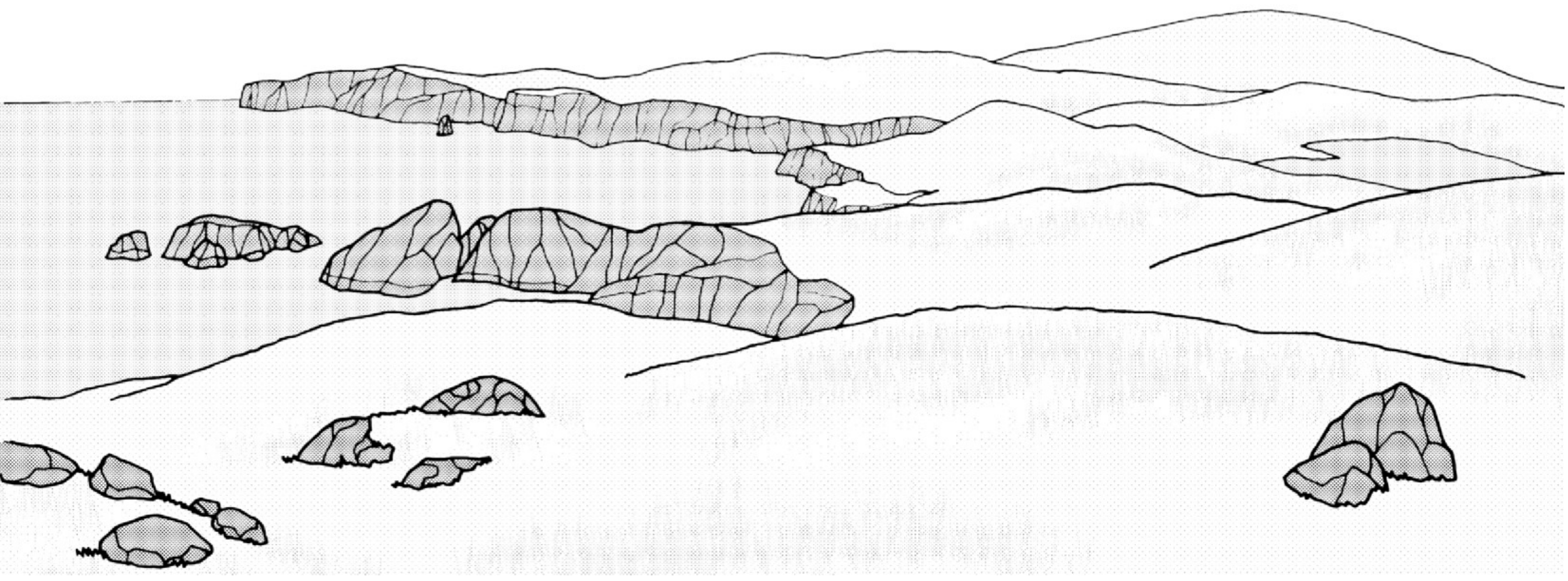
2021

A report to the Shetland Oil Terminal

Environmental Advisory Group

by

Aquatic Survey and Monitoring Ltd



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Surveys of dogwhelks *Nucella lapillus* in the vicinity of Sullom Voe, Shetland, August 2021

A report for SOTEAG

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Data access

Summary

This report presents the 2021 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 2021. 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 2018.

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 2018) and assessed against the Oslo and Paris Commission (OSPAR) assessment criteria.

RPSI values in adult dogwhelks (Sullom Voe <0.01-0.03%; Yell Sound 0.00-0.01%) were very low and very similar to values from the 2018 survey. However, VDSI values in adults (Sullom Voe 0.61-1.28; Yell Sound 0.00-0.71) increased since 2018. These increases are thought to represent inherent variability rather than a change in environmental conditions but the scale of the increases in Sullom Voe mean that the degree of imposex in 2021 was significantly higher in the Voe than in Yell Sound. That had been the case in 2015 and all previous surveys, but not in 2018 when the difference was not significant.

Imposex 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. 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.

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. Changes in VDSI resulted in changes in OSPAR Classification for seven sites, from A to B. However, all sites remain below the Environmental Assessment Criteria (EAC). Improvements in imposex incidence over the period of the monitoring likely result 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

The population data again confirm that juveniles are being produced at all sites and reproductive capacity is no longer considered a significant limitation to the viability of those dogwhelk populations.

Since the last dogwhelk survey in 2018 there has been continued evidence of increasing numbers of dogwhelks on the shores between the Sullom Voe terminal jetties. However, the widescale decline in adult and juvenile dogwhelk abundances, in Sullom Voe and Yell Sound, that was described from the 2018 survey is still apparent, though with some indication that it is levelling off. Surveyor's observations and photographic evidence have confirmed that an increasing dominance of fucoid algae at many sites is a major factor in this decline, but a causal relationship is not yet clear. These changes are considered natural and are not associated with any activities at the Sullom Voe Terminal.

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 *et al*. 2018, 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 has been re-established between the jetties (Moore and Bunker 2022). However, the 2018 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 dry weight) 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). A repeat survey in June 2021 (SGS 2022) found a large reduction, with concentrations below detection limits at most sites, detectable concentrations at two sites close to the oil terminal and a maximum concentration of 0.008 mg/kg (8 ng/g dw).

[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.

The monitoring programme has also shown that reproductive capacity is only one of the factors that affects the size and characteristics of the dogwhelk populations. Notwithstanding the evident recovery at sites close to the terminal, Moore *et al*. 2018 showed statistically significant regional declines in abundance of both adults and juveniles in both Sullom Voe and Yell Sound. They also suggested that an increasing dominance of fucoid algae may be a major factor. Long-term trends of increased fucoid abundance have been described regionally by the SOTEAG rocky shore transect monitoring programme (Moore and Mercer 2021) and nationally in Scotland (Burrows *et al*. 2020). Evidence for local reductions in abundance of dogwhelks at transect sites where fucoids have increased is also given in (Moore and Bunker 2022).

This report describes the results of a dogwhelk monitoring survey carried out in August 2021 and compares them with the results of previous surveys in the programme.

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 *et al*. 2018).

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 3rd and 16th August 2021. A related monitoring survey on rocky shore transects was also carried out in that period (Moore and Bunker, 2022). A field log is given in Appendix 1

2.1 Survey site locations

Dogwhelks were surveyed and sampled at the same suite of 20 sites as in previous surveys (Figure 1 and Table 1), with one exception. At Norther Geo (site 20), the density of adult (toothed) dogwhelks in the vicinity of the site became too low for sustainable sampling, likely due to the extreme wave exposure. Surveying the population at Norther Geo continued, but in 2011 a replacement sampling site was established at Sweinna Stack (site 22), half way between sites 20 and 19. However, in 2021 the availability of adult dogwhelks at Sweinna Stack was also too low for adequate sampling in a reasonable time scale, so the sampling was abandoned. Options for future sampling on that coast will be discussed.

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 samples of juveniles (in addition to the standard adults sample) were collected for imposex analyses. Where two survey dates are given for a site, the sample collection and the population survey were carried out on different days and the sampling date is given first (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(s)	Mins	Area
1*	Easterwick	-1.31467	60.6283	04/08/21	5	YSII
2	Burgo Taing	-1.31915	60.5833	13/08/21	3	YSII
3*	Billia Skerry	-1.31467	60.5554	04/08/21	5	YSI
4	Scarf Stane	-1.35679	60.5332	14/08/21 & 09/08/21	5	YSI
5*	East of Ollaberry	-1.32868	60.5069	14/08/21	5	YSI
6	Grunn Taing	-1.31209	60.4929	05/08/21 & 09/08/21	5	B
7	Tivaka Taing	-1.31077	60.4832	05/08/21 & 11/08/21	2	SV
8	Noust of Burraland	-1.32506	60.4585	05/08/21 & 13/08/21	5	SV
9*	Mavis Grind	-1.38357	60.3989	16/08/21 & 03/08/21	5	SV
10	Voxter Ness	-1.34674	60.4136	05/08/21 & 06/08/21	5	SV
11	Northward	-1.33387	60.4354	05/08/21 & 06/08/21	4	SV
12*	The Kames	-1.30126	60.4718	05/08/21 & 06/08/21	5	SV
13	Skaw Taing	-1.28005	60.4877	05/08/21 & 10/08/21	5	B
14	Mossbank	-1.18893	60.4644	07/08/21	5	YSII
15	Orfasay	-1.10213	60.479	14/08/21	5	YSII
16	Samphrey	-1.15565	60.4751	14/08/21	5	YSII
17	Uynarey	-1.19196	60.5082	14/08/21 & 08/08/21	4	YSI
18	Little Roe	-1.2731	60.4985	14/08/21 & 08/08/21	5	B
19	The Brough	-1.19897	60.5803	04/08/21 & 08/08/21	2	YSII
20#	Norther Geo	-1.18365	60.6356	No sample & 04/08/21	5	YSII

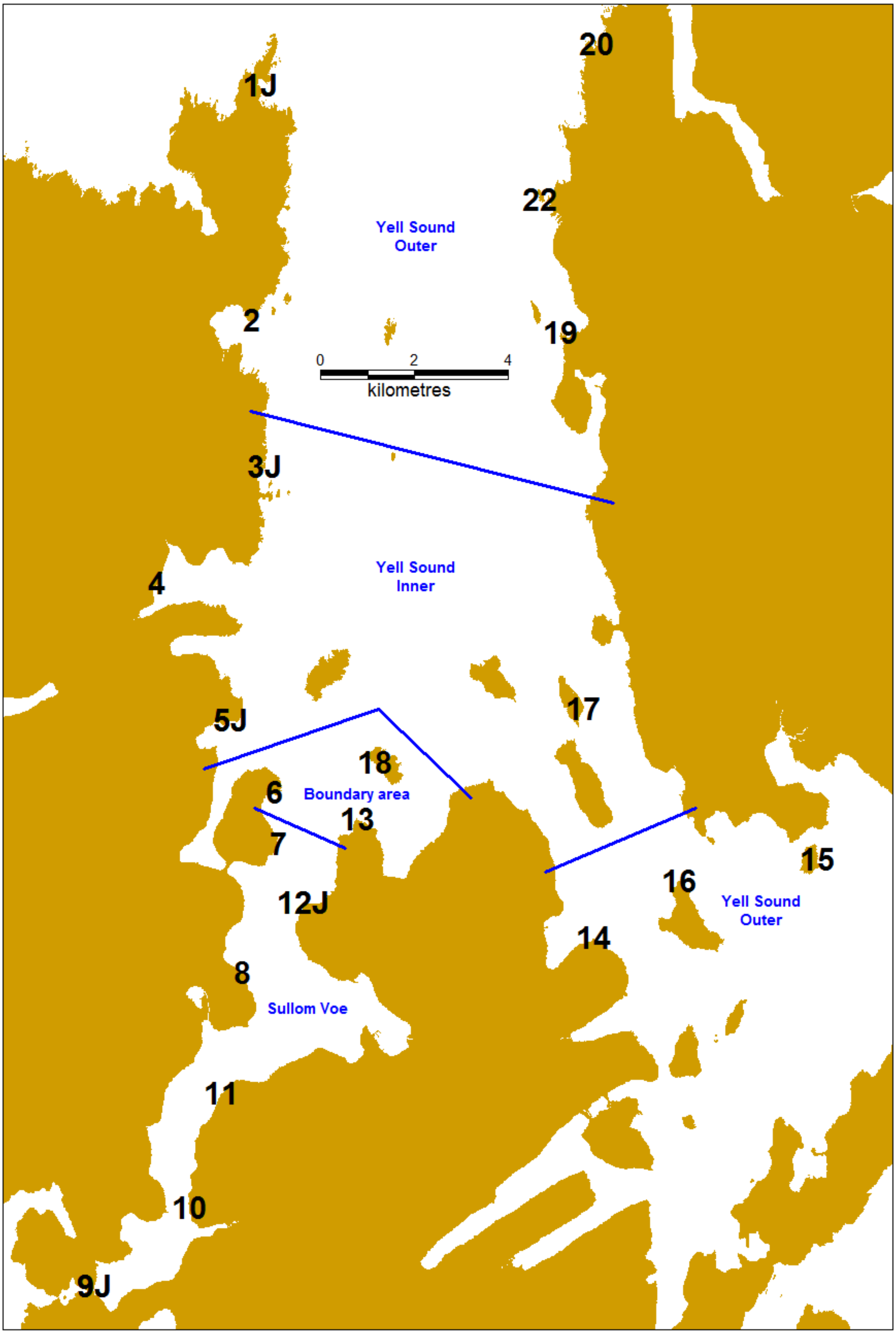

Figure 1 *Dogwhelk sampling sites in Sullom Voe and Yell Sound. (**J** indicates sites where untoothed adults, sub-adults and juvenile size classes were also sampled). Blue lines demarcate sites used for data analysis: Yell Sound (Outer (A) & Inner (B)), Sullom Voe and Boundary sites.*

2.2 Collecting population study data

2.2.1 Defined population study areas

At each site, a timed search for dogwhelks was carried out within a defined area (established in 1991) – typically an area of bedrock around 4m x 4m, relocated using annotated photographs on a laminated site location sheet.

In recent surveys it has become increasingly apparent that the character of the population study areas at some sites has changed, with substantial increases in the abundance of fucoid algae. This is briefly discussed in the report from the 2018 survey (Moore *et al.* 2018). Unfortunately, the dogwhelk monitoring methodology did not include routine photography of each site, so these habitat changes had not been adequately recorded. This was rectified in 2021, with comparative photographs taken of each site. In addition, to aid future relocation (particularly at some sites where algae now obscure some of the relocation features), photos were taken with lines laid around the defined areas.

2.2.2 Collection and measuring dogwhelks

Site specific protocols for the timed searches are given on the site location sheets. 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, carry out the search, one collecting dogwhelks on the open rock surface, the other, armed with a pair of forceps, collecting dogwhelks from crevices, hollows and (at a couple of sites) under boulders. Most of the juveniles are found in those more protected niches.

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 transported to Aberdeen (on overnight ferry) 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).

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

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.

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.

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.

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.

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 2021 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	10	9
		15-21	0	0.00	0.00	8	12
		21-26	0	0.00	0.00	9	10
		Adults	20	<0.01	0.42	20	20
2	Burgo Taing	Adults	32	<0.01	0.68	19	21
3	Billia Skerry	10-15	0	0.00	0.00	11	8
		15-21	22	<0.01	0.33	9	10
		21-26	20	0.02	0.40	10	10
		26-35	10	0.01	0.20	10	6
		Adults	21	<0.01	0.33	19	21
4	Scarf Stane	Adults	0	0.00	0.00	21	17
5	East of Ollaberry	10-15	0	0.00	0.00	13	7
		15-21	0	0.00	0.00	11	9
		21-26	0	0.00	0.00	10	10
		26-35	0	0.00	0.00	8	12
		Adults	30	0.01	0.56	23	17
6	Grunn Taing	Adults	28	<0.01	0.33	18	22
7	Tivaka Taing	Adults	59	0.02	1.18	22	18
8	Noust of Burraland	Adults	65	0.03	1.29	20	20
9	Mavis Grind	15-21	33	0.06	0.67	9	11
		21-26	33	0.10	0.67	9	11
		26-35	42	0.02	0.75	12	8
		Adults	43	<0.01	0.86	21	19
10	Voxter Ness	Adults	58	<0.01	1.00	24	16
11	Northward	Adults	33	<0.01	0.61	18	22
12	Kames	10-15	0	0.00	0.00	11	7
		15-21	8	<0.01	0.17	12	7
		21-26	11	<0.01	0.22	9	11
		26-35	25	0.01	0.50	12	8
		Adults	68	0.01	1.18	22	18
13	Skaw Taing	Adults	5.26	<0.01	0.10	19	20
14	Mossbank	Adults	4	0.00	0.04	22	17
15	Orfasay	Adults	37	<0.01	0.56	16	24
16	Samphrey	Adults	0	0.00	0.00	12	27
17	Uynarey	Adults	6	<0.01	0.12	17	22
18	Little Roe	Adults	26	<0.01	0.52	27	12
19	The Brough	Adults	33	<0.01	0.71	21	17

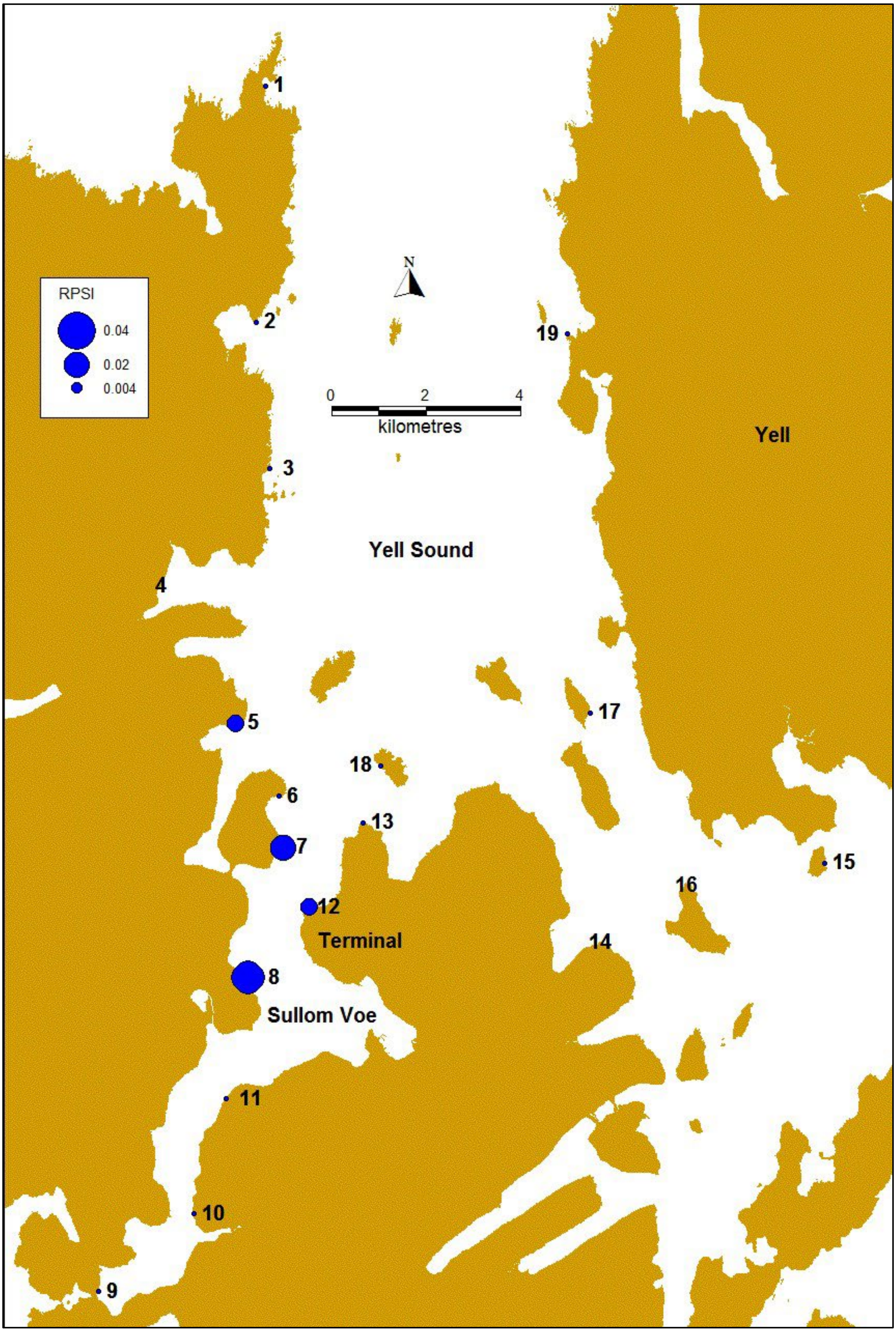

Figure 3 RPSIs in toothed adult dogwhelks (Nucella lapillus) from populations in Sullom Voe and Yell Sound sampled during the 2021 survey.

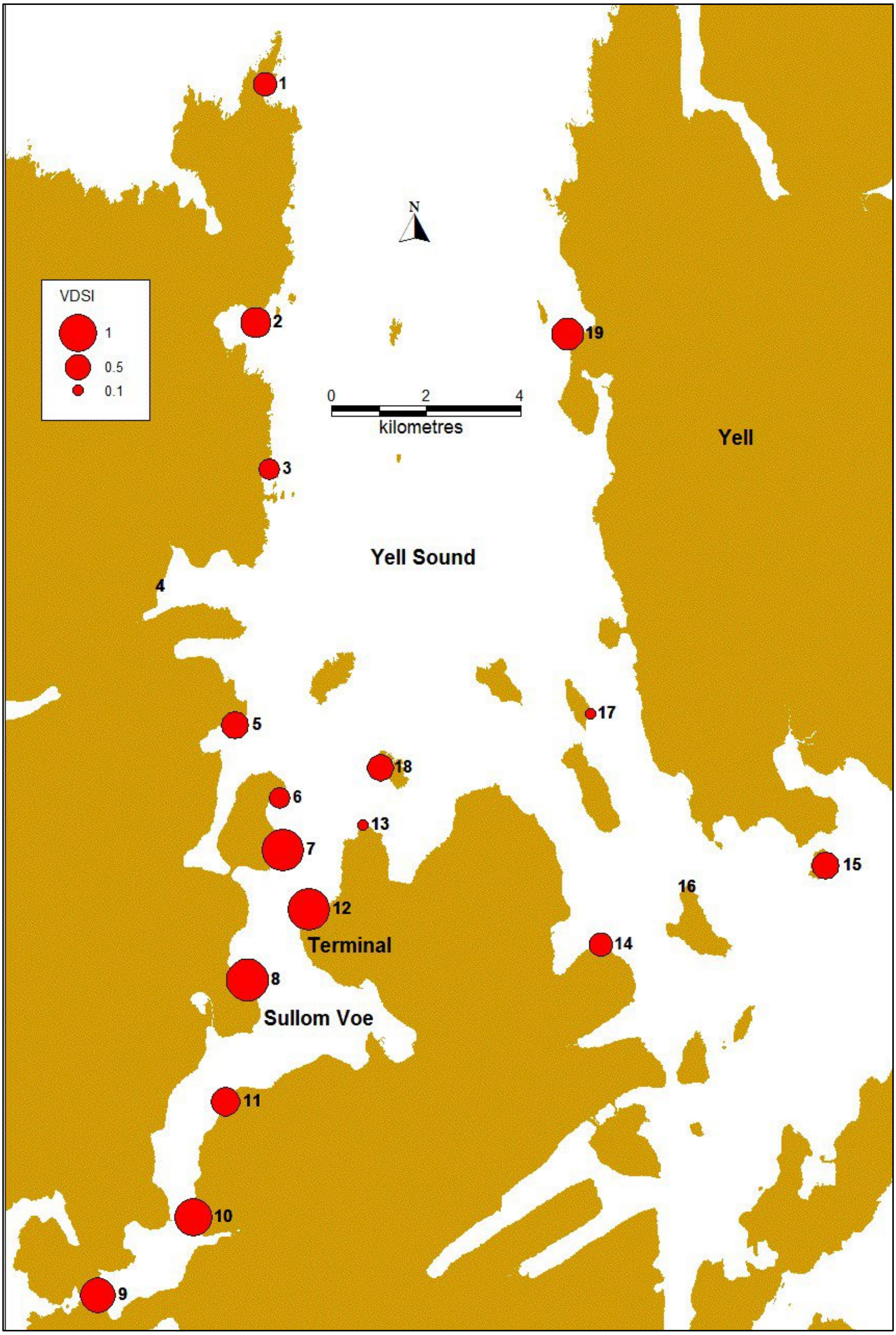

Figure 4 VDSIs in toothed adult dogwhelks (<u>Nucella lapillus</u>) from populations in Sullom Voe and Yell Sound sampled during the 2021 survey.

3.1.1 Toothed adult survey

RPSI values from sites sampled in 2021 within Sullom Voe ranged from <0.01 to 0.03%. 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 (0.03%, Table 3, site 8).

The VDSI values ranged from 0.61 to 1.28 (Table 3) at sites within Sullom Voe. The highest VDSI scores from the 2021 survey were found in populations from the Sullom Voe sites: at Noust of Burraland (site 8, Table 3, Figure 4 VDSI 1.28); and at Tivaka Taing (site 7, Table 3, Figure 4, VDSI 1.18). The VDSI from the Yell sites ranged from 0.00 to 0.71 and the VDSI from the Boundary sites ranged from 0.10 to 0.52.

In surveys up to and including 2015, there was a strong negative correlation between the degree of imposex in populations and distance from Sullom Voe. This trend was still apparent in 2018 but statistically there was no significant difference in VDSI between sites within Sullom Voe and those outside in Yell Sound. However, the 2021 results suggest a return to a stronger trend than 2018 (Figure 5), and while regression analysis shows that the correlation is poor ($R^2 = 0.162$) the difference in VDSI between sites within Sullom Voe and those in Yell Sound is statistically significant (ANOVA with Tukey method, $p<0.05$) (Figure 6).

There was no evidence of sterility (VDS > 4) in any of the populations sampled in 2021 (Table 4).

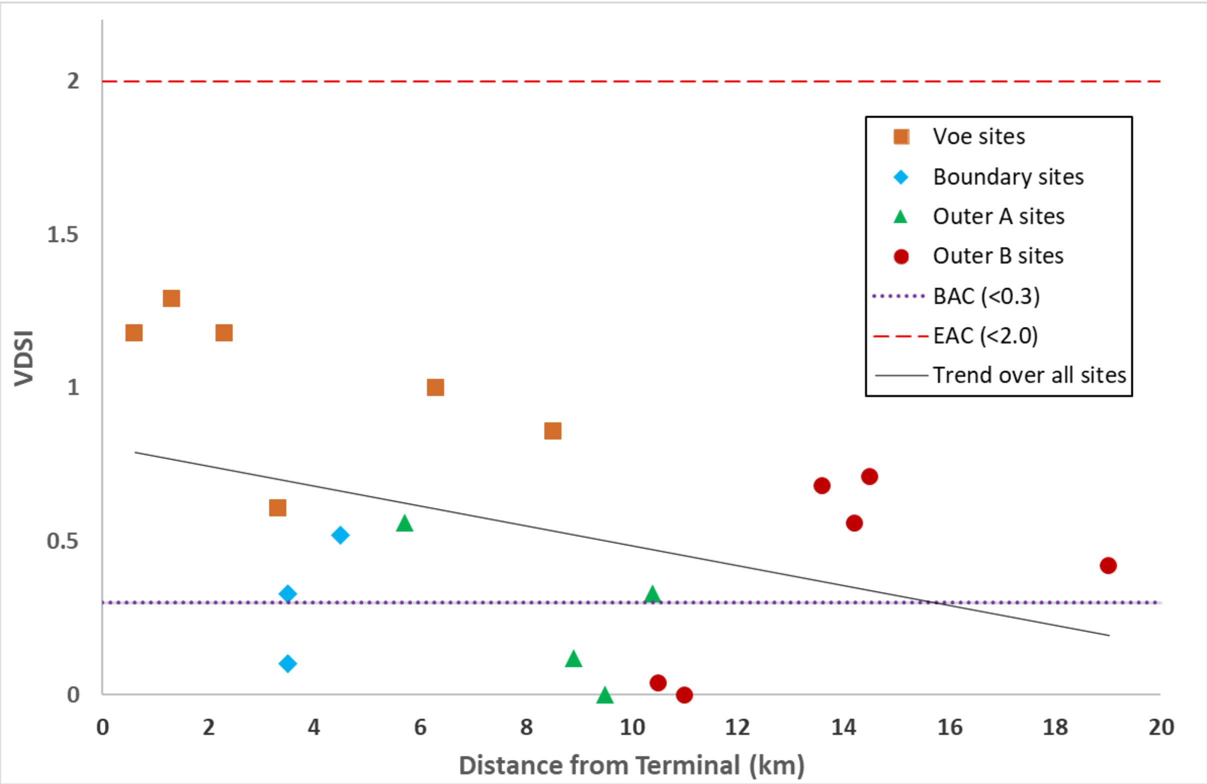

Figure 5 2021 VDSI values in adult dogwhelks Nucella lapillus shown by geographic groupings and distance from terminal. The Background Assessment Criteria (BAC) and Environmental Assessment Criteria (EAC) are also shown.

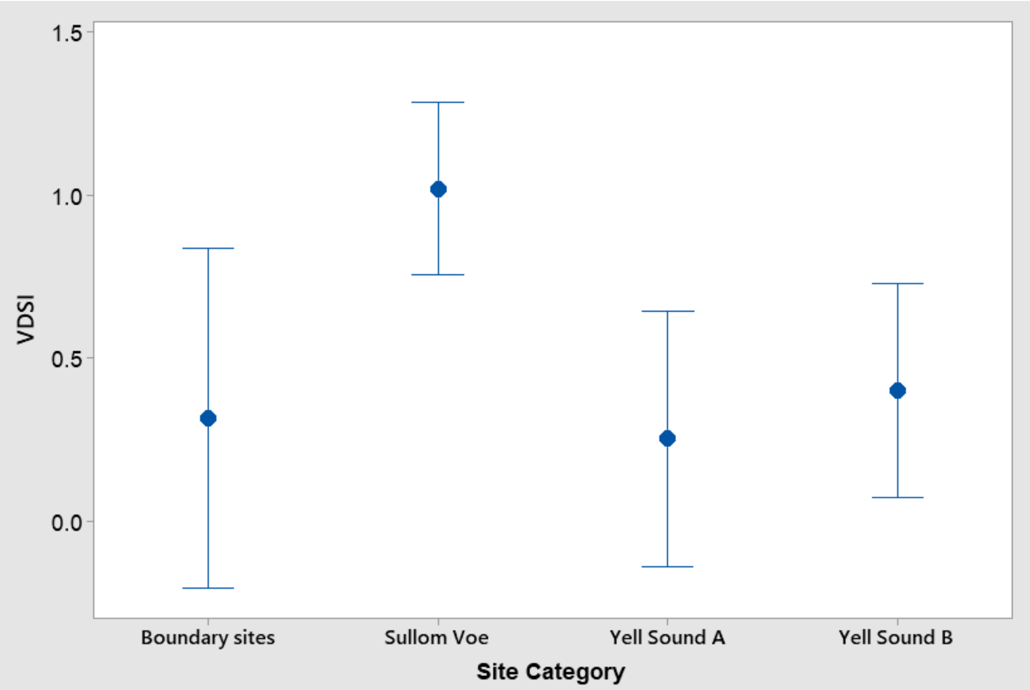

Figure 6 Comparison of average VDSI values (2021) in adult dogwhelks from geographic grouping in Sullom Voe and Yell Sound. Error bars are 95% confidence limits.

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). However no juveniles (10-15 mm) were sampled at Mavis Grind (site 9) as none were found after more than 30 minutes of searching[2].

Imposex was not detected in any of the age classes at the Easterwick site (Table 3, site 1) or at the East of Ollaberry site (Table 3, site 5). The highest level of imposex was observed in untoothed adults from a site inside Sullom Voe, Mavis Grind (Table 3, site 9, 26-35 mm, 0.02% RPSI, 0.75 VDSI). The highest level of imposex in the Yell Sound was from untoothed adults at Billia Skerry (Table 3, site 3, 21-26 mm, 0.02% RPSI, 0.40 VDSI) and sub-adults at Billia Skerry (Table 3, site 3, 15-21 mm, RPSI <0.01%, VDSI 0.33).

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

[2] This lack of 10-15mm juveniles in the area sampled for imposex analysis at Mavis Grind contrasts with the defined Mavis Grind population study area, 20-30 metres south, where 11 juveniles (<16mm) were collected in 5 minutes (Section 3.2.1). This may be due to a habitat difference as the paucity of small juveniles in the area sampled for imposex has been noticed in previous surveys.

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 2011-2021. 2021 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 continued 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 2021. In 2021, VDSI has increased since 2018 at all sites in Sullom Voe and the Yell Sound except 3, 4, 14, 15, 16 where small decreases were observed (Figure 8). These increases 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 2018. There has been a steady increase in VDSI from site 3 (Billia Skerry) from 2011 to 2018 however levels still remain low and decreased in 2021.

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 – 2021 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 2021.

Table 4 The numbers of toothed animals and the percentage of females obtained from the surveys in 1987, 1991, 2018 and 2021. 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			2018			2018		
		Total	%F	%FS	Total	%F	%FS	Total	%F	%FS	Total	%F	%FS
1	Easterwick	-	-	-	48	60	0	39	54	0	40	50	0
2	Burgo Taing	-	-	-	40	73	0	39	62	0	40	47	0
3	Billia Skerry	41	54	0	40	50	0	40	48	0	40	47	0
4	Scarf Stane	40	63	0	38	45	0	32	53	0	40	55	0
5	East of Ollaberry	40	50	0	37	62	0	40	43	0	40	57	0
6	Grunn Taing	40	45	0	39	49	0	39	49	0	40	45	0
7	Tivaka Taing	40	45	22	39	44	29	40	58	0	40	55	0
8	Noust of Burraland	40	35	21	38	29	91	39	54	0	40	50	0
9	Mavis Grind	40	48	21	29	28	63	39	38	0	40	52	0
10	Voxter Ness	30	57	65	39	26	60	40	53	0	40	60	0
11	Northward	40	40	44	40	28	91	37	46	0	40	45	0
12	The Kames	38	42	93	39	44	100	39	46	0	40	55	0
13	Skaw Taing	40	50	0	39	44	35	37	43	0	39	49	0
14	Mossbank	-	-	-	40	50	15	40	30	0	40	56	0
15	Orfasay	-	-	-	40	48	0	40	50	0	40	40	0
16	Samphrey	-	-	-	40	48	0	39	44	0	40	31	0
17	Uynarey	34	56	0	40	53	0	40	40	0	40	44	0
18	Little Roe	38	55	0	39	54	14	39	38	0	40	69	0
19	Brough	-	-	-	40	53	0	40	55	0	40	55	0
20	Norther Geo	-	-	-	40	43	0	-	-	-	-	-	-
22	Sweinna Stack	-	-	-	-	-	-	39	46	0	-	-	-

Table 5 RPSI in adult dogwhelks, all surveys (except 93, 99 & 01, to make space) (- No sample).

Site No	Site name	1987	1990	1991	1995	1997	2004	2007	2009	2011	2013	2015	2018	2021
1	Easterwick	-	-	0.00	0.00	0.00	<0.01	<0.01	0.00	<0.01	0.00	0.00	0.00	<0.01
2	Burgo Taing	-	-	3.37	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.00	<0.01	0.00	<0.01
3	Billia Skerry	0.64	1.45	0.24	0.02	0.02	0.27	<0.01	0.13	0.00	0.00	0.00	0.01	<0.01
4	Scarf Stane	2.16	1.67	3.76	2.69	15.24	8.69	0.14	<0.01	0.00	0.04	0.00	0.00	0.00
5	East of Ollaberry	2.41	7.51	3.53	0.23	0.94	0.12	<0.01	<0.01	0.00	0.00	0.00	0.00	0.01
6	Grunn Taing	12.71	13.52	15.00	7.33	7.18	4.62	0.95	0.00	<0.01	<0.01	<0.01	<0.01	<0.01
7	Tivaka Taing	58.85	34.19	23.72	20.34	19.90	10.55	3.45	0.54	0.07	<0.01	<0.01	<0.01	0.02
8	Noust of Burraland	54.50	45.59	50.75	21.44	21.88	11.00	1.73	0.41	0.11	0.13	0.06	0.04	0.03
9	Mavis Grind	40.91	30.24	30.15	11.63	24.11	20.33	4.29	1.08	0.17	0.01	0.04	<0.01	<0.01
10	Voxter Ness	58.54	39.59	41.32	27.65	28.05	12.63	2.69	0.01	0.02	0.01	<0.01	<0.01	<0.01
11	Northward	34.03	30.54	42.57	26.70	36.70	14.73	7.86	0.31	0.31	0.04	0.37	0.01	<0.01
12	The Kames	56.78	69.44	54.93	31.32	73.12	16.99	0.90	0.26	0.17	0.30	0.03	<0.01	0.01
13	Skaw Taing	42.46	32.34	45.00	20.59	27.16	14.43	2.59	0.26	0.07	<0.01	<0.01	0.00	<0.01
14	Mossbank	-	-	5.04	0.37	0.76	0.07	0.01	0.67	0.00	0.00	0.00	<0.01	0.00
15	Orfasay	-	-	0.54	0.09	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01
16	Samphrey	-	-	1.30	0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.00	0.00	0.00	0.00
17	Uynarey	0.99	1.25	0.18	0.02	0.11	0.02	<0.01	<0.01	<0.01	0.00	<0.01	0.00	<0.01
18	Little Roe	13.46	9.69	18.89	5.30	12.00	3.76	1.62	0.03	<0.01	<0.01	0.00	0.00	<0.01
19	The Brough	-	-	0.63	<0.01	0.00	0.01	-	0.01	<0.01	0.00	<0.01	0.00	<0.01
20	Norther Geo	-	-	0.13	0.00	0.00	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 & 01, to make space) (- No sample).

Site No	Site name	1987	1990	1991	1995	1997	2004	2007	2009	2011	2013	2015	2018	2021
1	Easterwick	-	-	0.26	0.04	0.06	0.36	0.15	0.46	0.21	0.00	0.00	0.00	0.42
2	Burgo Taing	-	-	1.72	1.00	0.92	0.28	0.50	0.58	0.31	0.00	0.75	0.08	0.68
3	Billia Skerry	2.32	2.35	2.30	1.11	1.04	1.79	1.20	1.50	0.38	0.55	0.67	1.00	0.33
4	Scarf Stane	3.44	3.42	3.53	3.82	3.67	4.07	2.56	0.95	0.67	0.15	0.08	0.06	0.00
5	East of Ollaberry	3.21	3.95	3.39	2.47	2.33	1.57	0.70	0.38	0.13	0.05	0.00	0.06	0.56
6	Grunn Taing	4.00	4.00	4.00	4.13	4.00	3.46	3.50	0.59	1.44	0.85	0.47	0.79	0.33
7	Tivaka Taing	4.22	4.93	4.41	4.25	4.09	4.00	3.58	2.64	2.05	0.79	0.70	0.78	1.18
8	Noust of Burraland	4.21	4.33	5.00	4.65	4.24	4.05	4.00	3.53	2.19	1.74	1.63	0.71	1.29
9	Mavis Grind	4.26	4.64	4.75	4.35	4.27	4.25	4.11	3.67	2.40	1.05	1.65	0.27	0.86
10	Voxter Ness	4.71	4.83	4.80	4.57	4.07	4.10	3.78	1.30	1.25	1.23	1.00	0.62	1.00
11	Northward	4.44	4.87	5.18	4.40	4.07	4.18	4.08	3.14	2.73	1.40	2.36	0.59	0.61
12	The Kames	5.27	5.33	5.59	5.17	4.67	4.33	3.89	3.00	2.25	2.00	1.81	0.56	1.18
13	Skaw Taing	4.00	4.69	4.41	4.31	4.16	4.00	3.33	2.77	1.60	0.44	0.77	0.06	0.10
14	Mossbank	-	-	4.05	2.46	2.13	1.47	1.08	3.24	0.19	0.00	0.00	0.17	0.04
15	Orfasay	-	-	2.74	1.04	0.88	1.12	0.83	0.40	0.26	0.54	1.60	0.95	0.56
16	Samphrey	-	-	2.32	0.63	0.87	0.40	0.20	0.33	0.14	0.38	0.00	0.12	0.00
17	Uynarey	2.58	2.86	2.05	0.90	1.56	1.17	0.82	0.38	0.27	0.05	0.20	0.06	0.12
18	Little Roe	4.00	4.04	4.14	4.06	3.93	3.63	3.56	1.95	0.62	0.50	0.00	0.00	0.52
19	The Brough	-	-	2.57	1.16	0.43	0.89	-	0.38	0.08	0.08	0.19	0.14	0.71
20	Norther Geo	-	-	1.35	0.00	0.30	0.08	-	0.20	-	-	-	-	-
22	Sweinna Stack	-	-	-	-	-	-	-	-	0.06	0.00	0.00	0.00	-

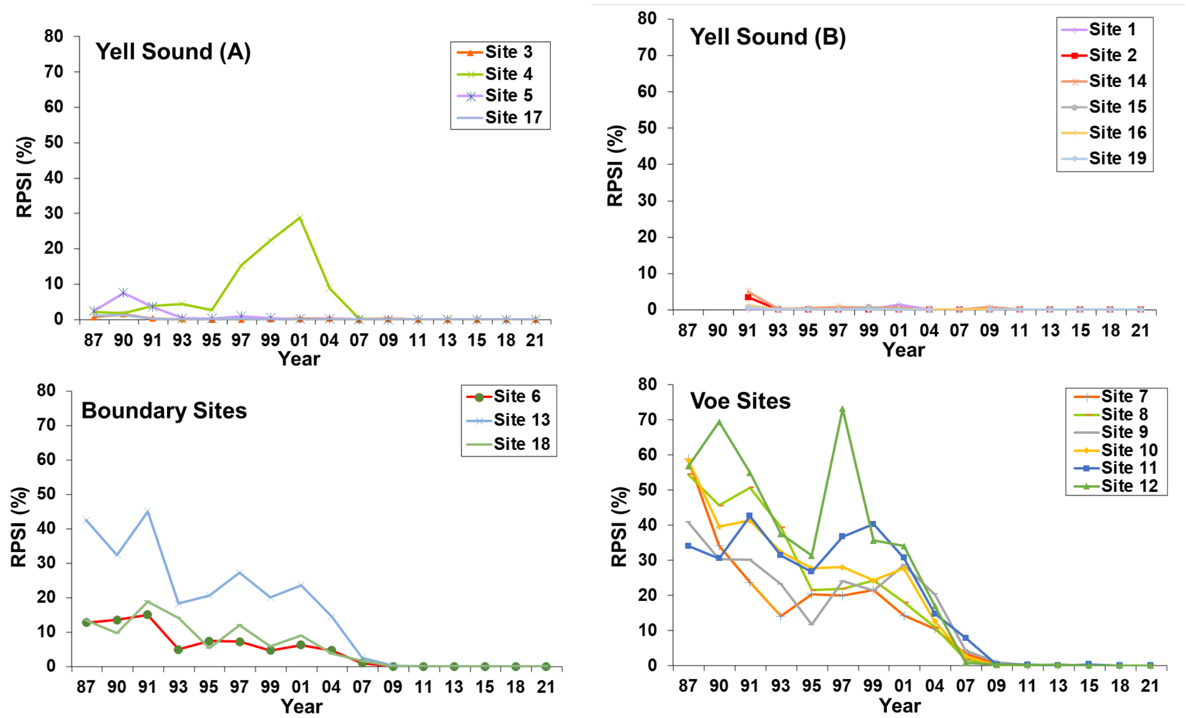

Figure 7 *RPSI values for dogwhelk populations in the surveys from 1987-2021 shown by geographical groupings.*

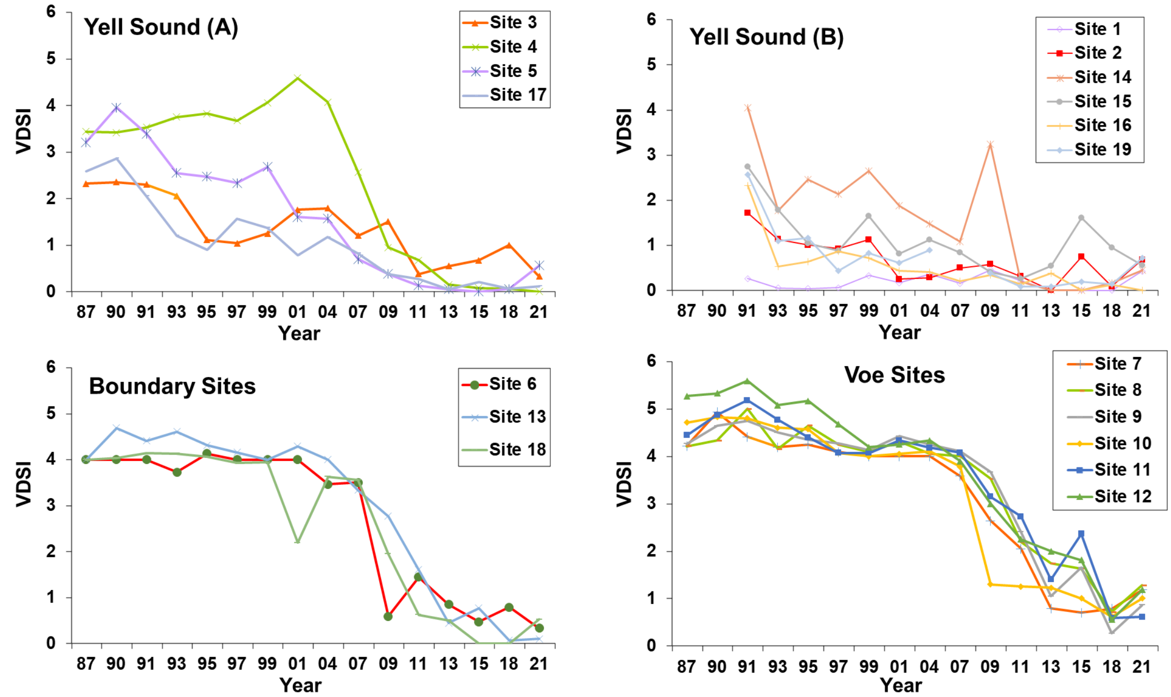

Figure 8 *VDSI values for dogwhelk populations in the surveys from 1987-2021 shown by geographical groupings.*

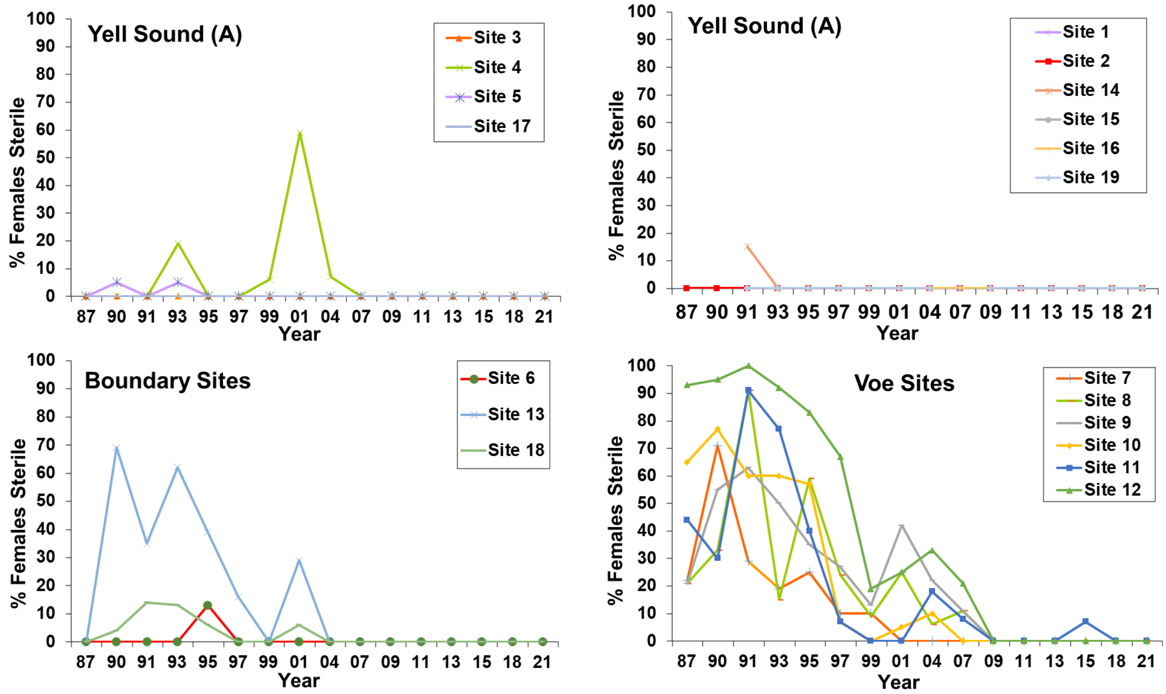

Figure 9 The percentage of sterile female dogwhelks (<u>Nucella lapillus</u>) sampled in the surveys from 1987-2021.

3.2 Population structure studies

3.2.1 Population characteristics and changes since the last survey

Results are presented in Appendix 2 in the form of histograms. Histograms from 2018 and 2021 are plotted side-by-side for easy comparison. Histograms for 1993 to 2015 are printed in previous reports. Table 7 summarises the population data from 2021 and compares it with data from 2018. Note that analysis of the juveniles has been confined to individuals with shell height <16mm. Figure 10a to Figure 10d plot the fluctuations in abundance of dogwhelks (all sizes) for selected sites. Figure 11a to Figure 11d plot the fluctuations in juvenile dogwhelk abundances.

Samples collected in 2021 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, and a tail of younger dogwhelks. Site specific characteristics of the defined population study areas greatly affect the structure of the samples, so that some samples have relatively few juveniles or no clear adult peak; but the histograms mostly show the same sample structures year on year. Mean and median shell heights showed no notable changes.

Juveniles were present at every site, though some were particularly sparse. The sample from East of Ollaberry (site 5) is a good example, with only two juveniles (<16mm) found in the allocated 5 minutes of collecting, compared to 10 juveniles in 2018. Other sites where juvenile densities have notably reduced since 2018 include Burgo Taing (site 2), Noust of Burraland (site 8) and Orfasay (site 15). However, increases occurred at Mavis Grind (site 9)[3] and Voxter Ness (site 10).

Abundance (number of dogwhelks of all sizes collected per minute) also varied considerably between sites but were similar at most sites to those recorded in 2018. Notable changes occurred at some sites,

[3] Though this contrasts with the paucity of small juveniles in the area sampled for imposex analysis at Mavis Grind – see Section 3.1.2.

including increases at Scarf Stane (site 4), Mavis Grind (site 9) and Norther Geo (site 20) and a decrease at Voxter Ness (site 10). Sample size (i.e. the total number of dogwhelks collected from the defined population study area) was lower at some sites than recommended for such studies. The recommended minimum of 100 dogwhelks was not achieved at seven sites and was less than 50 at two sites (East of Ollaberry (46) and Voxter Ness (24)).

Table 7 Comparison of summary data from August 2018 and 2021. 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.

	2018					2021				
Site	**No./min**	**Juvs/min**	**Mean**	**Median**	**Min**	**No./min**	**Juvs/min**	**Mean**	**Median**	**Min**
1	34.0	2.8	22.7	24	11	32.0	3.4	21.6	24	7
2	51.0	2.3	27.4	29	6	50.0	0.3	28.5	29	11
3	43.8	1.0	25.5	27	11	47.8	1.4	24.8	26	10
4	6.4	1.6	21.1	29	10	12.6	3.0	21.6	29	7
5	15.2	1.6	27.2	30	10	9.2	0.4	30.0	31	11
6	13.6	0.8	26.7	30	7	16.6	0.2	27.9	31	7
7	49.5	12.0	23.6	29	6	71.0	11.5	26.1	31	9
8	19.8	1.6	25.3	27	10	18.2	1.0	25.9	27	10
9	11.8	0.6	26.6	32	9	21.0	2.2	27.0	31	12
10	12.0	0.0	29.6	30	16	4.8	1.4	22.5	29	12
11	24.5	1.5	27.8	30	8	20.2	1.2	28.4	30	8
12	18.6	0.8	29.6	31	8	19.6	0.8	28.7	30	9
13	37.0	1.2	28.0	29	9	36.8	1.4	26.4	28	7
14	32.2	0.6	29.5	31	9	37.6	1.2	29.5	31	6
15	42.6	1.4	24.9	26	9	28.2	1.0	25.3	26	10
16	27.6	1.2	26.6	29	6	36.2	0.8	26.3	28	10
17	39.2	2.0	25.4	28	10	53.5	1.5	24.8	27	11
18	42.4	0.4	28.8	29	10	27.2	1.0	27.9	28	10
19	39.5	0.0	23.7	24	17	60.0	1.0	23.3	23	13
20	5.2	0.6	18.6	-	11	12.4	1.0	19.7	21	12

3.2.2 Temporal changes over the course of the monitoring programme

Populations in Sullom Voe that were severely affected by imposex 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. The Kames (site 12) was the worst affected site, with no juveniles in the 1991 survey and an adult population skewed to a few large old individuals, suggesting that recruitment of young animals has been reduced and the population was dominated by old survivors. Those characteristics gradually changed and by 2001 the Kames population was much larger, with numerous juveniles and a wide range of adult sizes. Populations at other sites in Sullom Voe also showed signs of reproductive stress but less clearly, and by 2011 it was concluded that it was difficult to distinguish any further improvements in population structure due to the declining imposex at Voe sites. In 2018 it was shown that despite their improved reproductive capacity the abundance of both adults and juveniles in both Sullom Voe and Yell Sound had significantly declined over a number of years. This was most apparent for juveniles at the boundary sites (see Figure 11b).

Average abundance data shown in Figure 12a and b suggests that decline may be levelling off, but the longer term trend is very clear. Calculations of average abundance in 2021 across all Sullom Voe sites (7 to 12) gives a value of 25.8 dogwhelks per minute and 32.9 per minute across all sites in Yell Sound. Those values are higher than 2018 but are still low compared to most of the previous surveys. The average abundance values for juveniles were 3.0 per minute and 1.3 per minute, respectively; so, like 2018, there was a lower average value for juveniles abundance in Yell Sound compared to Sullom Voe.

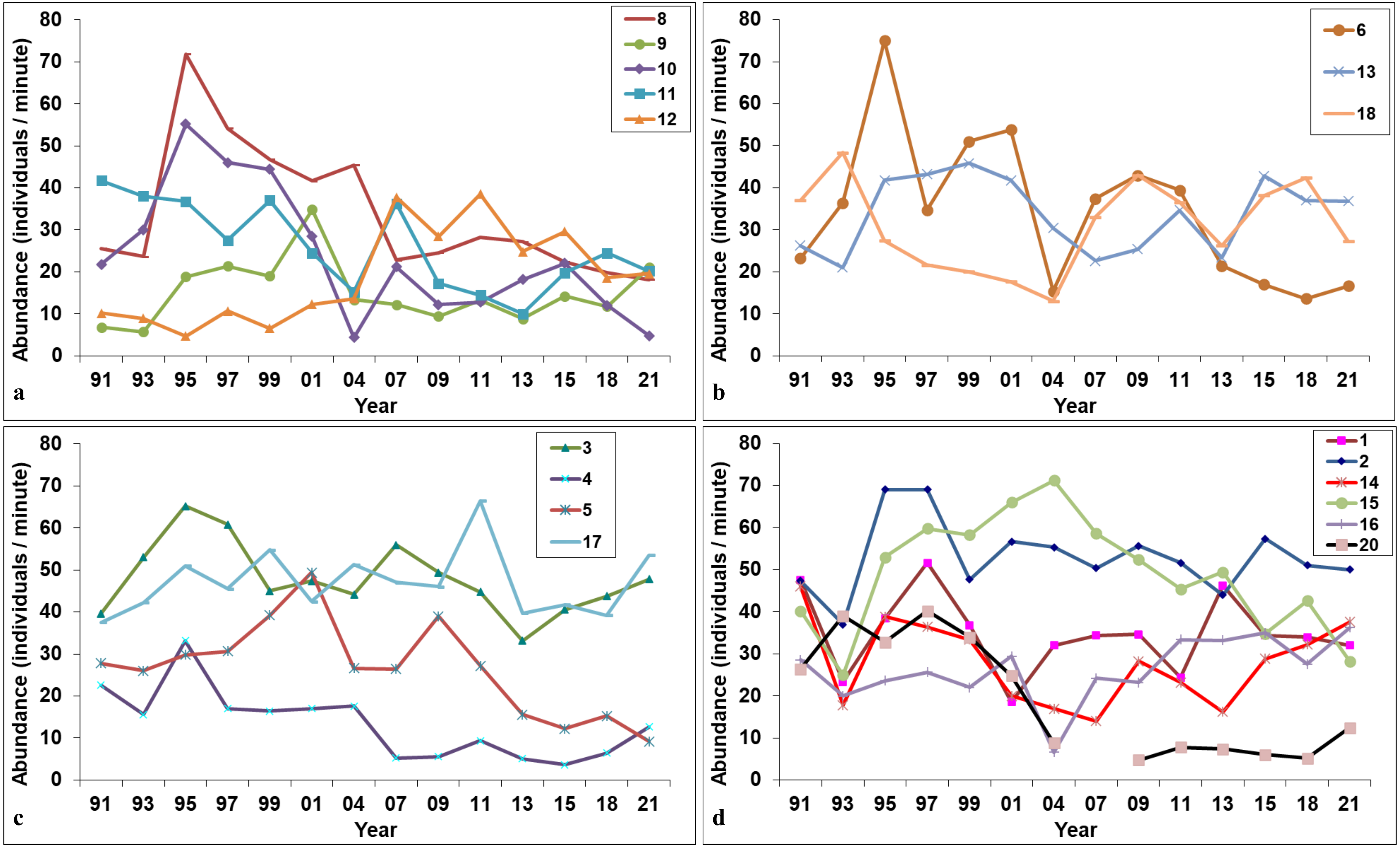

Figure 10 Temporal changes in abundance of dogwhelks (all sizes) at selected sites in regional groupings: a) Sullom Voe, b) Boundary sites, c) Inner Yell Sound, d) Outer Yell Sound.

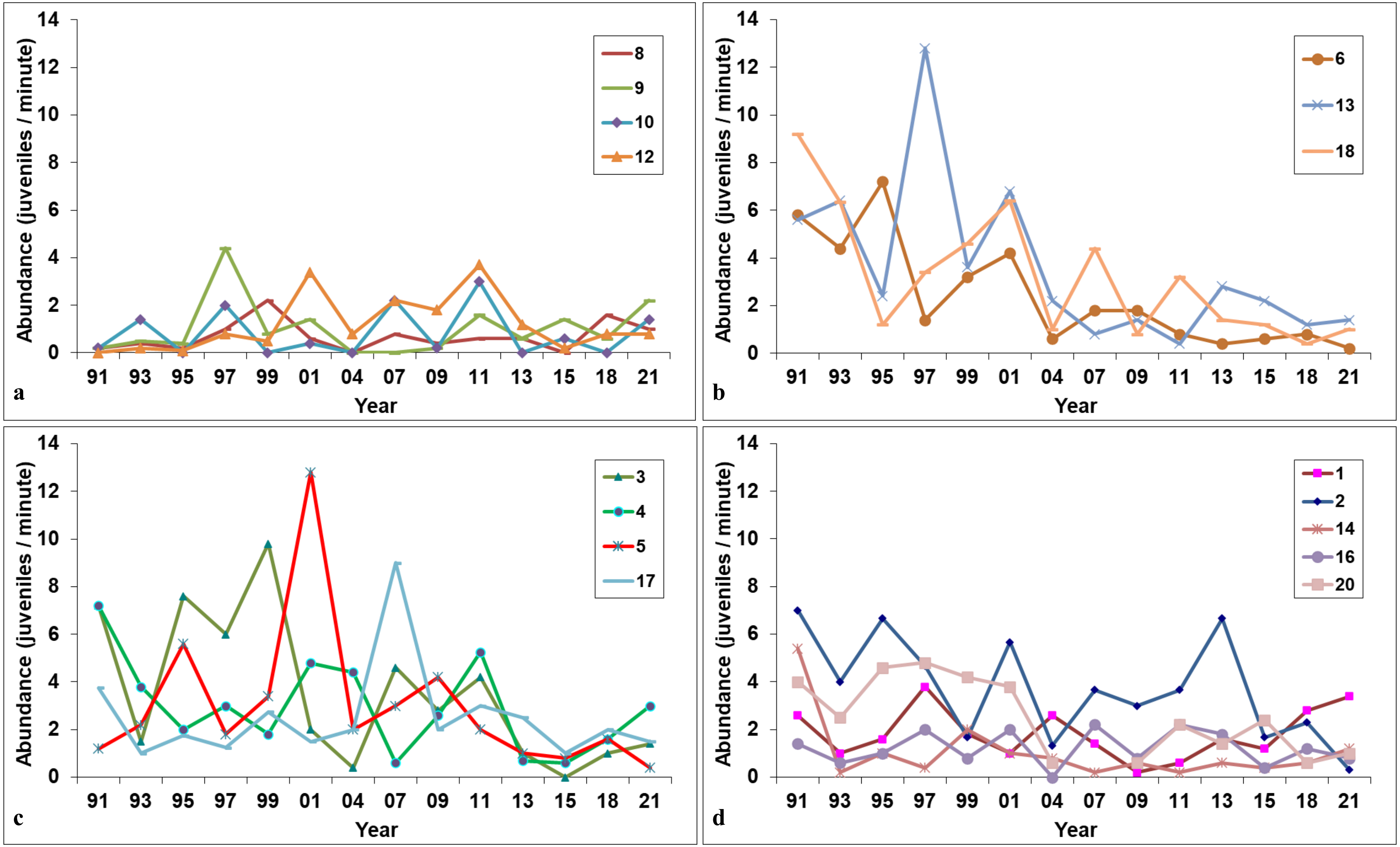

Figure 11 Temporal changes in abundance of juvenile dogwhelks at selected sites in regional groupings: a) Sullom Voe, b) Boundary sites, c) Inner Yell Sound, d) Outer Yell Sound.

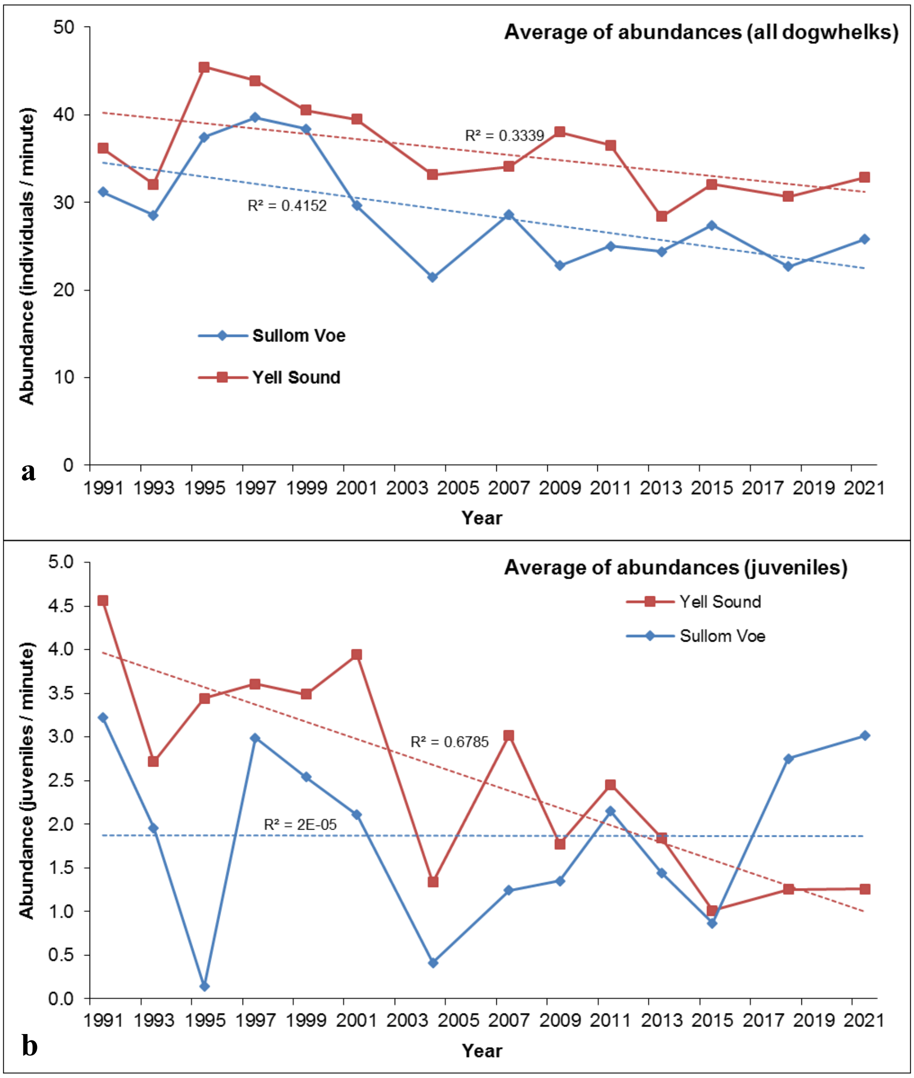

Figure 12 Temporal changes in average abundance of a) dogwhelks (all sizes) and b) juvenile dogwhelks (<16mm) collected from all Sullom Voe sites (7 to 12) and all Yell Sound sites (1 to 6, 13 to 20). Trend lines are included.

The 2018 report (Moore *et al*. 2018) suggested that increasing fucoid cover may be a major factor but supporting evidence was limited to informal observations by the surveyors. Photographs of each site were therefore taken in 2021 and have been compared with the original photographs taken in 1991. Examples are shown in Figure 13 which illustrate the substantial increases in fucoid cover that occurred at several sites, but Table 8 shows that this is not representative of all sites. Some sites had smaller increases in fucoid, some had similar fucoid cover and some had no fucoid in 1991 or 2021 (because they are too wave exposed). Table 8 also shows the percentage changes in dogwhelk abundance between the 1991 and 2021 surveys and shows that large decreases in dogwhelks (all sizes) mainly occurred at sites where there were large increases in fucoids.

Figure 13. Photographs of selected dogwhelk population study areas from the early 1990s (left) and 2021 (right) to illustrate an increase in fucoid cover.

Table 8 Changes in fucoid cover (assessed from comparison of site photos) and percentage changes in dogwhelk abundance, between 1991 and 2021. All dogwhelks = percentage change in numbers of dogwhelks collected per minute. Juveniles = percentage change in numbers of juveniles (<16mm) collected per minute. Coloured bars (using conditional formatting from Excel) are included to highlight the changes.

	Site	Fucoid cover	All dogwhelks	Juveniles
1	Easterwick	No fucoid	-33	31
2	Burgo Taing	Small increase	6	-96
3	Billia Skerry	Moderate increase	21	-81
4	Scarf Stane	Large increase	-44	-58
5	East of Ollaberry	Large increase	-67	-67
6	Grunn Taing	Large increase	-28	-97
7	Tivaka Taing	Small increase	-12	-36
8	Noust of Burraland	Similar	-29	400
9	Mavis Grind	Similar	209	1000
10	Voxter Ness	Large increase	-78	600
11	Northward	Moderate increase	-52	50
12	The Kames	Large increase	92	>1000
13	Skaw Taing	Moderate increase	40	-75
14	Grunna Taing	Small increase	-18	-78
15	Orfasay	Similar	-30	-38
16	The Helliack	No fucoid	27	-43
17	Uynarey	Small increase	43	-61
18	Little Roe	Small increase	-26	-89
19	The Brough	No fucoid	7	-50
20	Norther Geo	No fucoid	-53	-75

4 Discussion and conclusions

4.1 Assessment of imposex data against OSPAR assessment criteria

Changes in VDSI from the 2021 survey worsened in OSPAR Classification for 7 sites across the surveyed area (Table 9). These included changes at 1 site inside the Voe: site 9 (Mavis Grind) which recorded a rise in VDSI from below 0.3 to 0.86 and changing to a class B. One boundary site (site 18 Little Roe) also decreased from class A to B as did five of the Yell Sound sites (sites 1, 2, 5, 14 & 19). The overall assessment status has changed little since 2013 however, as for 2018, all sites are still classed as below the EAC (i.e. OSPAR class A or B) (Figure 14).

Table 9 Temporal changes in OSPAR imposex classes at sites in Sullom Voe and Yell Sound. See Table 2 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	2021
1	19.0	-	-	A	A	A	A	B	A	B	A	B	A	A	A	A	B
2	13.6	-	-	B	B	B	B	B	A	A	B	B	B	A	B	A	B
3	10.4	C	C	C	C	B	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	A
5	5.7	C	C	C	C	C	C	C	B	B	B	B	A	A	A	A	B
6	3.5	D	D	D	C	D	D	D	D	C	C	B	B	B	B	B	B
7	2.3	D	D	D	D	D	D	D	D	D	C	C	C	B	B	B	B
8	1.3	D	D	D	D	D	D	D	D	D	D	C	C	B	B	B	B
9	8.5	D	D	D	D	D	D	D	D	D	D	C	C	B	B	A	B
10	6.3	D	D	D	D	D	D	D	D	D	C	B	B	B	B	B	B
11	3.3	D	D	E	D	D	D	D	D	D	D	C	C	B	C	B	B
12	0.6	E	E	E	E	E	D	D	D	D	C	C	C	C	B	B	B
13	3.5	D	D	D	D	D	D	D	D	D	C	C	B	B	B	A	A
14	10.5	-	-	D	B	C	C	C	B	B	B	C	A	A	A	A	B
15	14.2	-	-	C	B	B	B	B	B	B	B	B	A	B	B	B	B
16	11.0	-	-	C	B	B	B	B	B	B	A	B	A	B	A	A	A
17	8.9	C	C	C	B	B	B	B	B	B	B	B	A	A	A	A	A
18	4.5	D	D	D	D	D	C	C	C	C	C	B	B	B	A	A	B
19	14.5	-	-	C	B	B	B	B	B	B	-	B	A	A	A	A	B
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 2021 show that these sites are significantly more impacted by TBT than populations at sites in Yell Sound. That had been the case in 2015 and all previous surveys, but was not the case in 2018 when the levels of imposex in the Voe were not statistically higher than in Yell Sound. The apparent increases in imposex from 2018 to 2021 are thought to represent inherent variability rather than a change in environmental conditions, but do suggest less recovery than was suggested by the 2018 report. 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. 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). However, a repeat survey in June

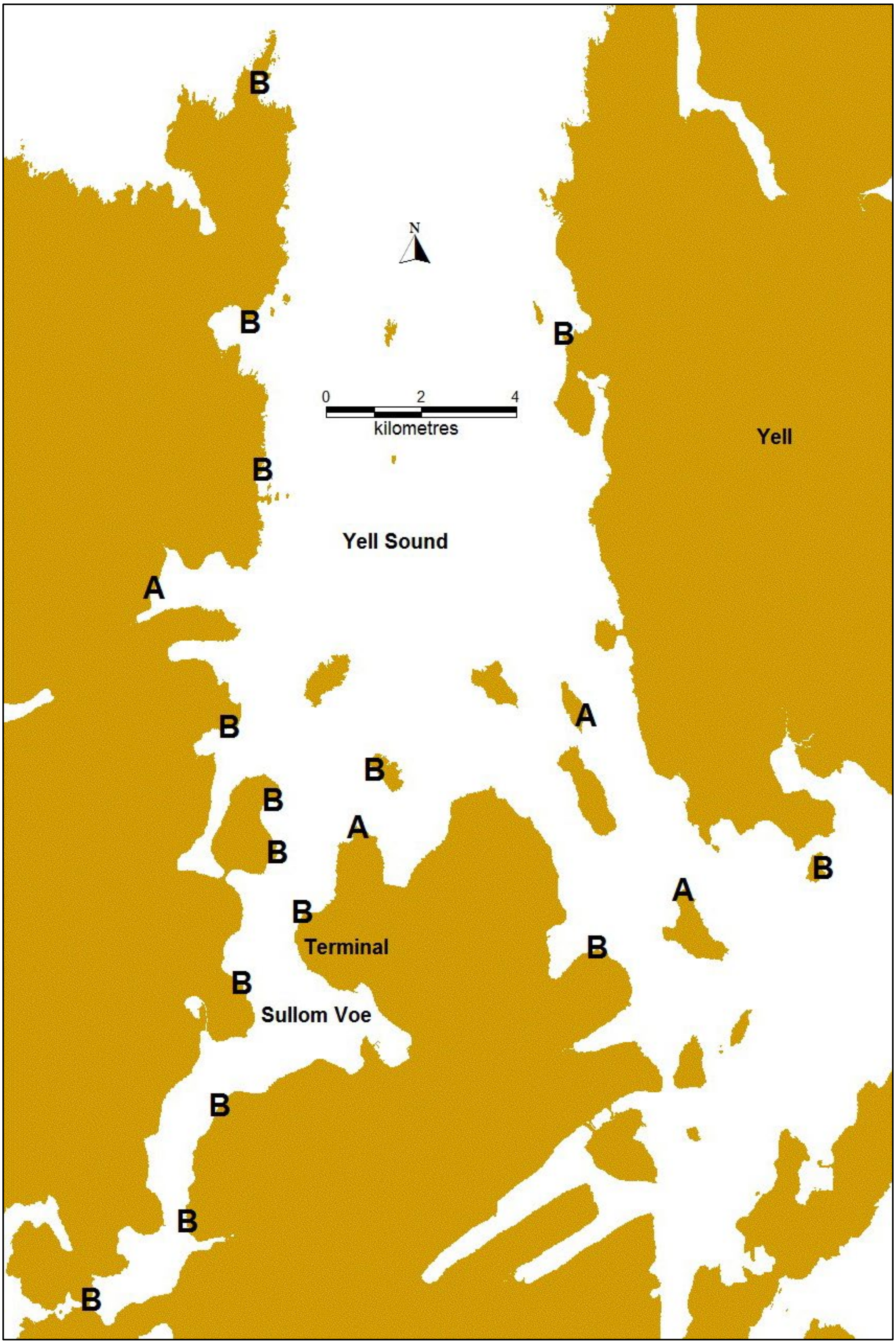

Figure 14 Assessment of VDSI data from adult dogwhelks (Nucella lapillus) sampled from sites around Sullom Voe and Yell Sound in 2021. Data are presented in accordance with OSPAR assessment classes (See Table 2).

2021 (SGS 2022) found much lower concentrations, suggesting that dogwhelks are being exposed to TBT from a different source. The sediments that were sampled for TBT are situated some distance from the rocky shores where dogwhelks live, so may not be representative of contamination close to or on the shores (e.g. in sediment under boulders or long-lived bivalves).

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 or 2021, 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 other changes 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. As with the 2018 results, the VDSI values from all sites were below the EAC indicating exposure to TBT was low.

Data from the rocky shore transect monitoring programme (Moore and Bunker 2022) 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[4] in 1991 and then reappeared in 2006. In 2011 juveniles reappeared under lower shore boulders at the two transect sites between the jetties, the first records there since 1987. It is likely that juveniles were gradually moving south along the lower shore from the populations north of the terminal. In 2018 they were almost back to the levels typically present before the TBT contamination. In 2021 populations on the two jetty transects were higher than ever previously recorded, but at The Kames transect site numbers have shown a downward trend in recent years.

The Kames is not the only site to show a pattern of declining population in recent years, conflicting with the recovery from effects of TBT. Declines were first reported in 2015 (Moore and Gubbins 2015) and the 2018 report (Moore *et al*. 2018) showed that it was statistically significant. This report describes several populations that have reduced and shows some of the photographic evidence that fucoids have increased in some of those areas. Moore and Bunker 2022 provide additional evidence of a link between reducing dogwhelk densities and increasing fucoid cover on some transect sites. The evidence of a relationship is therefore strong but a causal effect is not clear as barnacles (their main prey) are still abundant at those sites. Whatever the cause, it is now complicating the story shown by the imposex data but is not related to activities at Sullom Voe Terminal.

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[4] *The Kames* transect site and *The Kames* dogwhelk site are at different locations; the former being approximately 200 metres closer to the terminal – a significant distance for dogwhelks!

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Appendix 1 Field log of rocky shore monitoring surveys in Sullom Voe 3rd to 16th August 2021

Survey Team: Jon Moore (JM), ASML, Cosheston, Pembrokeshire
Anne Bunker (AB), ASML, Bentlass, Pembrokeshire

(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).

31 July (Saturday)

am/pm	Trains from Whitland to Durham. Stay with Tom Mercer, Frosterley

2 Aug (Monday)

pm	Trains from Durham to Aberdeen.
1900	Northlink ferry to Lerwick.

3 Aug (Tuesday)

Weather:	Dry and bright with full cloud cover and light breeze
Low tide:	0.86m @ 12:40
0730	Arrive on ferry in Lerwick. Pick up hire car. Food shopping in Lerwick Co-op.
0900	Arrive at Picking Shed (self-catering cottage), Lower Voe. Prepare for survey work.
1100	Drive to Mavis Grind
1130-1400	Survey Mavis Grind transect (ST5.5) and dogwhelk population (SVD9)
1430-1600	Pollution Base. Wait for ER staff (John & Ross). Collect life jackets and check RIB *Fugla* etc.
1630	Return to Picking Shed. Data entry and specimens.
Eve	Dinner at Mid Brae Inn.

4 Aug (Wednesday)

Weather:	Sunny with light southerly breeze
Low tide:	0.82m @ 13:40
am	Prepare for survey work. Drive to Lerwick for hire car paperwork.
1130	Pollution Base. Head out in boat, up Yell Sound.
1240-1420	Dogwhelk population survey and collection at Billia Skerry (SVD03)
1430-1520	Dogwhelk population survey and collection at Easterwick (SVD01)
1605-1635	Dogwhelk population survey at Norther Geo (SVD20)
1645-1700	Attempt dogwhelk collection at Sweinna Stack (SVD22), but too few toothed adults found.
1710-1725	Dogwhelk collection at The Brough (SVD19)
1800	Return to Pollution Base and Picking Shed. Put samples of live dogwhelks in net bag in intertidal.
eve	Dinner in Picking Shed.

5 Aug (Thursday)

Weather:	Dry and bright with light southeast wind becoming stronger and southerly late afternoon.
Low tide:	0.74m @ 14:30
am	Prepare for survey work. Drive to Lerwick for hire car paperwork.
1130	Pollution Base. Head out in boat.
1215-1230	Dogwhelk collection at Tivaka Taing (SVD7). Photos for site relocation
1240-1305	Dogwhelk collection at Grunn Taing (SVD6). Photos for site relocation
1315-1330	Dogwhelk collection at Skaw Taing (SVD13) . Photos for site relocation
1340-1500	Dogwhelk collection at The Kames (SVD12). . Photos for site relocation
1510-1530	Dogwhelk collection at Noust of Burraland (SVD8) . Photos for site relocation
1540-1610	Dogwhelk collection at Voxter Ness (SVD10).
1620-1640	Dogwhelk collection at Northward (SVD11).

1700	Return to Pollution Base, then Picking Shed. Put samples of live dogwhelks in net bag in intertidal.
eve	Dinner with Daniel Owen, Gruting.

6 Aug (Friday)

Weather:	Grey but mostly dry, with strong south east wind, backing north east late afternoon. Horrible lashing rain storm for brief period while on boat leaving Voxter.
Low tide:	0.65m @ 15:10
am	Pick up dogwhelk samples from shore and package them in cool boxes, with ice packs (separated from samples by cardboard to avoid them getting too cold).
1145	Meet Will Arthur at SVT. Give him two cool boxes of dogwhelk samples for shipment on overnight ferry to Aberdeen. Dogwhelks to be collected at Aberdeen by Maria Campbell, Marine Scotland, for imposex analysis.
1200	Pollution Base. Head out in boat.
1330-1520	Survey Voxter Ness transect (ST4.6) and dogwhelk population (SVD10). Photos for site relocation.
1540-1625	Dogwhelk population survey at Northward (SVD11). Photos for site relocation
1635-1715	Dogwhelk population survey at The Kames (SVD12). Photos for site relocation
1800	Return to Pollution Base, then Picking Shed
eve	Takeaway fish & chips from Frankies. Picking Shed. Data & photos.

7 Aug (Saturday)

Weather:	Grey, with occasional showers and strong (force 6+) southeast winds, reducing later.
Low tide:	0.56m @ 15:50
am	Drive to Lerwick to exchange hired Vauxhall Corsa (faulty) for Ford Fiesta. Shopping and museum. Return to Picking Shed. Prepare for survey.
1330	Drive to Scatsta and walk along coast to Scatsta Ness.
1410-1515	Survey Scatsta Ness (uncleared) transect (ST6.13). New photos & video for site relocation. Bottom station covered by tide, so not surveyed (but surveyed on 13^{th}).
1525-1630	Survey Scatsta Ness (cleared) transect (ST6.12). New photos & video for site relocation.
1630	Walk back to car, drive to Mossbank and walk to Grunna Taing.
17:25-1815	Dogwhelk population survey at Grunna Taing (SVD14). New photos for site relocation
1900	Return to Picking Shed
eve	Baked ling for dinner at Picking Shed. Data & photos.

8 Aug (Sunday)

Weather:	Mixed. Initially bright with some sun, becoming gloomy with constant drizzle. Light north east breeze.
Low tide:	0.47m @ 16:30
am	Planning survey schedule. Data entry and validation. Photos download and catalogue. Preparation for survey.
1300	Pollution Base. Head out in boat.
1450-1520	Dogwhelk population survey at The Brough (SVD19). New photos & video for site relocation.
1530-1635	Survey West Sandwick transect (ST4.7). New photos & video for site relocation.
1705-1745	Dogwhelk population survey at Unarey (SVD17). New photos & video for site relocation.
1815-1850	Dogwhelk population survey at Little Roe (SVD18). New photos & video for site relocation.
1915	Return to Pollution Base, then Picking Shed
eve	Dinner at Picking Shed. Data & photos.

9 Aug (Monday)

Weather:	Morning: Grey, but dry and bright enough, with just enough wind to keep the midges off. Afternoon: Grey but dry and bright, NE wind force 4.
Low tide:	0.28m @ 05:00; 0.41m @ 17:00
0450	Drive to Lunna and walk to Riven Noust
0535-0700	Survey Riven Noust transect (ST2.9). New photos & video for site relocation.
0800	Return to Picking Shed.

am	Specimens, data entry, data validation, photo download and catalogue. Preparation for survey.
1315	Drive to Brae. Hire cordless drill from Garriock Bros. Pollution Base – head out in boat to Colla Firth.
1500-1610	Survey Ola's Ness transect (ST3.10). Add additional screws for stations D & E.
1635-1700	Dogwhelk population survey at Scarf Stane (SVD04).
1730-1825	Survey Grunn Taing transect (ST4.1).
1820-1845	Dogwhelk population survey at Grunn Taing (SVD06).
1915	Return to Pollution Base
eve	Dinner at Busta House Return to Picking Shed. Preparation for morning.

10 Aug (Tuesday)

Weather:	Morning: initially very dull (used head torch at first site), becoming brighter with some rain and light northerly wind. Afternoon: Grey but dry and bright with light NW wind.
Low tide:	0.22m @ 05:40; 0.38m @ 17:40
0500	Drive to Lunna and walk to West Lunna Pund.
0530-0655	Survey West Lunna Pund south transect (ST5.8). Measure distances between station screws.
0710-0805	Survey West Lunna Pund north transect (ST6.14).
0830	Return to Picking Shed.
am	Data, specimens, photo download, survey preparation and rest.
1400	Drive to Pollution Base. Head out in boat.
1515-1645	Survey Croo Taing transect (ST6.3).
1715-1805	Survey West of Mioness transect (ST1.1).
1820-1910	Survey South of Swarta Taing transect (ST3.5).
1920-1955	Dogwhelk population survey at Skaw Taing (SVD13).
2015	Return to Pollution Base, then Picking Shed
eve	Pizzas at Picking Shed. Specimens, data & photos.

11 Aug (Wednesday)

Weather:	Morning: Drizzle and calm, with some midges, Afternoon: Grey, dry, with force 4 SE wind
Low tide:	0.2m @ 06:10; 0.37m @ 18:10
0500	Drive to Vidlin and walk to Kirkabister.
0550-0700	Survey Kirkabister transect (ST6.11). Then drive and walk to Vidlin Ness.
0725-0900	Survey Vidlin Ness transect (ST3.8). Add additional screws for stations C, D & E
0930	Return to Picking Shed.
am	Data, specimens, photo download, survey preparation and rest.
1430	Drive to Brae. Shopping and Garriock Bros. Pollution Base. Head out in boat.
1630-1705	Survey Gluss Isle East transect (ST3.4).
1715-1740	Dogwhelk population survey at Tivaka Taing (SVD07).
1750-1850	Survey The Kames transect (ST4.3). Add additional screws for station C.
1915	Return to Pollution Base, then Picking Shed
eve	Dinner at Picking Shed. Specimens, data & photos.

12 Aug (Thursday)

Weather:	Morning: Grey but dry and fairly bright with force 3-4 westerly wind; Afternoon:
Low tide:	0.23m @ 06:50; 0.4m @ 18:50
0530	Drive to Pollution Base. Head out in boat.
0645-0745	Survey Roe Clett transect (ST2.3).
0800-0855	Survey South of Skaw Taing transect (ST5.1).
0930	Return to Pollution Base, then Picking Shed
am/pm/eve	Rest. Specimens, data & photos. Preparation for Friday. Dinner with Daniel Owen, Gruting.

13 Aug (Friday)

Weather:	Sunny with light southerly breeze. A few midges
Low tide:	0.3m @ 07:30; 0.46m @ 19:40
0530	Drive to Pollution Base. Head out in boat.
0635-0715	Survey Fugla Ayre transect (ST6.1).
0735-0750	Survey bottom station on Scatsta Ness (uncleared) transect (ST6.13).
0810-0900	Survey Noust of Burraland transect (ST3.3). Add additional screws for stations A, B, C & D.
0910-0940	Dogwhelk population survey at Noust of Burraland (SVD08).
1000	Return to Pollution Base, then Picking Shed
am/pm	Rest. Specimens, data & photos, etc.
1600	Drive to North Roe and walk to survey stations.
1715-1900	Survey Burgo Taing transect (ST3.12). Add additional screws for station A.
1800-1830	Dogwhelk population survey and collection at Burgo Taing (SVD02).
1915-2015	Survey North Burra Voe transect (ST6.14). Add additional screws for stations B & C.
2100	Return to Picking Shed.
eve	Dinner at Picking Shed.

14 Aug (Saturday)

Weather:	Morning: Sunny & initially very calm, increasing slightly. Evening: Grey, dull, with force 4 NW wind
Low tide:	0.41m @ 08:20; 0.55m @ 20:20
0530	Drive to Pollution Base. Head out in boat.
0700-0720	Dogwhelk collection at Uynarey (SVD17).
0740-0810	Dogwhelk population survey and collection at Orfasey (SVD15).
0830-0905	Dogwhelk population survey and collection at The Helliack (SVD16).
0920-0935	Dogwhelk collection at Grunna Taing, Mossbank (SVD17).
0950-1005	Dogwhelk collection at Little Roe (SVD18).
1030	Return to Pollution Base. Return hired drill to Garriock Bros. Return to Picking Shed.
am/pm	Rest. Specimens, data & photos, etc.
1730	Drive to Pollution Base. Head out in boat.
1800-1835	Dogwhelk collection at Scarf Stane (SVD04).
1850-1950	Dogwhelk population survey and collection at East of Ollaberry (SVD05).
2030	Return to Pollution Base, then Picking Shed.
eve	Dinner at Picking Shed.

15 Aug (Sunday)

Weather:	Grey but dry and fairly bright with force 2 NW breeze
Low tide:	0.55m @ 09:10
0730	Drive to Pollution Base. Head out in boat.
0810-0910	Survey Jetty 3 transect (ST5.2).
0930-1025	Survey South of Jetty 2 transect (ST6.2).
1040	Return to Pollution Base, then Picking Shed.
am/pm/eve	Rest. Specimens, data & photos, etc. Dinner at Burrastow House.

16 Aug (Monday)

Weather:	Sunny, with light NW breeze
Low tide:	0.67m @ 10:10
0915-1045	Dogwhelk collection at Mavis Grind (SVD09)
1100	Meet Will Arthur at SVT. Give him cool box of dogwhelk samples for shipment on overnight ferry to Aberdeen. Dogwhelks to be collected at Aberdeen by Maria Campbell, Marine Scotland, for imposex analysis.

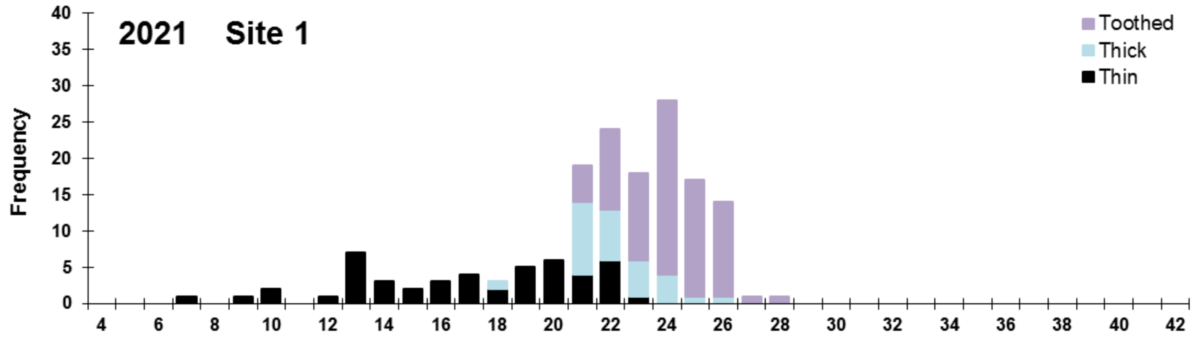
am/pm	Picking Shed. Packing. Leave Picking Shed Lerwick. Bags to Post Office for Parcelforce carriage to Pembrokeshire. Return hire car.
1730	Northlink ferry to Aberdeen

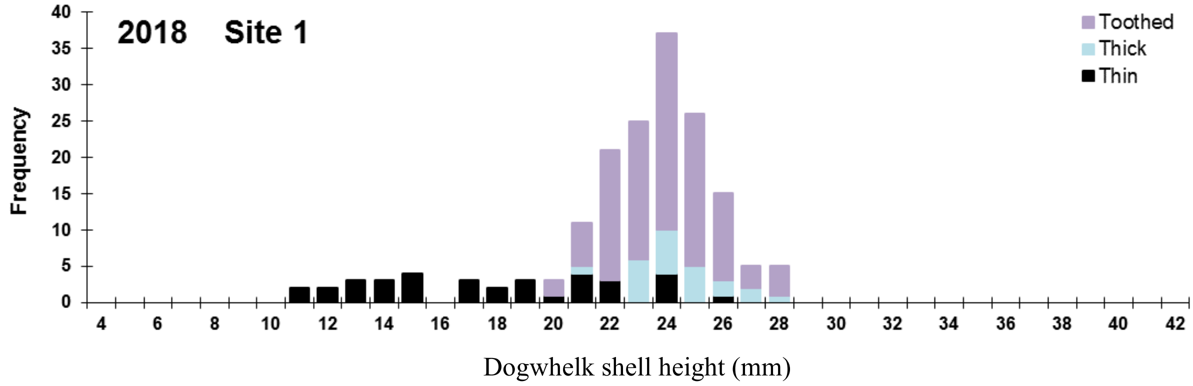
17 Aug (Tuesday)

am/pm	Trains from Aberdeen to Pembrokeshire

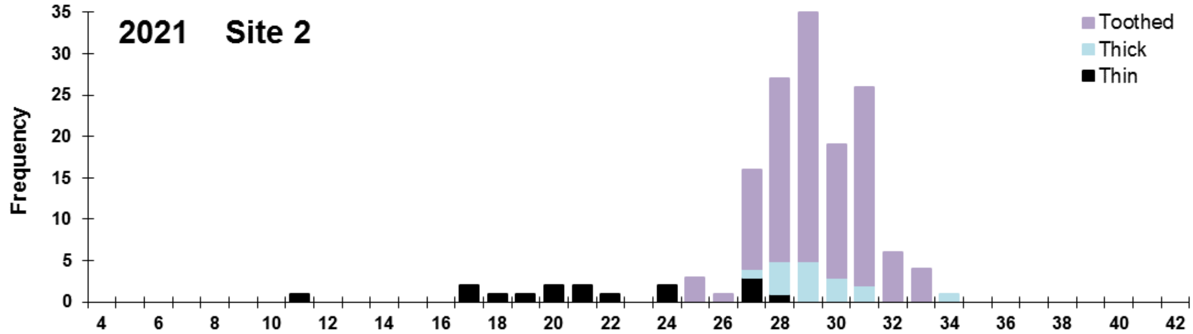
Appendix 2 Size class histograms from 2018 and 2021

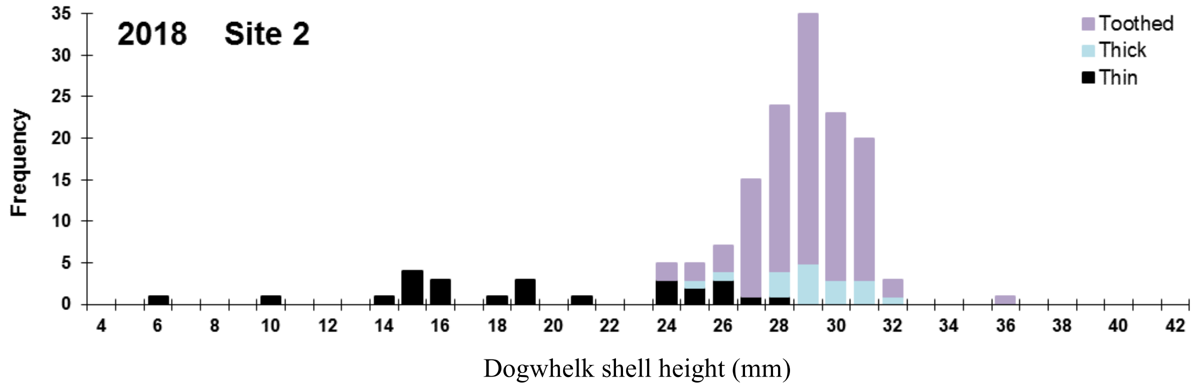
1 Easterwick



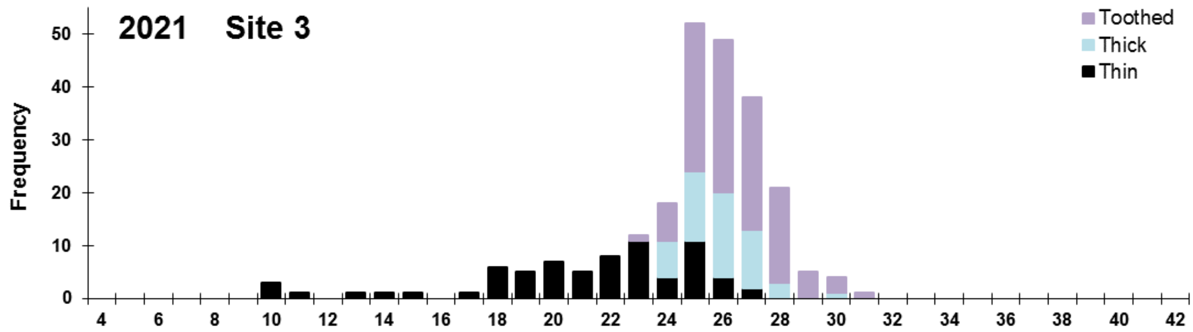


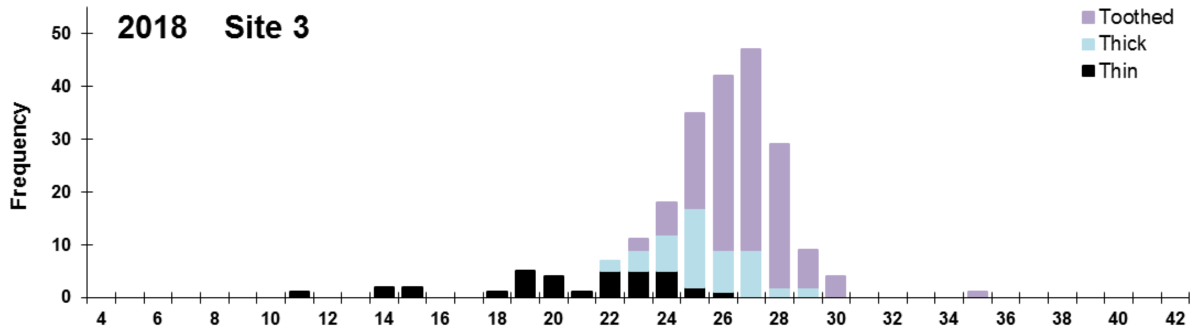
2 Burgo Taing





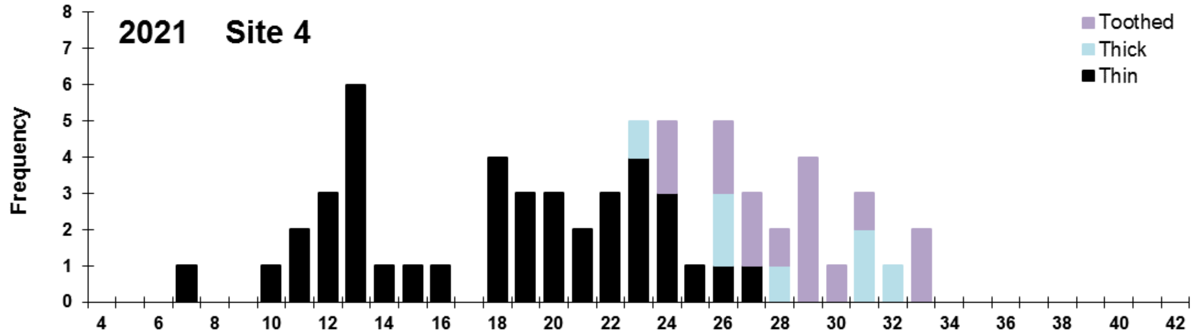
3 Billia Skerry

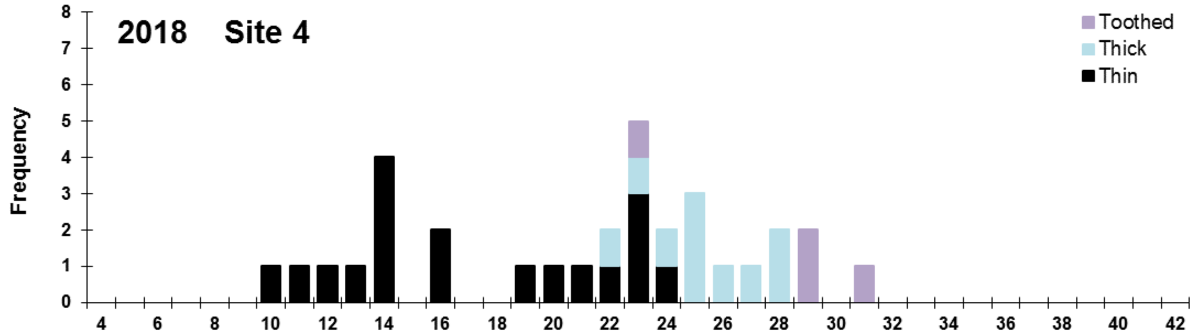




Dogwhelk shell height (mm)

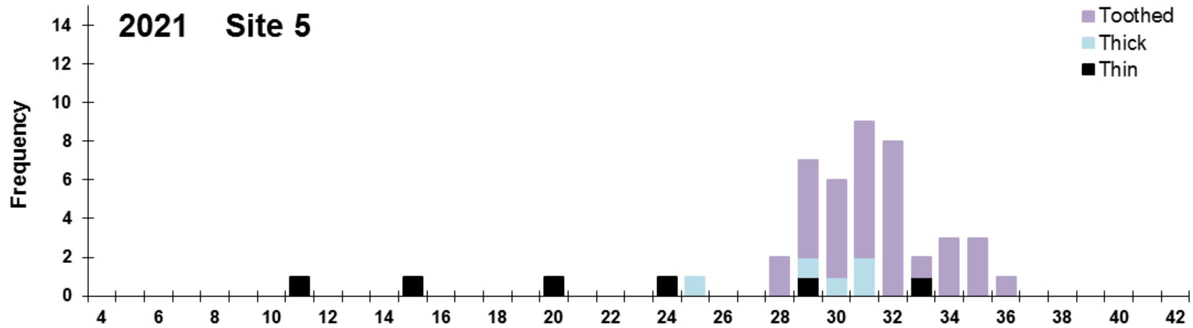
4 Scarf Stane

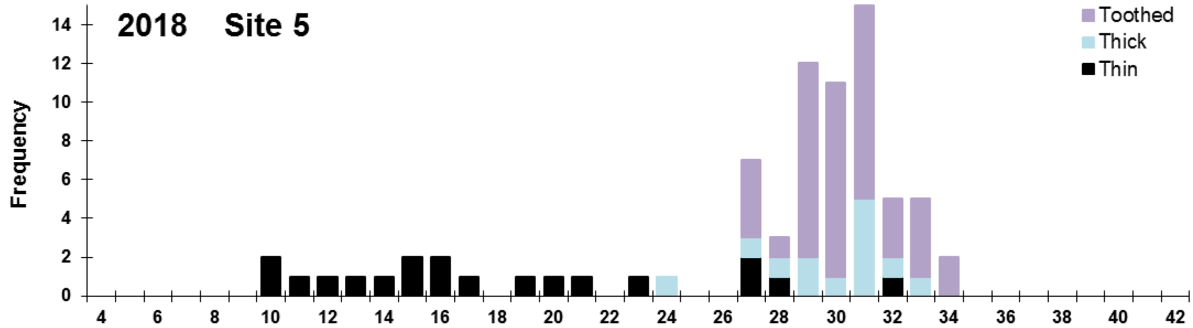




Dogwhelk shell height (mm)

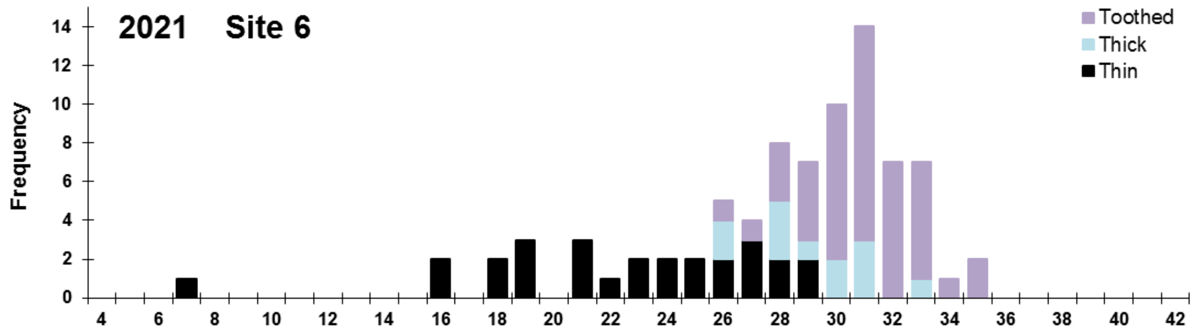
5 East of Ollaberry

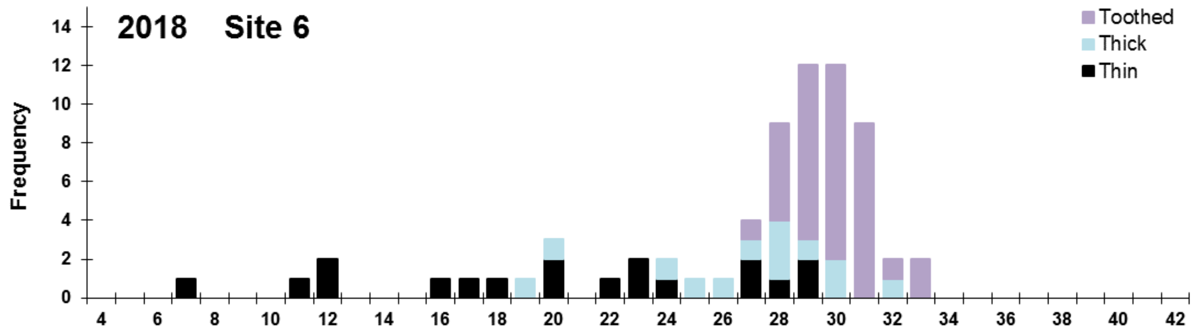




Dogwhelk shell height (mm)

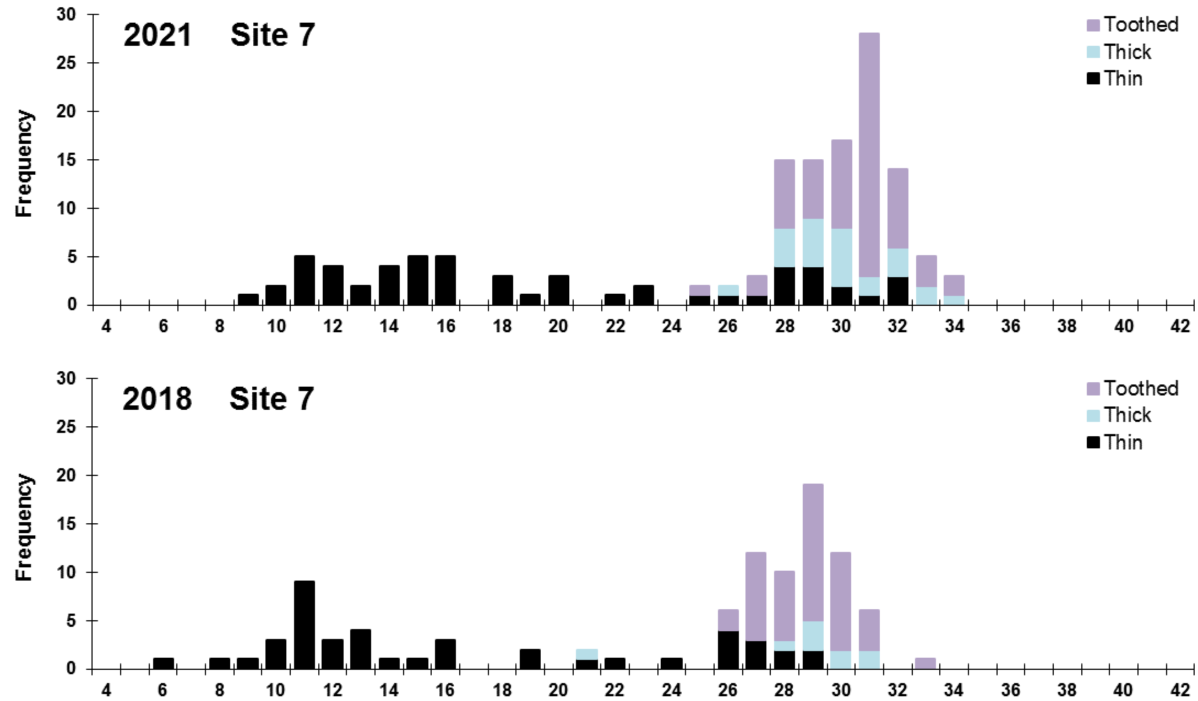
6 Grunn Taing





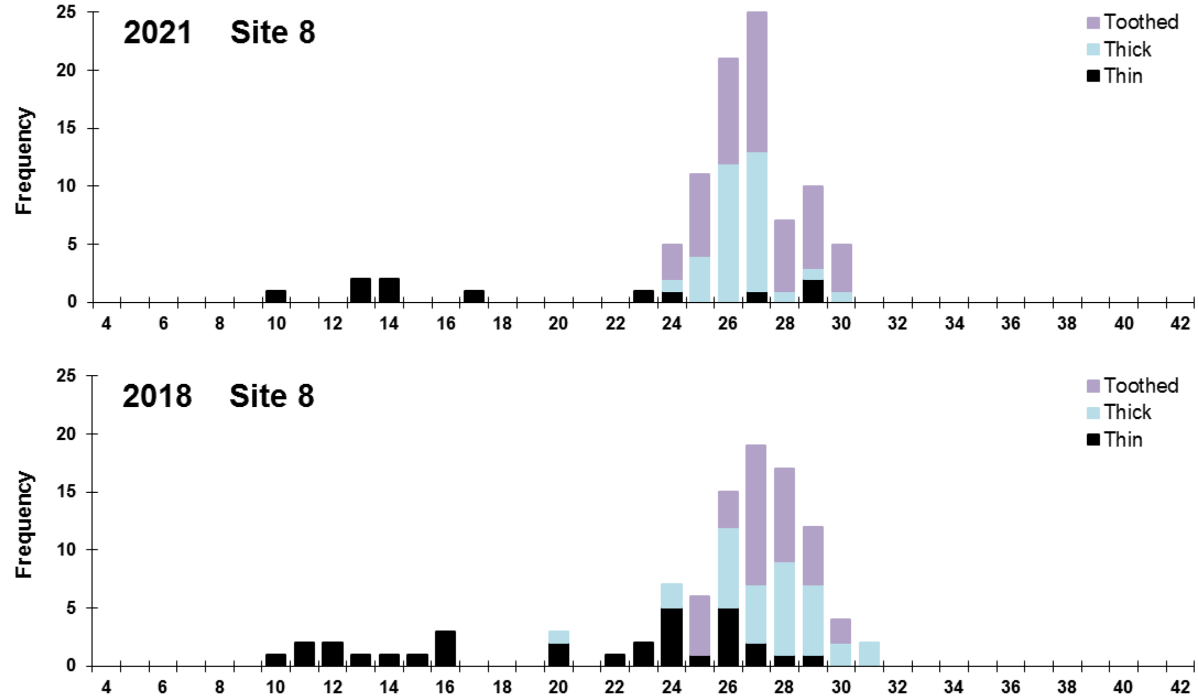
Dogwhelk shell height (mm)

7 Tivaka Taing



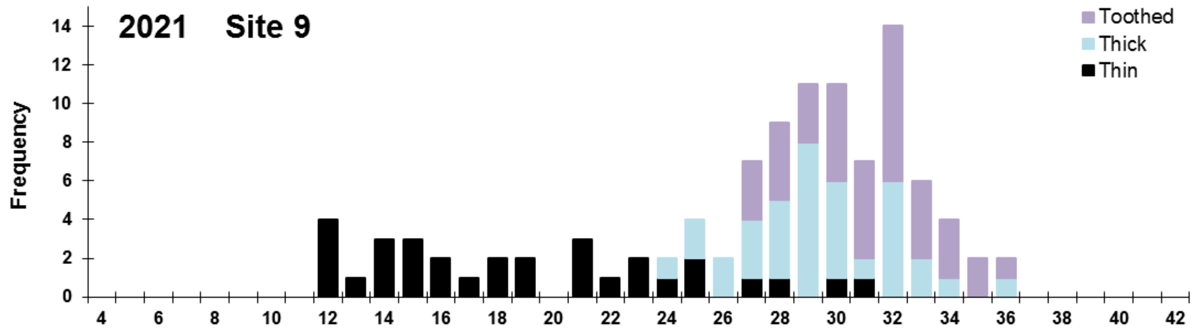
Dogwhelk shell height (mm)

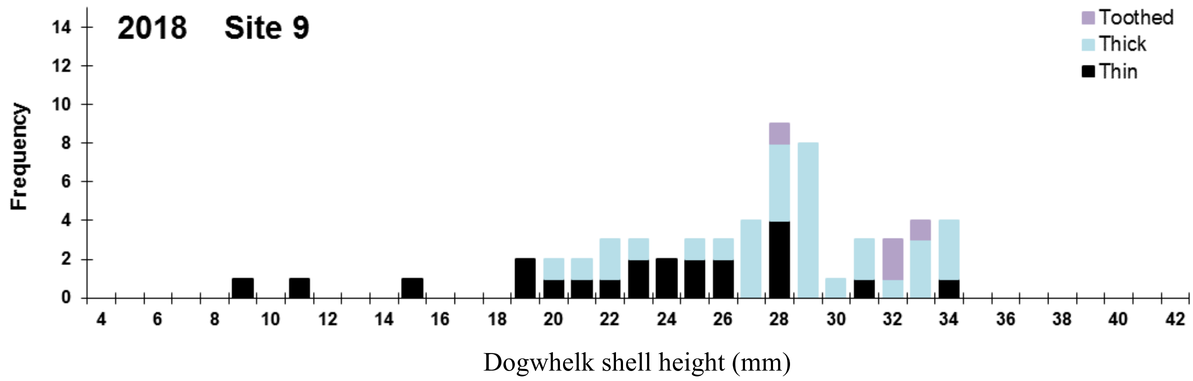
8 Noust of Burraland (Blanches Geo)



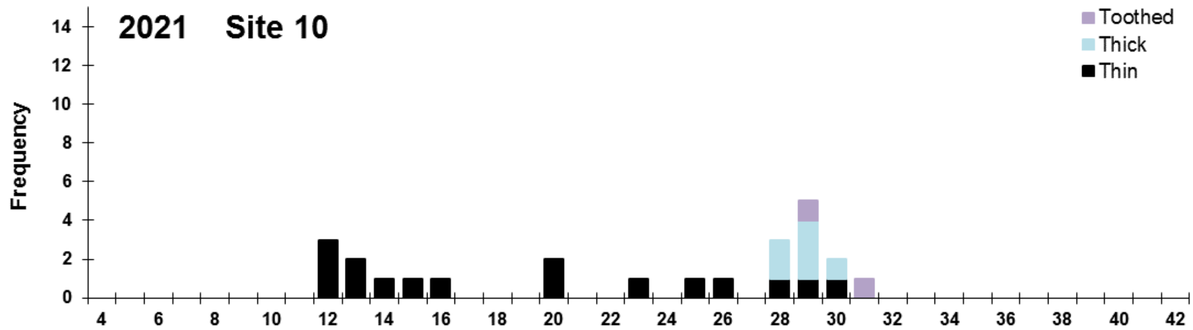
Dogwhelk shell height (mm)

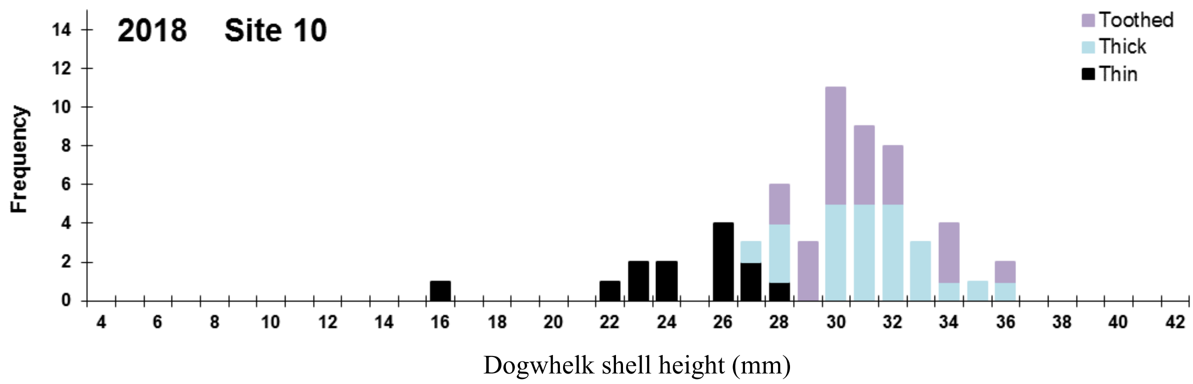
9 Mavis Grind



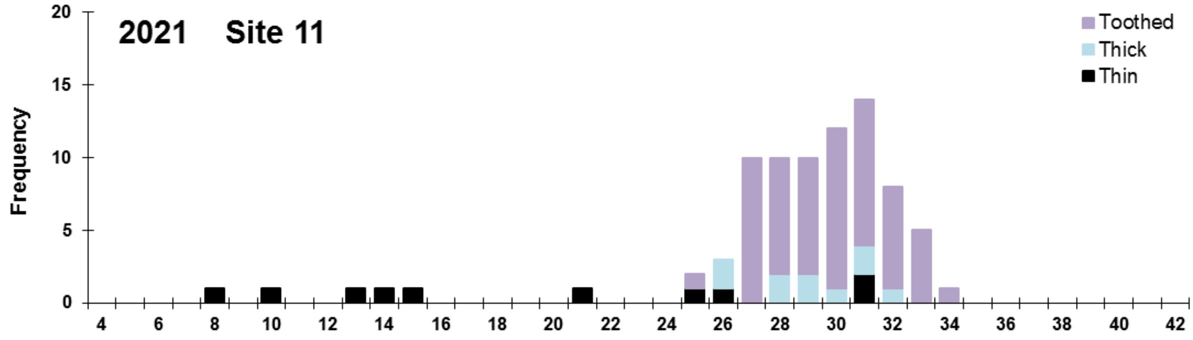


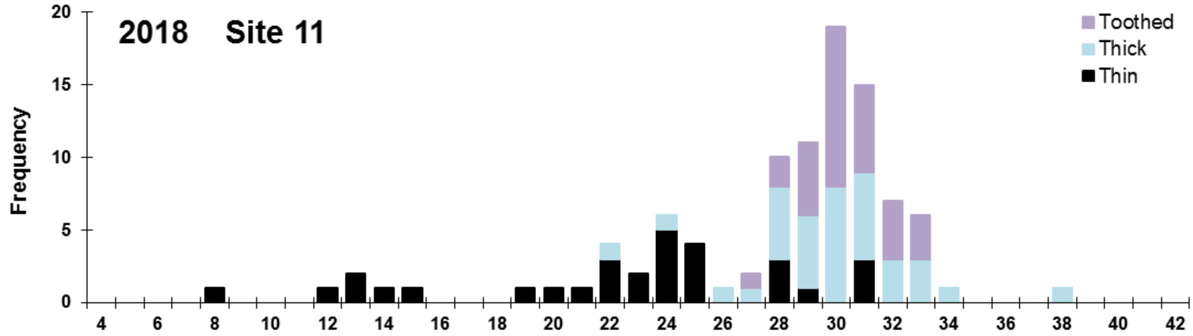
10 Voxter Ness





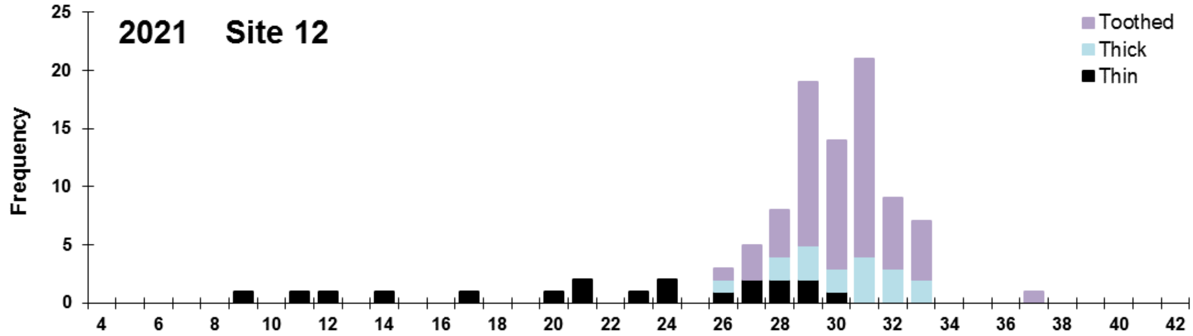
11 Northward

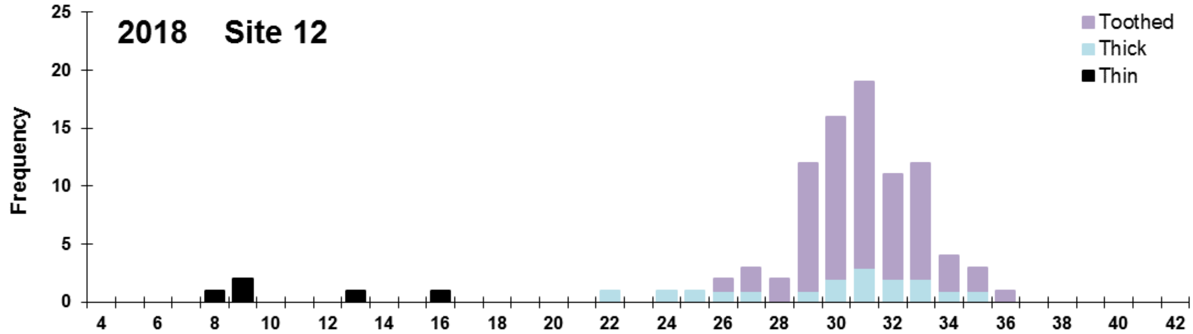




Dogwhelk shell height (mm)

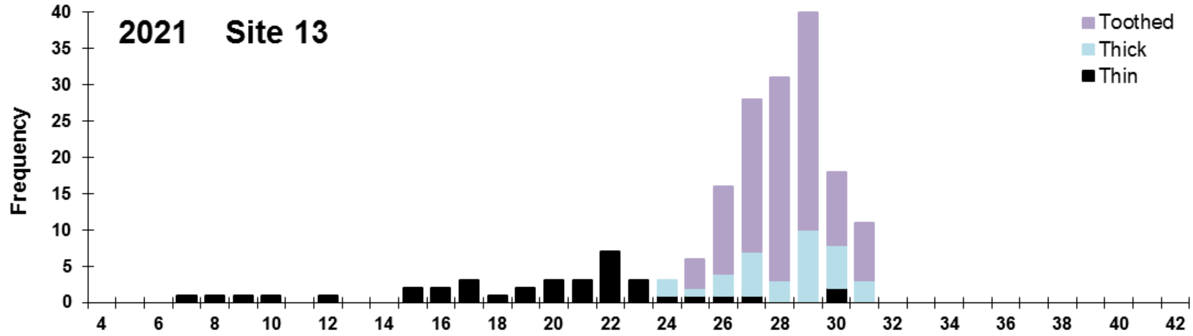
12 The Kames

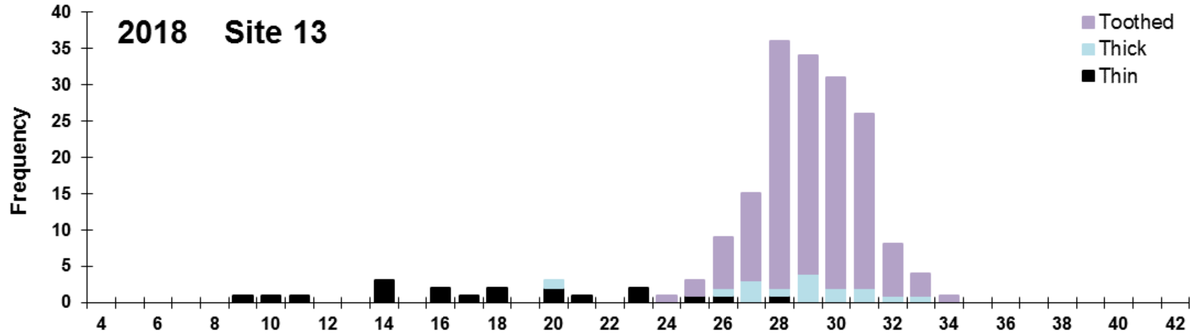




Dogwhelk shell height (mm)

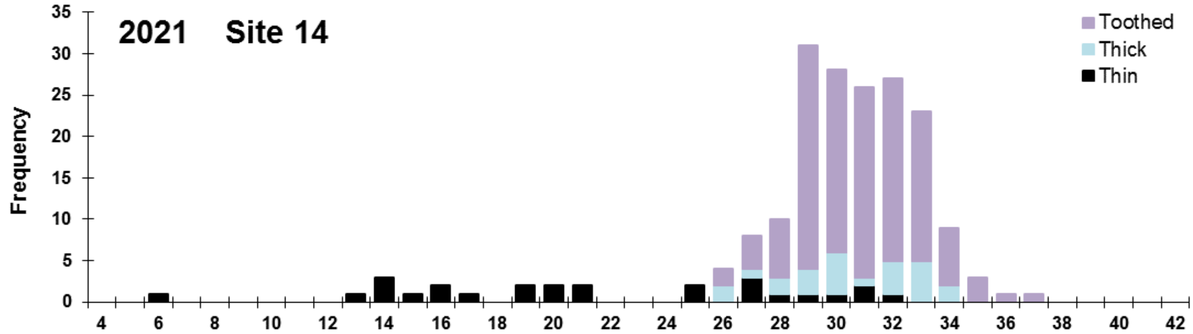
13 Skaw Taing

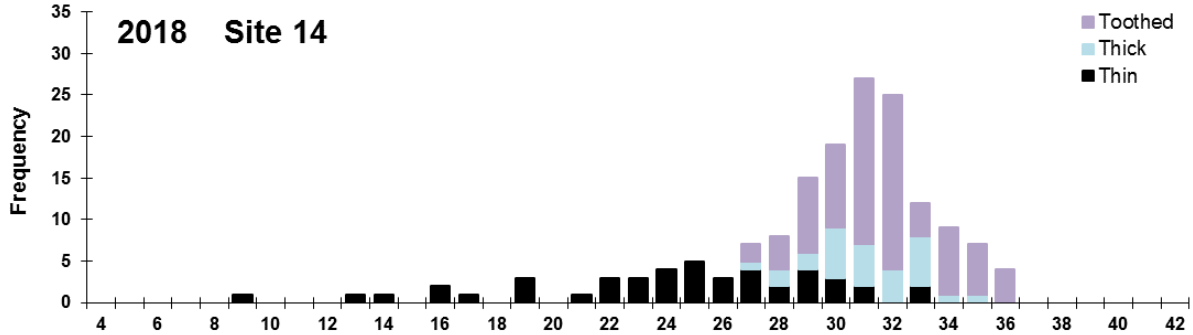




Dogwhelk shell height (mm)

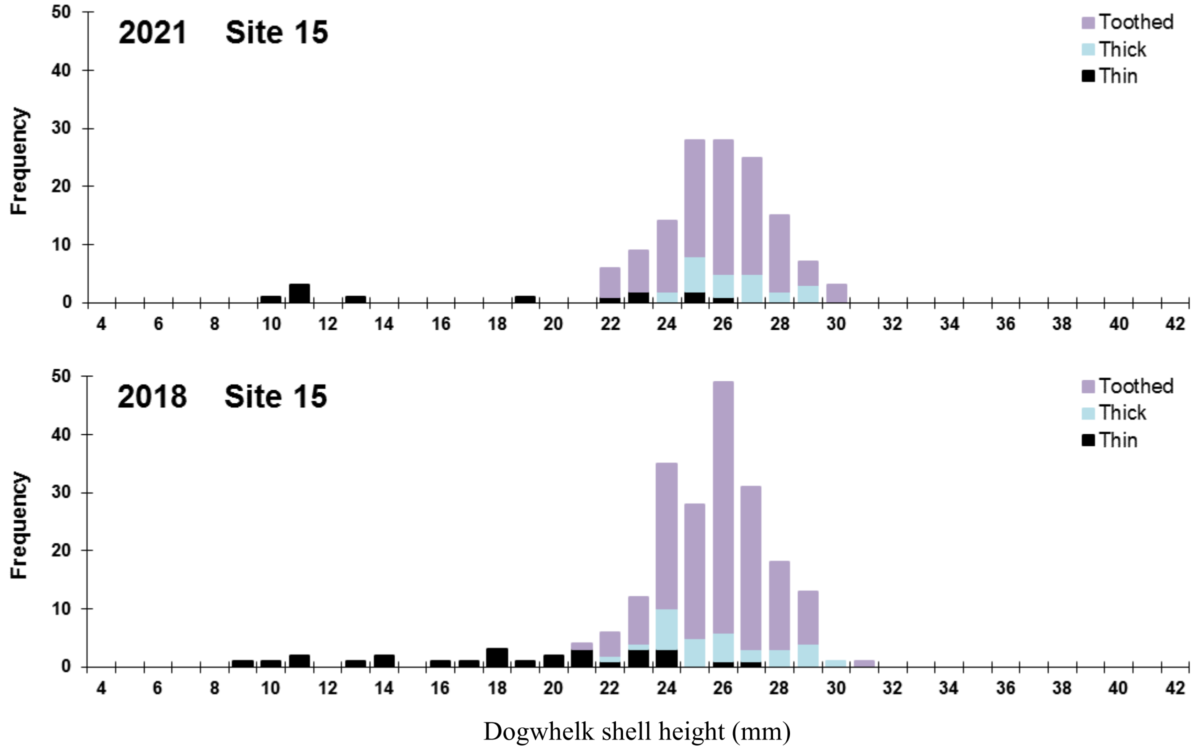
14 Mossbank (aka Grunna Taing)



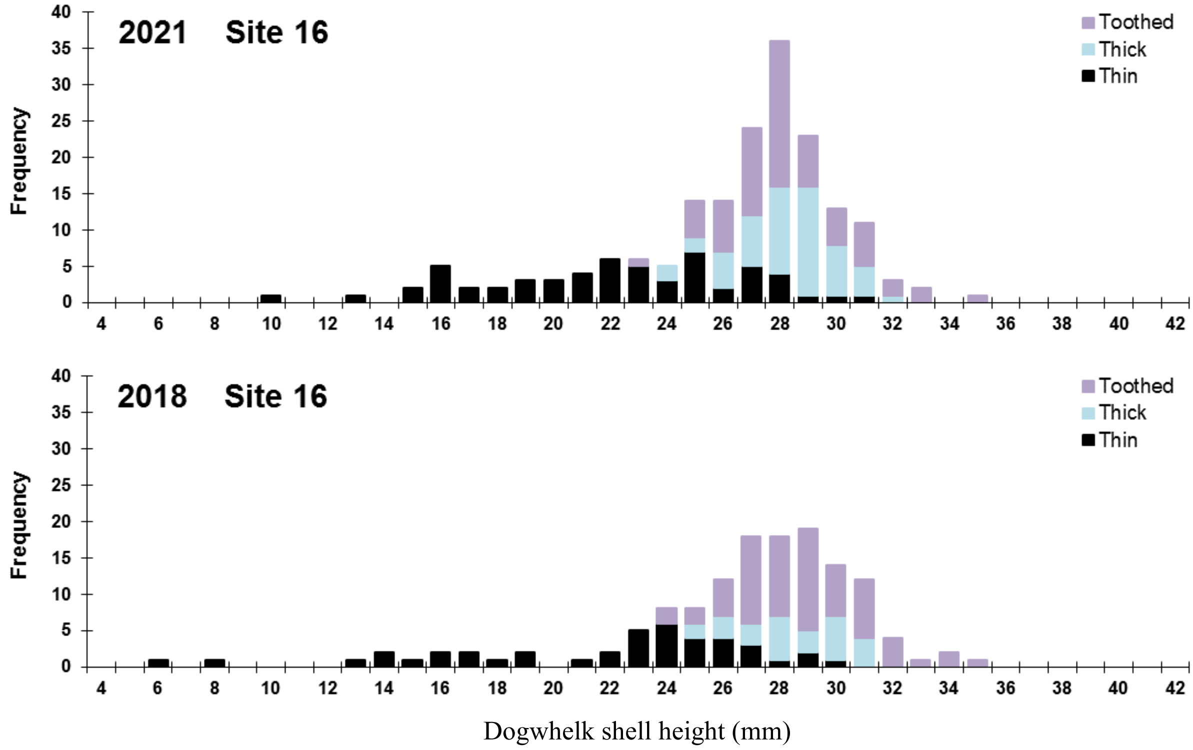


Dogwhelk shell height (mm)

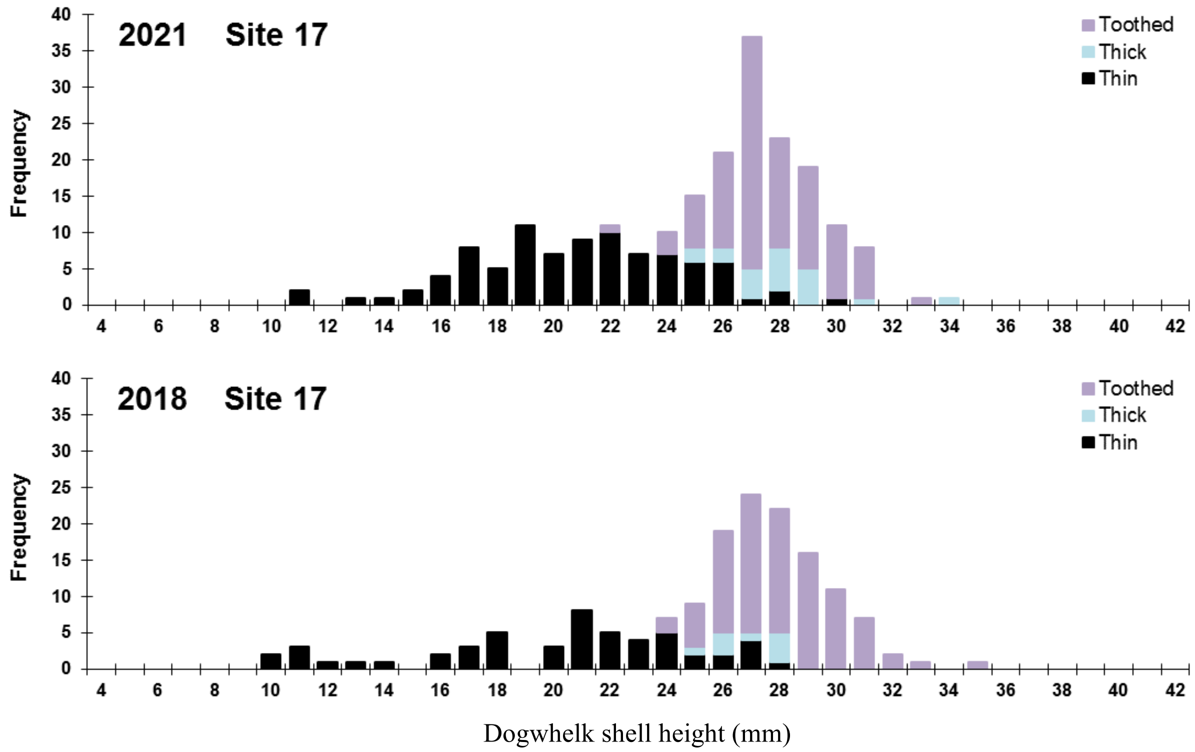
15 Orfasay



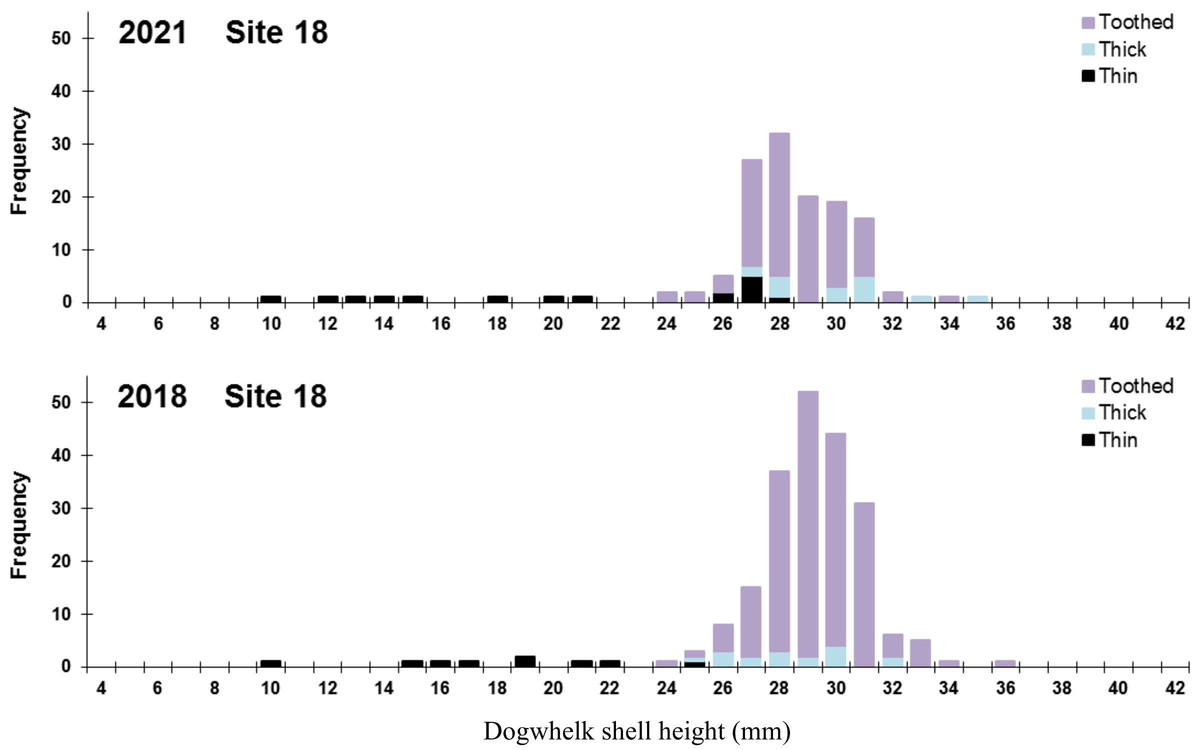
16 Samphrey (aka The Helliack)



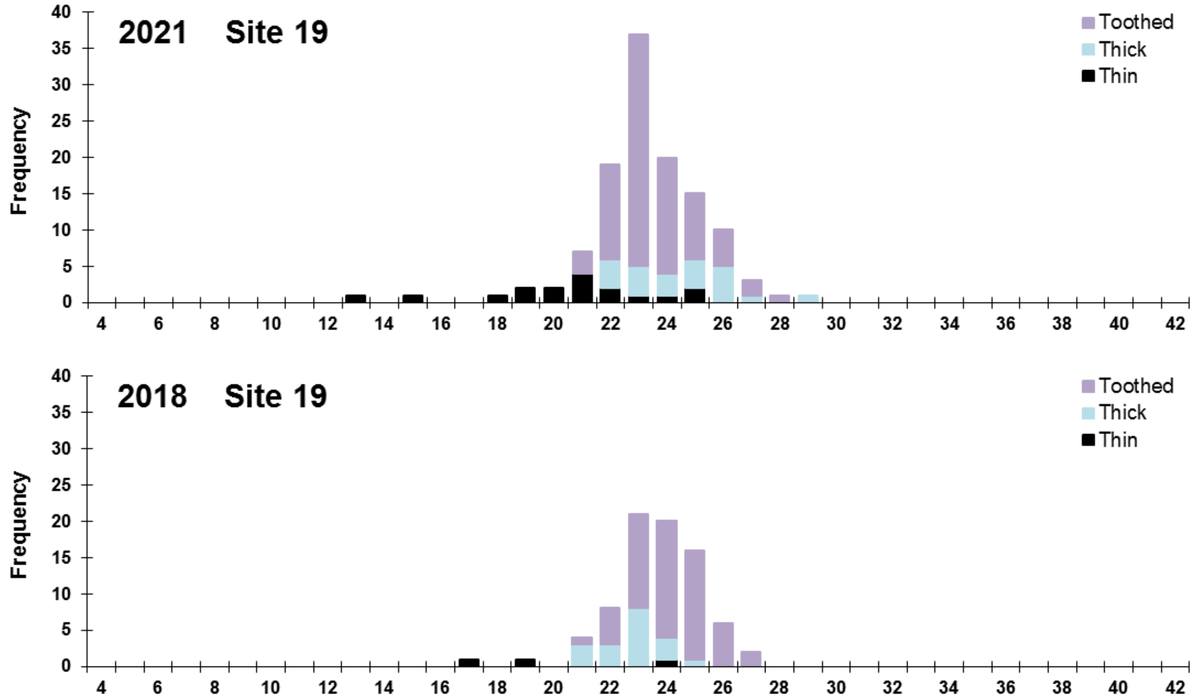
17 Uynarey



18 Little Roe

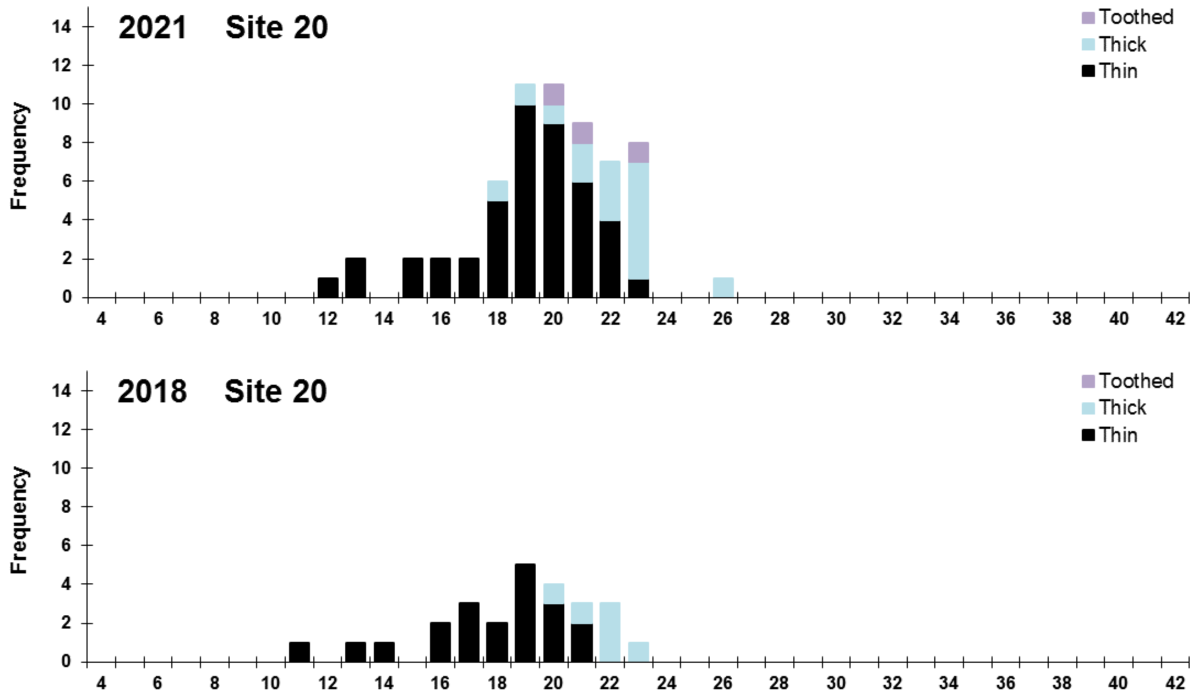


19 The Brough



Dogwhelk shell height (mm)

20 Norther Geo



Dogwhelk shell height (mm)