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Surveys of dogwhelks *Nucella lapillus* in the vicinity of Sullom Voe, Shetland, August 2009

A report for SOTEAG

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Status:	Final
Date of Release:	13th January 2010

Recommended citation:

Moore, J.J. and Gubbins, M.J. (2010). *Surveys of dogwhelks* Nucella lapillus *in the vicinity of Sullom Voe, Shetland, August 2009.* A report to SOTEAG from Aquatic Survey & Monitoring Ltd., Cosheston, Pembrokeshire and Marine Scotland Science, Aberdeen. 56 pp +iv.

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Summary

This report presents the 2009 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 2009. 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 seven surveys, at approximately 2 year intervals, between 1991 and 2007.

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 eighteen 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 ten previous imposex surveys (1987 to 2007) and assessed against the Oslo and Paris Commission (OSPAR) assessment criteria.

The degree of imposex (RPSI and VDSI measurements) in toothed adults from sites within Sullom Voe in 2009 shows that these sites continue to be more impacted by TBT from the oil terminal activities than populations at sites in Yell Sound. The RPSI and VDSI values of populations outside the Voe (RPSI 0.00-0.67%; VDSI 0.2-3.24), in the well flushed waters of Yell Sound, were much lower than at sites within the Voe. As in previous surveys, the degree of imposex in populations in Yell Sound generally decreases with distance from Sullom Voe. Also, while RPSI and VDSI values in adults from Sullom Voe (RPSI 0.01-1.08%; VDSI 1.30-3.67) were generally lower than the values in the 2007 survey, imposex continues to develop in dogwhelks that have recently recruited to those populations, demonstrating that TBT contamination must still be present, possibly in subtidal sediments. Dogwhelks were still completely absent from the rocky shores between the Sullom Voe terminal jetties.

Nevertheless, for the first time in this programme of imposex monitoring, the 2009 data show that there was no evidence of sterility in any of the populations. The RPSI and VDSI measurements at the sites within the Voe show that these populations can continue to reproduce, albeit with lower capacity than they would have without any imposex. Also for the first time since the imposex surveys commenced in 1987, substantial decreases in VDSI have been observed at sites within the Voe and at those at the boundary with Yell Sound, reducing the OSPAR classification of some sites from D to C or B (notably at Voxter Ness (10)). The population data 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.

Sullom Voe populations still, however, fluctuate markedly and show signs of reproductive stress, but it is now suggested that this may not be due solely to the effects of imposex. Dogwhelks on wave sheltered shores, like those in Sullom Voe, are often on the edge of their natural habitat range and are more likely to have seasons of poor recruitment and/or poor survival. It therefore seems likely that some of the apparently abnormal features observed in the Sullom Voe populations may be close to the natural condition, presumably worsened by imposex. Distinguishing any further improvements that are due to the declining imposex may now be more difficult.

Results from four sites in Yell Sound have also been examined closely in this report. While levels of imposex have decreased considerably from 2007 at most sites, increases (substantial in VDSI) were observed at Billia Skerry (3) and Moss Bank / Grunna Taing (14). In the case of Billia Skerry, this was reflected throughout the smaller juvenile size classes, suggesting that this may be the result of locally recently increased exposure to TBT, but the potential cause of this is unclear. However, population data are so far showing no clear signs of an impact at these sites, but will be closely examined in future surveys. At Scarf Stane (4) where imposex and population data were showing an impact from TBT contamination, presumably from a transient source, the 2009 data now suggest that recovery is well underway. Finally, the population at Norther Geo (2), which is unaffected by imposex, has declined for unexplained reasons, possibly related to its isolation.

Generally, the survey indicates continued improvement in imposex incidence across the area, likely resulting from reduced inputs from shipping to the area. The recent IMO ban on TBT paints on large vessels should further reduce these inputs.

Contents

1 Introduction

During the late 1980s and in 1990, SOTEAG-funded surveys of rocky shores in Sullom Voe (Moore, 1990) showed that dogwhelk *Nucella lapillus* populations around the Voe were declining. This observation was supported by work being carried out for the Department of the Environment on imposex in Sullom Voe and other Scottish waters (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 SOTEAG rocky shore monitoring programme in 1991. This was to include detailed studies on dogwhelk imposex and population structure.

Taylor et al. (1992) described the results of that survey, which provided a baseline for any future changes in the structure of dogwhelk populations and the levels of imposex within those populations. The report 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 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. However, at Grunn Taing and Tivaka Taing on Gluss Island, the population structures still appeared normal. 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.

The report also compared the levels of dogwhelk imposex at sites in Sullom Voe and Yell Sound in 1991 with levels found in 1987 and 1990 (Bailey and Davies, 1991). This showed that there had been a progressive decline in the reproductive capacity of female dogwhelks in Sullom Voe.

It was recommended that monitoring of the dogwhelk populations surveyed in 1991 should be carried out at two-yearly intervals and SOTEAG has continued the programme on that basis. Monitoring surveys were carried out in 1993, 1995, 1997, 1999, 2001, 2004 and 2007. The reports from those surveys are available from SOTEAG.

The monitoring has followed the gradual decrease in levels of imposex, an increase in production of juvenile dogwhelks and improvements in population structure at the Sullom Voe sites. By 1997 imposex levels had appreciably reduced and juveniles were being produced, though sometimes in low numbers, at all sites in Sullom Voe. However, a large proportion of females at those sites were sterile, particularly at The Kames 700m north of the terminal. Over the next 10 years the levels of imposex progressively improved but this was not always evident in the dogwhelk population structure, suggesting that other ecological factors were also involved. However, by 2007 the incidence of sterility was much less and juvenile production appeared to be greater at all of the dogwhelk population study sites. It was also apparent over the same period that the increasing numbers of dogwhelks at The Kames was resulting in a gradual migration of dogwhelks south towards the terminal. This was evident in data from a rocky shore transect monitoring site (also called The Kames) that lies approximately 200m south of the dogwhelk monitoring site. Dogwhelks re-appeared at that transect site in 2006, the first dogwhelks that had been recorded there since 1991. More information on the rocky shore transect monitoring programme and the results of the 2009 survey are given in Moore (2009).

This report describes the results of a dogwhelk monitoring survey carried out in August 2009 and compares them with the results of the previous survey (Moore et al., 2007) and other surveys in the programme.

2 Background

Tributyltin (TBT) compounds have been recognised as some of the most toxic substances ever intentionally released into the aquatic environment. Extensive reviews have been published outlining the toxicity of TBT to aquatic organisms (e.g. Hall and Pinkney, 1985; Laughlin and Linden, 1987; Muller *et al.*, 1989; IMO, 1989; IPCS, 1990). The detrimental effects of TBT from small boats and its use in aquaculture were clearly identifiable and appropriate legislative controls introduced. In July 1987, the retail sale of antifouling paints and the sale by retail or wholesale of antifouling treatments containing organotin compounds within the United Kingdom was prohibited (*The Control of Pollution [Antifouling Paints and Treatments] Regulations 1987*). Also in 1987, all antifouling agents, whether or not they contained TBT, became subject to the provisions of the *Food and Environment Protection Act (1985)* and the use of TBT in antifouling products was prohibited on vessels less than 25m in length, and in aquaculture.

The importance of the input of TBT from large commercial vessels in coastal waters, however, has been more difficult to assess, since it is usually impossible to separate the impact of TBT from this source and the effects of other sources, such as adjacent small boat harbours, marinas and ship repair yards. The economics of running large ships requires that they spend the majority of their time offshore, where dilution and dispersion processes quickly reduce the concentrations of TBT released to insignificant levels. There are times, however, when these ships need to dock, and it is at these times in particular that contamination from TBT may be a problem. Further, TBT will also adsorb onto fine particles and thus become concentrated in seabed sediments where degradation is slower (Watanabe *et al.* 1995). Release from these sediments is a long-term contamination issue.

Extensive laboratory and field investigations have been undertaken demonstrating the occurrence of male sexual characteristics in female dogwhelks resulting from exposure to TBT. This condition has been termed imposex (Blaber, 1970). The sensitivity and usefulness of using the dogwhelk as an indicator of TBT contamination is well established (e.g. Gibbs *et al*., 1987; Bailey and Davies, 1989) and has been included in international monitoring programmes under the Oslo and Paris Commission (Davies *et al*., 1997; Gubbins *et al.*, 2004). It has also been shown that the effect of TBT on dogwhelks can cause adverse effects on their population structure (Spence *et al.*, 1990).

In Scotland, the development of the North Sea oil industry led to the requirement for a number of deep water ports able to handle oil and gas tankers. Several new purpose-built ports were constructed, in some cases in relatively remote areas, free from small boat or mariculture activity. Sullom Voe is one such port; the Voe is a large fiordic inlet on the mainland of Shetland (Figure 1). The mouth of the Voe is 2.5km wide and the Voe itself extends approximately 13km southwards (Dooley, 1981). A large oil terminal, situated on the promontory of Calback Ness, was opened in November 1978. There was a peak in the tonnage and number of crude and gas tankers visiting the terminal in 1984 (Figure 2). The tonnage and numbers have gradually fallen since then and in 2008 were at around 20% of the peak levels. There are no fish farms within the Voe and no significant small boat activity occurs in the area. TBT contamination, therefore, arises solely from tankers (Bailey and Davies, 1988) and, up until 1986, from TBT antifoulants used on towing vessels, navigational buoys and harbour craft (Shetland Islands Ports Authority and Shetland Islands Council, *pers. comm.*, 1991). Reductions in shipping traffic, a historical change from free association to co-polymer TBT based antifoulants and recent IMO restrictions on the use of TBT on large vessels (no new applications in 2003 and no exposed TBT paints on vessels in 2008) means that TBT inputs to the area should be reducing.

The following report details results of a survey which used the common dogwhelk (*Nucella lapillus* L.) as an indicator of TBT contamination arising from oil terminal operations in Sullom Voe.

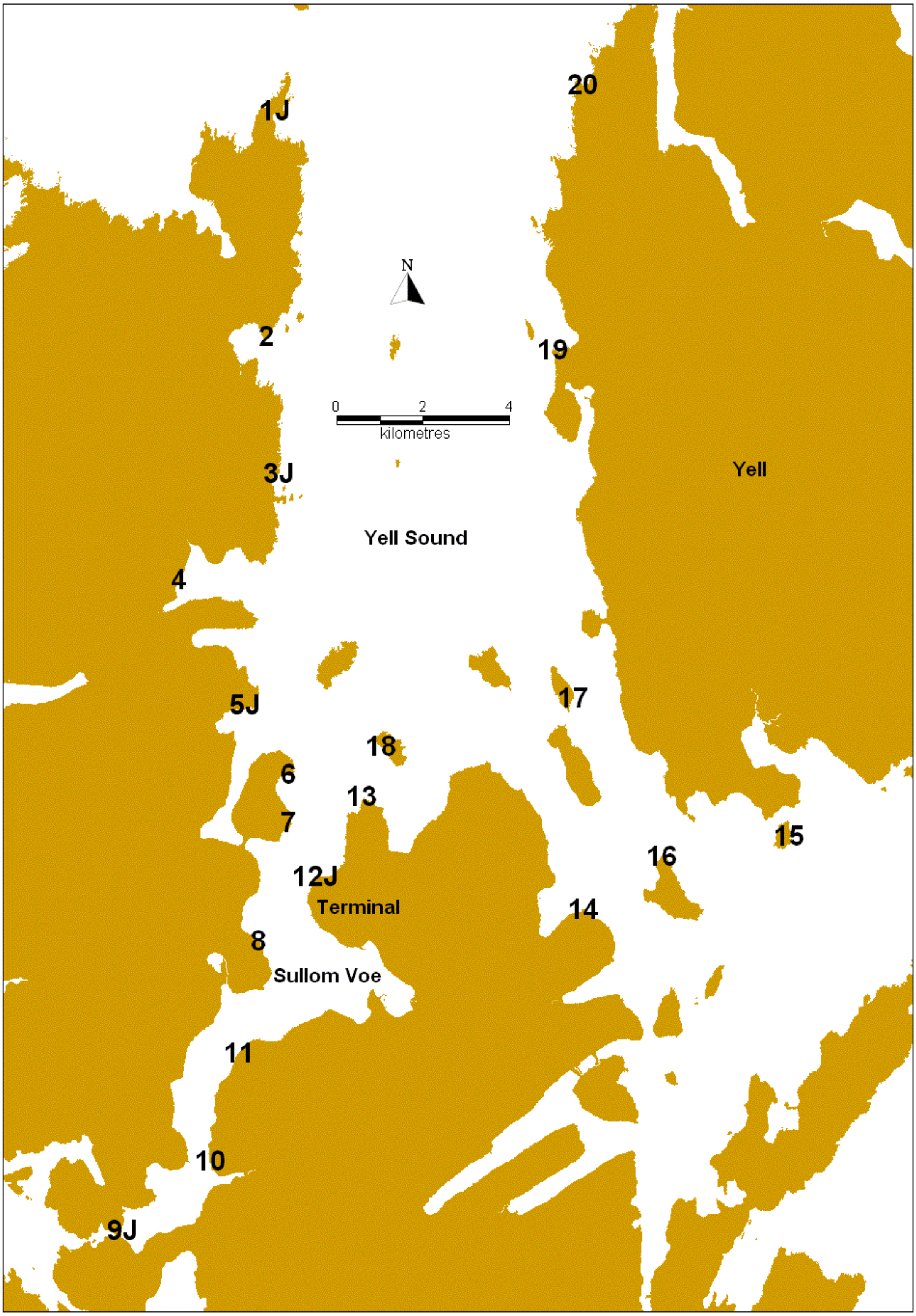
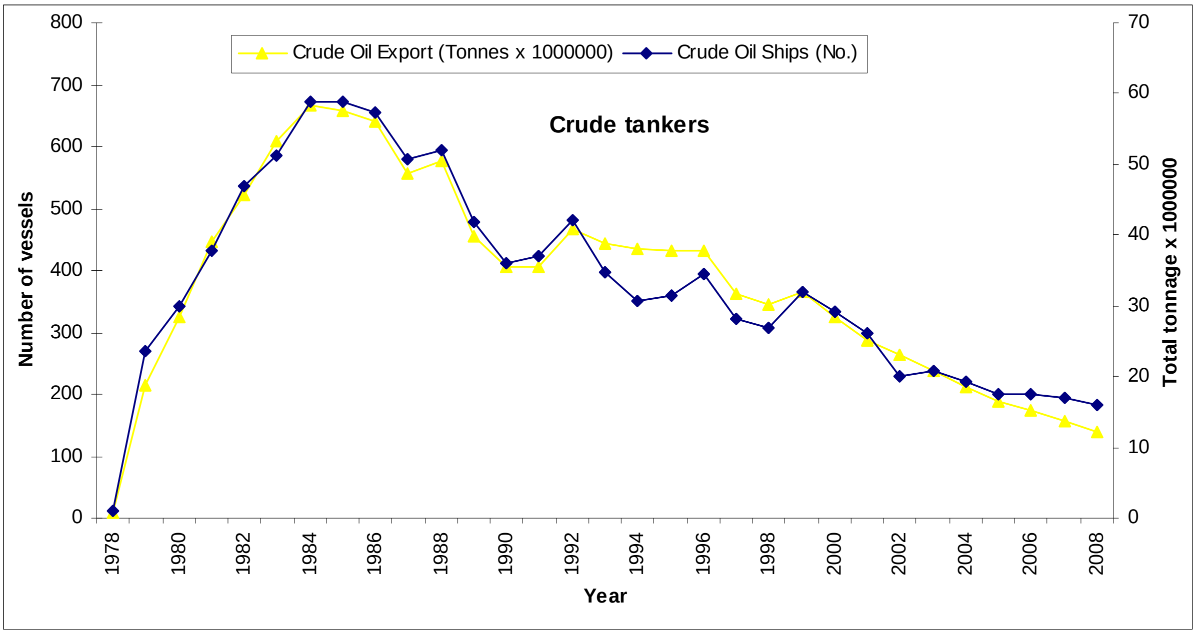


*Figure 1 Dogwhelk sampling sites in Sullom Voe and Yell Sound. (**J** Indicates sites where untoothed adults, sub-adults and juvenile size classes were sampled).*



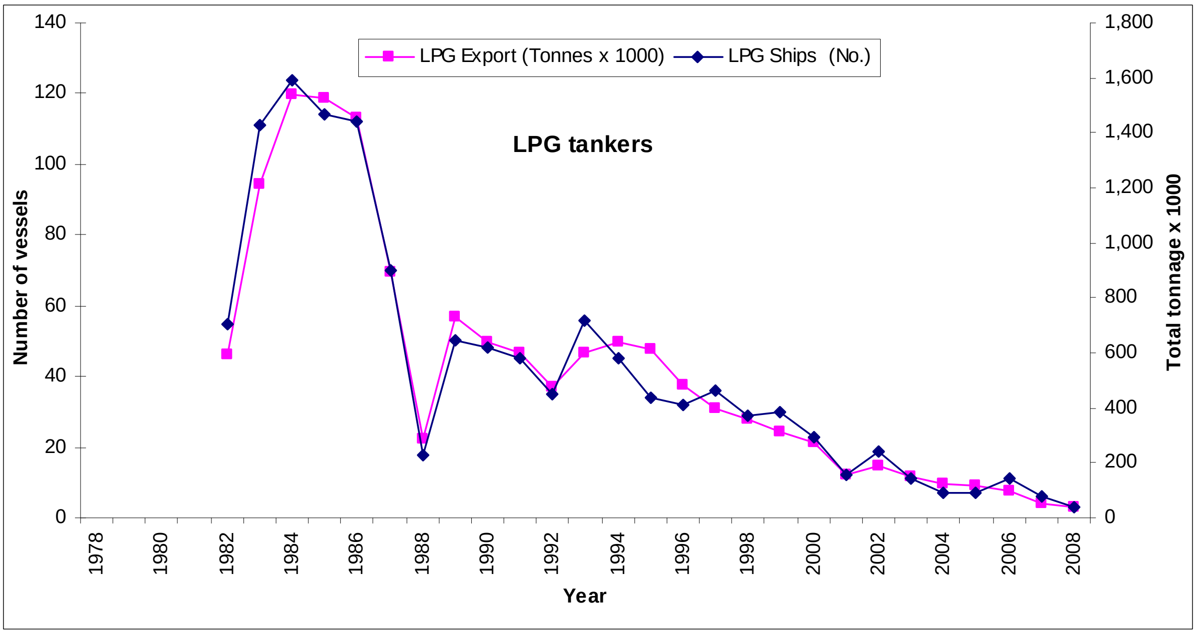


Figure 2 Number and total tonnage of crude and LPG tankers visiting Sullom Voe.

3 Methods

3.1 Field survey

The methodology used in this survey was the same as used in the previous surveys. Fieldwork was carried out by Jon Moore and Christine Howson (with assistance from Gordon Wilson and Dave Manson on 2 days) between the 31st July and the 13th of August 2009. The field log is given in Appendix 1.

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.

The collection of dogwhelks for imposex analysis and the collection and measurement of dogwhelks for population structure analysis were carried out during the same survey.

3.2 Survey site location

Dogwhelk populations were surveyed at 20 sites in Sullom Voe and Yell Sound (Figure 1 and Table 1). The survey was carried out during the same period as a related monitoring survey on rocky shore transects (Moore, 2009).

Table 1 Sampling sites for 2009 dogwhelk surveys. Time is the period used for the population study collections. Asterisks (*) indicate sites where juveniles were collected for imposex analyses, in addition to adults. Easting / Northing are the OS grid ref. positions of the population study sites. The population survey and the sampling at Skaw Taing (13) were carried out on different days for logistical reasons.

	Site name	Easting	Northing	Survey date	Time (mins)
1*	Easterwick	437600	1194300	06/08/09	5
2	Burgo Taing	437400	1189100	11/08/09	3
3*	Billia Skerry	437687	1185940	06/08/09	5
4	Scarf Stane	435400	1183500	12/08/09	5
5*	East of Ollaberry	436900	1180600	10/08/09	5
6	Grunn Taing	437900	1179000	05/08/09	5
7	Tivaka Taing	437900	1177900	05/08/09	2
8	Noust of Burraland	437218	1175147	05/08/09	5
9*	Mavis Grind	434078	1168484	07/08/09	5
10	Voxter Ness	436100	1170090	08/08/09	5
11	Northward	436763	1172569	05/08/09	4
12*	The Kames	438520	1176653	10/08/09	5
13	Skaw Taing	439600	1178500	04/08/09 & 10/08/09	5
14	Mossbank	444702	1175889	12/08/09	5
15	Orfassey	449449	1177576	09/08/09	5
16	Samphrey	446514	1177103	09/08/09	5
17	Uynarey	444474	1180762	09/08/09	4
18	Little Roe	440035	1179648	09/08/09	5
19	The Brough	443997	1188797	10/08/09	2
20	Norther Geo	444700	1194900	06/08/09	5

The sites were originally selected and established in 1991. Selection was made using Admiralty Charts, Ordnance Survey maps, and first hand examination of the shoreline. Sites were selected at varying distances from the terminal area to establish the geographical variation in imposex. The exact placement of each site was based on the presence of whelks and the accessibility.

Accurate relocation of the sites is very important, particularly with regard to the population structure studies. Site location sheets, including annotated photographs, were prepared in draft after the 1991 survey and finalised after the 1995 survey. The annotated photographs and notes provide enough information to allow field workers to return to exactly the same area of search. Ordnance Survey Grid Ref. coordinates have since been collected with handheld GPS (±5m) (see Table 1) and are now used to aid relocation.

3.3 Dogwhelk sampling and field measurement

At each site, a timed search for dogwhelks was carried out within a defined collection area (marked on the site location sheets). One person carried out a general search of the area (ignoring crevices and under boulders), whilst the other only searched crevices and under boulders / cobbles (where juveniles are more likely to be found). The original aim was to collect a minimum of 100 dogwhelks at each site, so the size of the collection area and the standard collection time was originally established to achieve this. 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 (minimum 2 minutes, maximum 10 minutes). The standard collection time for a site is included on the site location sheet. Collection times at most sites have remained fixed to those standard times, but there has been some variation at a few sites to keep the total number of dogwhelks collected within reasonable limits (see Notes below). At sites where the populations are large and very conspicuous on the open rock surface the number of dogwhelks, particularly the adults, collected is affected by the pick-up speed of the collector. From 1997 onwards survey a rule was applied to limit pick-up to one dogwhelk per arm-movement (i.e. disallowing pick-up of multiple dogwhelks in one hand hold). However, this does not remove the potential bias and pick-up rates over 50 per minute should be interpreted with caution.

The shell height of every specimen collected during the search was measured to the nearest millimetre using callipers. 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. The presence of teeth is usually considered a sign that the animals have stopped growing, although field observations and specimens collected at some sites showed that this was not always the case. Individuals sometimes show signs of considerable growth after teeth had been laid down; and a few individuals, confusingly, have thin shell edges and teeth. The presence of teeth was, therefore, used as the primary indication of maturity, even if the shell edge was thin and the teeth were far back in the aperture. The necessity for a thorough examination of each dogwhelk is clearly important.

Particular emphasis was placed on the need to limit destructive sampling of populations with low abundances (see also Notes below). Sampled dogwhelks were normally counted and measured on-site and then carefully returned to the sampling area. Only on a very few occasions, where densities of dogwhelks were particularly high and survey logistics limited the time available, were the sampled dogwhelks taken away from the site and measured elsewhere. Usually these were returned to the site on the next available tide, unless it was clear that the population was so large that our sample would make no significant difference.

Samples of dogwhelks for imposex analysis were then collected from the same site. As this was necessarily destructive sampling, the collection area was usually located a short distance (up to 50m) away from the population survey area. The adult survey required 40 mature adult dogwhelks (identified by thickened shell rim and the presence of teeth) to be taken from each site. Additionally, at five sites a 'juvenile survey' was carried out (sites 1, 3, 5, 9 and 12). At these sites, attempts were made to collect 20 dogwhelks from each of the size classes 10-15mm, 15-21mm, 21-26mm and 26-35mm. At a few sites it was not possible to find 20 of each size class within a reasonable period of time, so some samples were smaller. These additional dogwhelks were also subjected to laboratory analyses for imposex (it is not possible to accurately determine the degree of imposex in individuals with a shell length of less than 8mm). 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.

Notes:

Site 9 (Mavis Grind) was extended to the north in 1993 where a larger population was found. Comparison of data from 1991 takes account of this change.

In 1997 and 1999, the very small populations of juveniles at the Kames (site 12) were considered too small to allow further destructive sampling for imposex analysis, so a new site was established at Brei Wick (site 21), north of The Kames. This site was sampled for imposex analysis only. From 2001, however, the population of the Kames was judged to have recovered sufficiently to allow collection to begin again (but not within the population survey area).

From 2007 onwards at The Kames (site 12) the population study collection time was halved (from 10 to 5 minutes) due to a considerable increase in the dogwhelk population. At this site, the defined collection area is in two parts, separated by a bedrock ridge; so rather than 5 minutes on each part the collection in 2007 and 2009 was just 5 minutes on the southern most section.

3.4 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).

3.4.1 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.

3.4.2 Determination of the Vas Deferens Sequence Index (VDSI)

The development of imposex may be divided into six stages (Figure 3), depending upon the developmental state of both the penis and vas deferens in the female (Gibbs *et al.*, 1987). In the first stage, vas deferens development begins at the site of the vulva, by infolding of the mantle cavity epithelium.

Stage two consists of formation of a small penis behind the right eye tentacle. As imposex progresses, growth of the distal end of the vas deferens, at the base of the newly forming penis, commences (stage 3). Individuals at stage 4 have a fully grown penis, complete with penial duct, and the ends of the vas deferens join. Eventually, vas deferens tissue proliferates over the opening of the vulva (stage 5), rendering the female incapable of breeding since she can no longer release egg capsules. The egg capsules, unable to be released, form a solid mass within the capsule gland. In this final stage (stage 6), the capsule gland eventually 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 which may be used to compare the reproductive competency of different populations. (Note: although it is normally bad practice to calculate a mean of categorical data, the VDSI index is commonly used by most researchers in this field and is used here to allow easy comparison).

The VDSI was assessed for each group of female dogwhelks examined for RPSI determination. A longitudinal incision was made through the roof of the mantle cavity of each individual close to the hypobranchial gland, and the capsule gland then rotated to expose its medial surface. The VDS was determined and the mean VDS calculated to provide an estimate of the VDSI of the population.

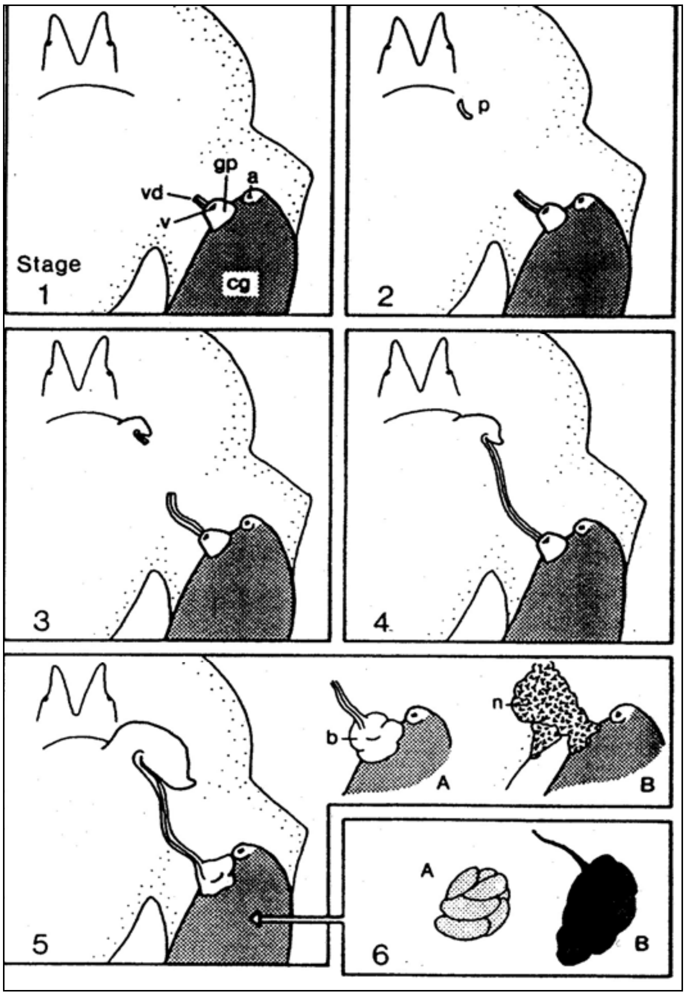


Figure 3 Stages in the development of imposex in Nucella lapillus *(from Gibbs* et al.*, 1987). (Abbreviations: a, anus; b blister; gp, genital papilla; n, nodule; p penis; v, vulva; vd, vas deferens).*

3.5 Population structure analysis

The size/frequency data from the field measurements were entered into a computer spreadsheet (Microsoft® Excel 2003) and 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.

4 Results

4.1 Laboratory studies on degree of imposex

4.1.1 Toothed adult survey

The highest RPSI value (Table 2, Figure 4a) from the toothed adult populations of *N. lapillus* was found at the bottom end of Sullom Voe (site 9, Mavis Grind, 1.08%). The RPSI values from toothed adult populations in Yell Sound (sites 1, 2, 5 and 15-17) were very low (0.03% or less). These low values of RPSI are generally associated with areas distant from sources of TBT (Bryan *et al.*, 1986; Bailey and Davies, 1989). Sites 3 (Billia Skerry) and 14 (Moss Bank / Grunna Taing) showed slightly higher than expected (from previous surveys) values of 0.13 and 0.67 respectively.

The VDSI values (Table 2, Figure 4b) follow a similar distribution to that seen in previous surveys. Populations within Sullom Voe (sites 7-12) showed VDSI values of 1.30 – 3.67. Most of the populations within the Yell Sound (sites 1-5, 15-17, 19-20) had low VDS indices (0.2-0.95). However a single site, Moss Bank / Grunna Taing (14) was an exception, showing a surprisingly high level of VDSI at 3.24.

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

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

Sites 6, 13 and 18 have VDSI values (0.59, 2.77 and 1.95 respectively) which reflect their intermediate position between Yell Sound and Sullom Voe. The VDSI values of animals from these sites are generally lower than those found of animals from Sullom Voe and higher than in populations sampled from sites further out into Yell Sound. However, this year, site 6 shows markedly reduced VDSI, more in line with values expected for sites further out in Yell Sound, and site 14 to the South in Yell Sound now shows higher levels than these boundary sites after a marked increase in VDSI.

Table 2 Results of the 2009 survey of imposex in dogwhelks in Sullom Voe and Yell Sound.

Site No	Name	Size	% RPSI	VDSI	% Incidence of Occurrence	No. Males	No. Females
1	Easterwick	10-15	0.00	0.167	17	6	10
		15-21	0.00	0.273	27	11	8
		21-26	0.00	0.222	22	9	11
		26-35	0.00	0.111	11	9	5
		Adults	0.00	0.455	45	22	18
2	Burgo Taing	Adults	<0.01	0.577	31	26	14
3	Billia Skerry	10-15	22.38	1.571	43	7	6
		15-21	0.11	1.667	78	9	11
		21-26	0.13	1.667	83	12	8
		26-35	0.02	1.643	71	14	6
		Adults	0.13	1.500	65	23	17
4	Scarf Stane	Adults	<0.01	0.950	70	20	20
5	East of Ollaberry	10-15	0.00	0.182	18	11	8
		15-21	0.00	0.273	27	11	10
		21-26	0.00	0.125	13	8	12
		26-35	<0.01	0.175	63	8	12
		Adults	<0.01	0.381	33	21	19
6	Grunn Taing	Adults	0.00	0.588	59	17	23
7	Tivaka Taing	Adults	0.54	2.636	100	22	16
8	Noust of Burraland	Adults	0.41	3.526	100	19	20
9	Mavis Grind	10-15	0.04	1.167	83	6	5
		15-21	10.63	2.358	100	12	4
		21-26	0.17	2.273	91	11	9
		26-35	1.08	3.000	100	10	10
		Adults	1.08	3.667	94	16	24
10	Voxter Ness	Adults	0.01	1.300	83	12	27
11	Northward	Adults	0.31	3.143	95	22	17
12	Kames	10-15	1.06	2.300	90	10	9
		15-21	<0.01	1.000	83	6	14
		21-26	1.42	1.273	75	12	8
		26-35	0.06	1.308	85	13	7
		Adults	0.26	3.000	93	14	26
13	Skaw Taing	Adults	0.26	2.765	100	17	23
14	Mossbank	Adults	0.67	3.235	100	17	22
15	Orfassey	Adults	<0.01	0.400	27	15	24
16	Samphrey	Adults	<0.01	0.333	28	18	22
17	Uynarey	Adults	<0.01	0.381	29	21	19
18	Little Roe	Adults	0.03	1.947	79	19	21
19	The Brough	Adults	0.01	0.375	41	22	16
20	Norther Geo	Adults	0.00	0.200	20	25	14

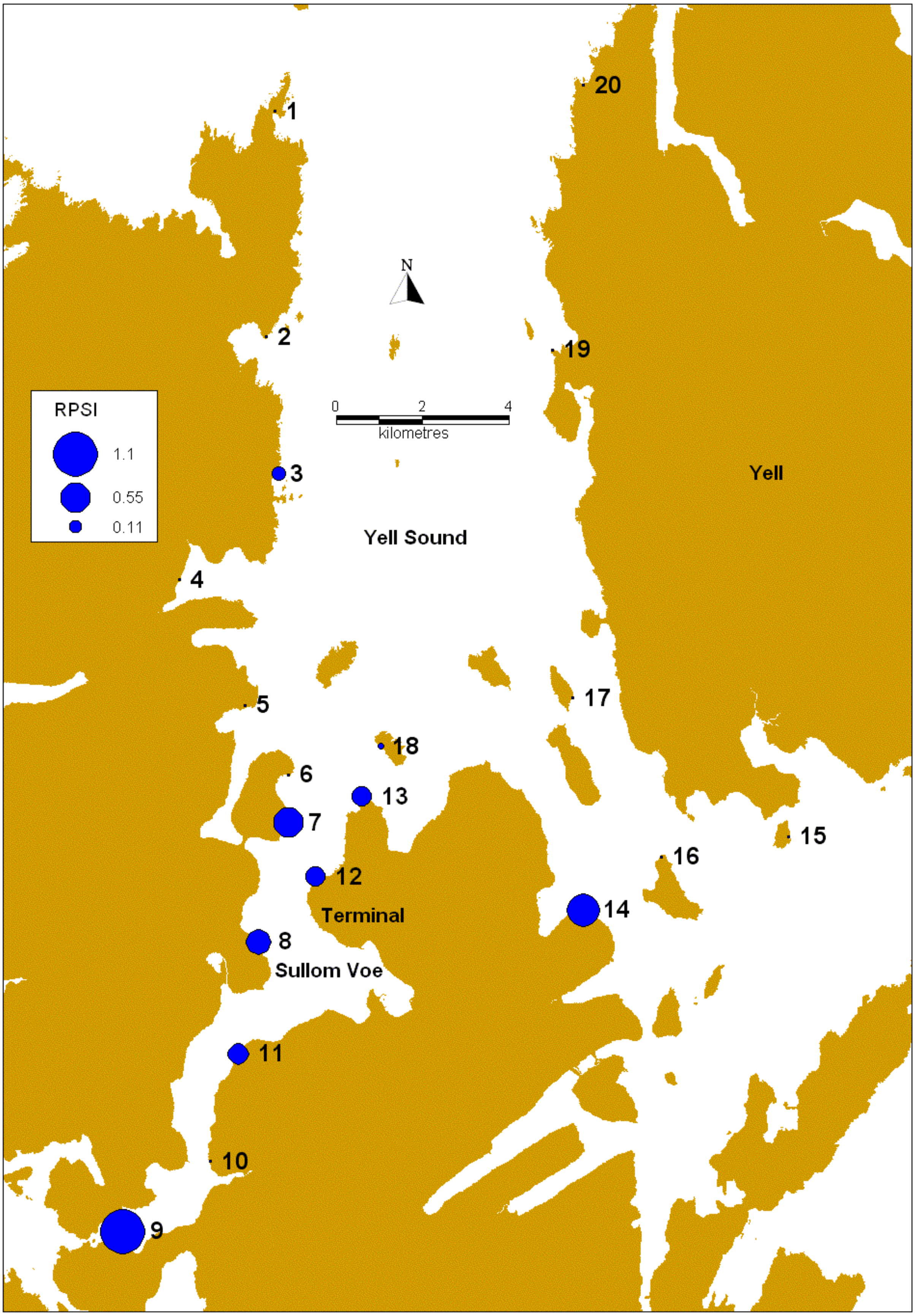


Figure 4a RPSIs in toothed adult dogwhelks (Nucella lapillus) from populations in Sullom Voe and Yell Sound sampled during the 2009 survey.

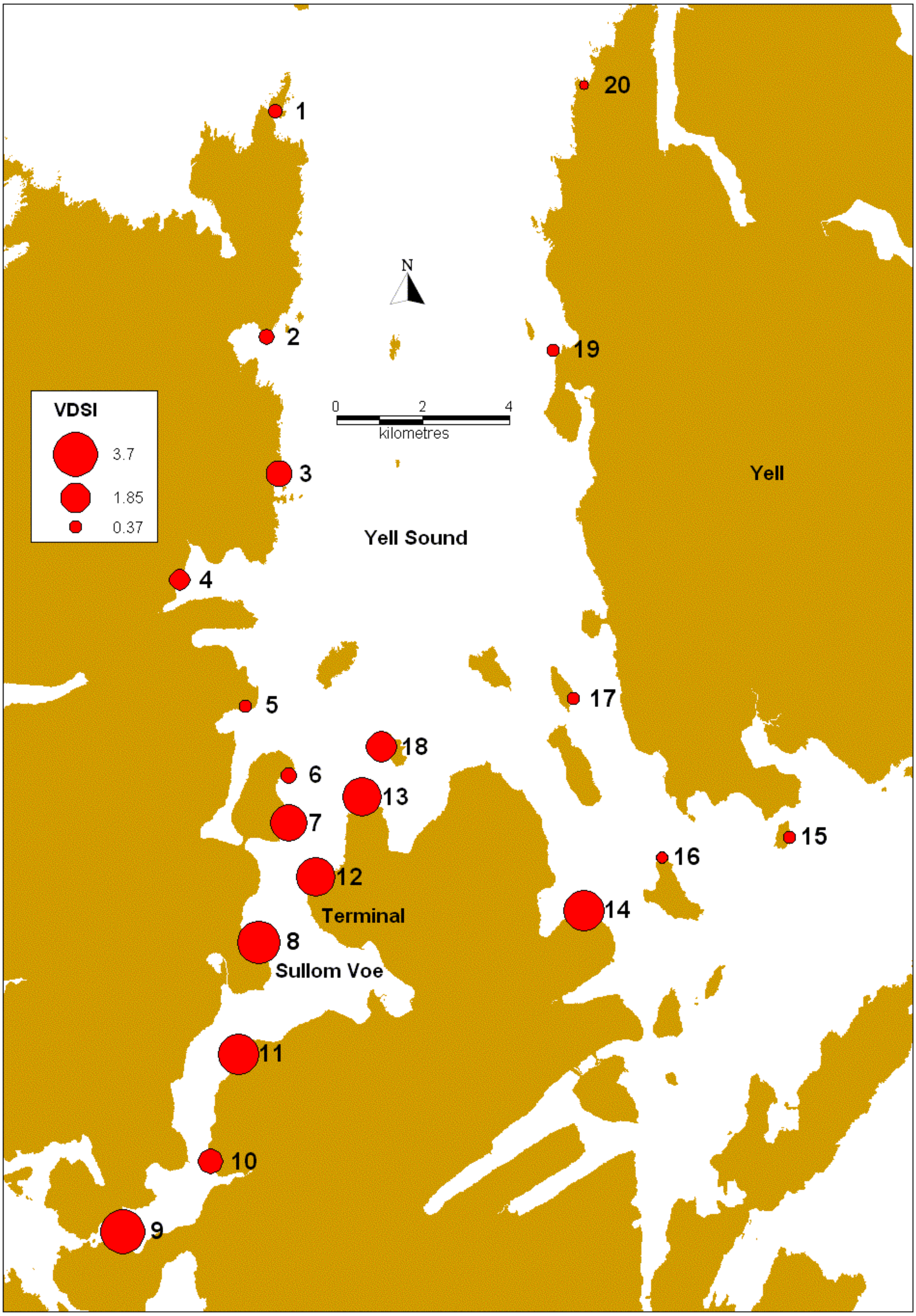


Figure 4b VDSIs in toothed adult dogwhelks (<u>Nucella lapillus</u>) from populations in Sullom Voe and Yell Sound sampled during the 2009 survey.

4.1.2 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 2 & Figure 1, sites marked with a J). As for the survey of adult dogwhelks, the highest levels of imposex (RPSI and VDSI) in these size classes were recorded from the two sites inside Sullom Voe, The Kames (site 12, e.g. 10-15 mm, 1.06% RPSI, 2.30 VDSI) and Mavis Grind (site 9, e.g. 21-26 mm, 10.63% RPSI, 2.36 VDSI) (Table 2).

Sites outside Sullom Voe displayed a much lower level of imposex development in the smaller size classes. Untoothed adults, sub-adults and juveniles from Easterwick (1), and East of Ollaberry (5) demonstrate low RPSI (<0.01%) associated with sites distant from sources of TBT (Bryan et al., 1986; Bailey and Davies, 1989). VDS in individuals of the smaller size classes from sites outside Sullom Voe was also low, in the range <0.3. An exception to this was Billia Skerry (3) where the smaller size classes displayed RPSI up to 22.38% (10-15 mm) and VDSI in the range 1.571-1.667. VDSI in adults from this site was also unusually high (see Section 4.1.1 and Table 2). The fact that both juveniles and adults show higher than expected VDSI would suggest that there is a significant exposure to TBT at this site. These levels of imposex were not recorded in samples from the last survey in 2007.

None of the untoothed adults, sub-adults or juveniles sampled showed VDSI >4, implying that there were no sterile females in these size classes of the sampled populations.

4.1.3 Comparison with previous surveys: Adults

A summary of the results from selected years over the whole monitoring programme is given in Tables 3, 4a and 4b and Figures 5a and 5b. For investigation of temporal trends in imposex, the sites have been classified by location and the data obtained in each survey are shown graphically in Figure 6a for RPSI, Figure 6b for VDSI and Figure 7 for the incidence of sterile females, using the following site designations:

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

Comparison of the degree of imposex in toothed adults

The RPSI and VDSI values for the populations at sites in Sullom Voe (7-12) have generally decreased with time. There is some variability between surveys, but the overall pattern remains one of decreasing imposex with time of animals 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. Changes in VDSI between 2001 and 2007 were smaller than the changes in RPSI, but since 2007 show a marked decrease. Significantly, for the first time, all sites within Sullom Voe show VDSI <4.00, showing that populations appear to be no longer reproductively impaired.

VDSI has decreased since 2007 at all sites except 1, 2, 16 & 20 (where levels were already very low and have changed very little) and at sites 3 (Billia Skerry) and 14 (Moss Bank / Grunna Taing) where the increases have been more substantial (1.2 – 1.5 and 1.08 – 3.24 respectively). RPSI has also decreased or remained at very low levels since 2007 at every site surveyed except these same sites 3 and 14.

Table 3 The numbers of toothed animals and the percentage of females obtained from the surveys in 1987, 1991, 2007 and 2009. 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			2007			2009		
		Total	%F	%FS	Total	%F	%FS	Total	%F	%FS	Total	%F	%FS
1	Easterwick	-	-	-	48	60	0	40	65	0	40	55	0
2	Burgo Taing	-	-	-	40	73	0	40	50	0	40	65	0
3	Billia Skerry	41	54	0	40	50	0	39	38	0	40	58	0
4	Scarf Stane	40	63	0	38	45	0	40	58	0	40	50	0
5	East of Ollaberry	40	50	0	37	62	0	40	50	0	40	53	0
6	Grunn Taing	40	45	0	39	49	0	40	45	0	40	43	0
7	Tivaka Taing	40	45	22	39	44	29	40	48	0	38	58	0
8	Noust of Burraland	40	35	21	38	29	91	40	68	11	39	49	0
9	Mavis Grind	40	48	21	29	28	63	40	23	11	40	40	0
10	Voxter Ness	30	57	65	39	26	60	40	23	0	39	31	0
11	Northward	40	40	44	40	28	91	37	35	8	39	56	0
12	The Kames	38	42	93	39	44	100	40	48	21	40	35	0
13	Skaw Taing	40	50	0	39	44	35	40	38	0	40	43	0
14	Mossbank	-	-	-	40	50	15	40	30	0	39	44	0
15	Orfasay	-	-	-	40	48	0	38	63	0	39	38	0
16	Samphrey	-	-	-	40	48	0	40	50	0	40	45	0
17	Uynarey	34	56	0	40	53	0	40	43	0	40	53	0
18	Little Roe	38	55	0	39	54	14	40	45	0	40	48	0
19	Brough	-	-	-	40	53	0	-	-	-	38	58	0
20	Norther Geo	-	-	-	40	43	0	-	-	-	39	64	0

Table 4a RPSI in adult dogwhelks (Nucella lapillus) from populations in Sullom Voe and Yell Sound from all surveys (- = No sample taken).

Site No	Site name	1987	1990	1991	1993	1995	1997	1999	2001	2004	2007	2009
1	Easterwick	-	-	0.00	0.00	0.00	0.00	0.00	1.43	<0.01	<0.01	0.00
2	Burgo Taing	-	-	3.37	<0.01	<0.01	0.02	0.003	0.03	<0.01	<0.01	<0.01
3	Billia Skerry	0.64	1.45	0.24	0.06	0.02	0.02	0.05	0.16	0.27	<0.01	0.13
4	Scarf Stane	2.16	1.67	3.76	4.38	2.69	15.24	22.29	28.81	8.69	0.14	<0.01
5	East of Ollaberry	2.41	7.51	3.53	0.31	0.23	0.94	0.39	0.09	0.12	<0.01	<0.01
6	Grunn Taing	12.71	13.52	15.00	4.92	7.33	7.18	4.69	6.2	4.62	0.95	0.00
7	Tivaka Taing	58.85	34.19	23.72	14.06	20.34	19.90	21.52	14.21	10.55	3.45	0.54
8	Noust of Burraland	54.50	45.59	50.75	39.39	21.44	21.88	24.26	18.06	11.00	1.73	0.41
9	Mavis Grind	40.91	30.24	30.15	23.19	11.63	24.11	21.33	28.61	20.33	4.29	1.08
10	Voxter Ness	58.54	39.59	41.32	32.38	27.65	28.05	24.27	27.65	12.63	2.69	0.01
11	Northward	34.03	30.54	42.57	31.37	26.70	36.70	40.26	30.71	14.73	7.86	0.31
12	The Kames	56.78	69.44	54.93	37.49	31.32	73.12	35.65	34.03	16.99	0.90	0.26
13	Skaw Taing	42.46	32.34	45.00	18.26	20.59	27.16	20.02	23.61	14.43	2.59	0.26
14	Mossbank	-	-	5.04	0.18	0.37	0.76	0.64	0.5	0.07	0.01	0.67
15	Orfasay	-	-	0.54	0.05	0.09	0.01	0.59	0.02	<0.01	<0.01	<0.01
16	Samphrey	-	-	1.30	<0.01	0.01	0.02	0.004	0	<0.01	<0.01	<0.01
17	Uynarey	0.99	1.25	0.18	0.01	0.02	0.11	0.027	0.02	0.02	<0.01	<0.01
18	Little Roe	13.46	9.69	18.89	14.10	5.30	12.00	5.81	8.91	3.76	1.62	0.03
19	The Brough	-	-	0.63	<0.01	<0.01	0.00	0.003	0	0.01	-	0.01
20	Norther Geo	-	-	0.13	0.01	0.00	0.00	0.00	0	0.00	-	0.00

*Table 4b VDSI in adult dogwhelks (*Nucella lapillus*) from populations in Sullom Voe and Yell Sound from all surveys (- = No sample taken).*

Site No	Site name	1987	1990	1991	1993	1995	1997	1999	2001	2004	2007	2009
1	Easterwick	-	-	0.26	0.05	0.04	0.06	0.33	0.17	0.36	0.15	0.46
2	Burgo Taing	-	-	1.72	1.13	1.00	0.92	1.125	0.25	0.28	0.50	0.58
3	Billia Skerry	2.32	2.35	2.30	2.06	1.11	1.04	1.25	1.76	1.79	1.20	1.50
4	Scarf Stane	3.44	3.42	3.53	3.75	3.82	3.67	4.06	4.59	4.07	2.56	0.95
5	East of Ollaberry	3.21	3.95	3.39	2.55	2.47	2.33	2.68	1.6	1.57	0.70	0.38
6	Grunn Taing	4.00	4.00	4.00	3.73	4.13	4.00	4.00	4	3.46	3.50	0.59
7	Tivaka Taing	4.22	4.93	4.41	4.19	4.25	4.09	4.00	4	4.00	3.58	2.64
8	Noust of Burraland	4.21	4.33	5.00	4.15	4.65	4.24	4.09	4.31	4.05	4.00	3.53
9	Mavis Grind	4.26	4.64	4.75	4.50	4.35	4.27	4.125	4.42	4.25	4.11	3.67
10	Voxter Ness	4.71	4.83	4.80	4.60	4.57	4.07	4.00	4.05	4.10	3.78	1.30
11	Northward	4.44	4.87	5.18	4.77	4.40	4.07	4.07	4.33	4.18	4.08	3.14
12	The Kames	5.27	5.33	5.59	5.08	5.17	4.67	4.19	4.25	4.33	3.89	3.00
13	Skaw Taing	4.00	4.69	4.41	4.61	4.31	4.16	4.00	4.29	4.00	3.33	2.77
14	Mossbank	-	-	4.05	1.77	2.46	2.13	2.65	1.88	1.47	1.08	3.24
15	Orfasay	-	-	2.74	1.78	1.04	0.88	1.65	0.81	1.12	0.83	0.40
16	Samphrey	-	-	2.32	0.53	0.63	0.87	0.72	0.43	0.40	0.20	0.33
17	Uynarey	2.58	2.86	2.05	1.20	0.90	1.56	1.375	0.78	1.17	0.82	0.38
18	Little Roe	4.00	4.04	4.14	4.13	4.06	3.93	3.94	2.19	3.63	3.56	1.95
19	The Brough	-	-	2.57	1.09	1.16	0.43	0.83	0.61	0.89	-	0.38
20	Norther Geo	-	-	1.35	0.56	0.00	0.30	0.43	0.17	0.08	-	0.20

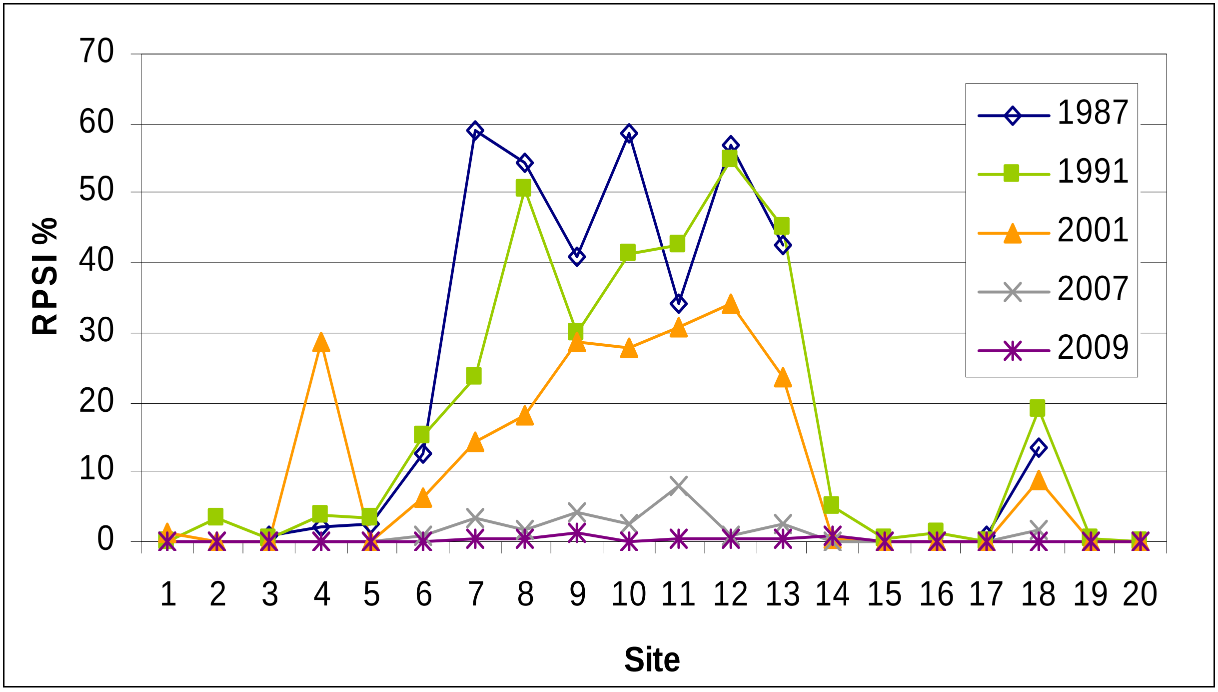


Figure 5a Comparison of RPSI values (1987-2009, selected years) in adult dogwhelks Nucella lapillus from all sites in Sullom Voe (6 to 12) and Yell Sound.

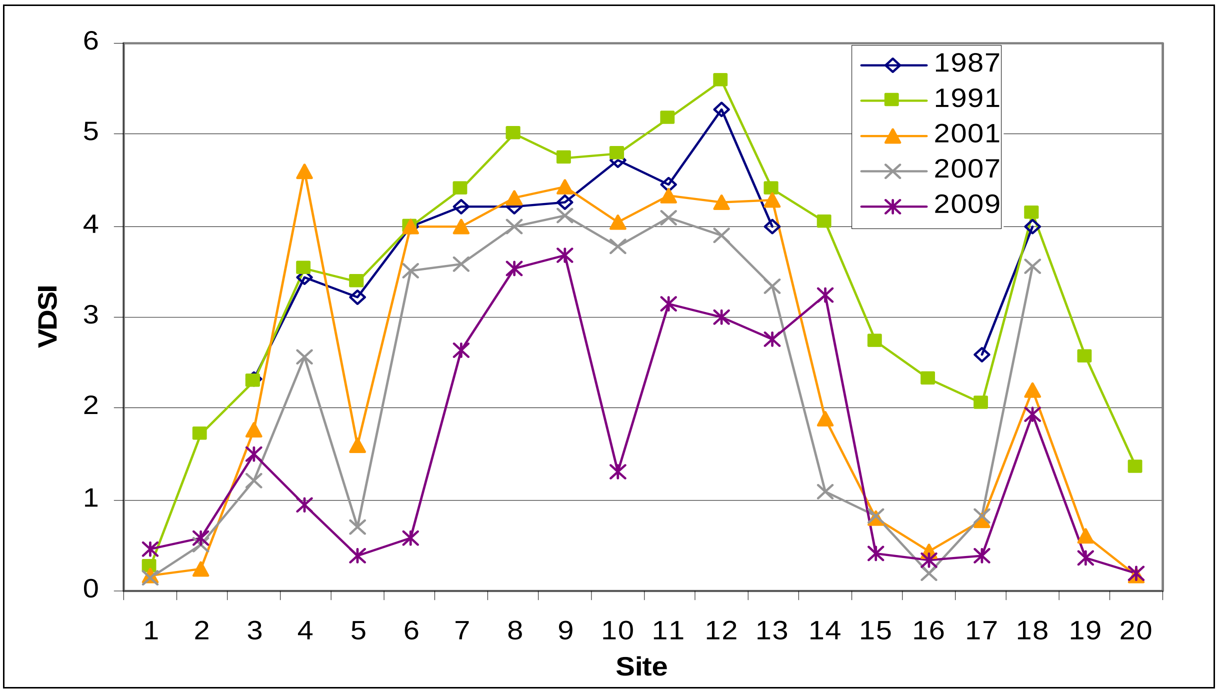


Figure 5b Comparison of VDSI values (1987-2009, selected years) in adult dogwhelks (Nucella lapillus) from all sites in Sullom Voe (sites 6 to 12) and Yell Sound.

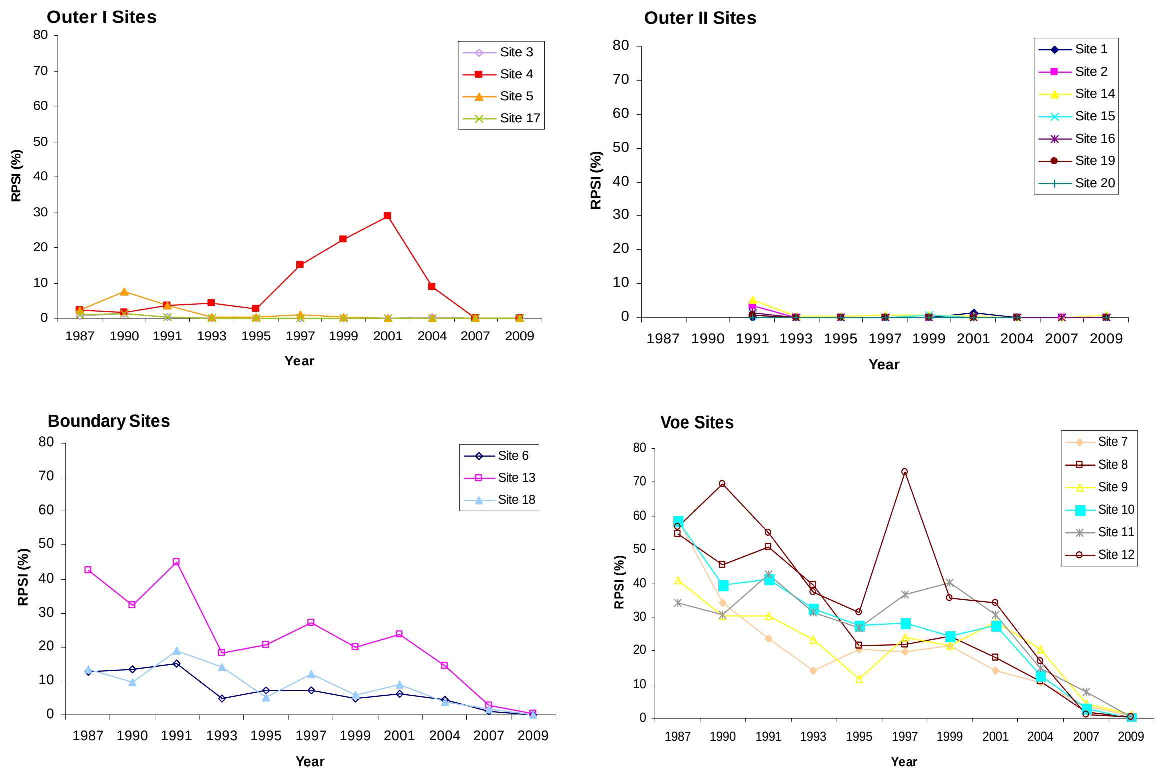


*Figure 6a RPSI values for dogwhelk (*Nucella lapillus*) populations in the surveys from 1987-2009 shown in the geographical groupings.*

Figure 6b VDSI values for dogwhelk (<u>Nucella lapillus</u>) populations in the surveys from 1987-2009 shown in the geographical groupings.

Comparison of incidence of sterility in the females obtained during 1987-2009

The incidence of female sterility at each site from each sampling survey from 1987 – 2009 is shown in Figure 7. The proportion of sterile females at all sites has decreased to 0% in 2009, with 4 sites within Sullom Voe showing decreases to this new level from 2007. This is the first absence of sterility recorded (to the statistical limits of the sampling strategy) since the start of the imposex monitoring in 1987.

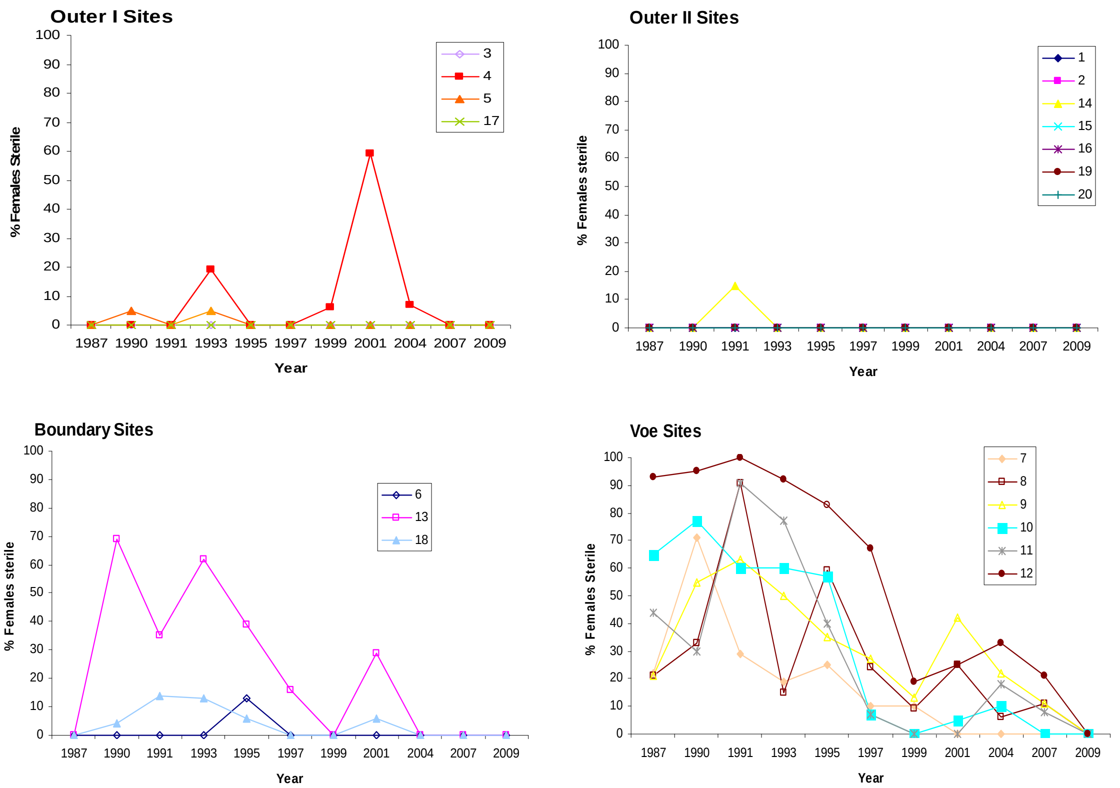


Figure 7 The percentage of sterile female dogwhelks (<u>Nucella lapillus</u>) sampled in the surveys from 1987-2009.

4.2 Population structure studies

Results are presented in Appendix 2 in the form of histograms. Shell height is plotted against frequency for the three age categories: (i) juveniles/first years; (ii) second years/young adults; and (iii) mature adults. Histograms from 1991, 2001, 2007 and 2009 are plotted side-by-side for easy comparison. Histograms for 1993, 1995, 1997, 1999 and 2004 have been omitted, to save space as they are printed in previous reports. A brief description of each site including details of the wave exposure and general communities is also given in Appendix 2. Table 5 summarises the population data from 2009; a comparison is made with the previous survey data from selected years. Note that analysis of the juveniles has been confined to those individuals of 15mm or less.

4.2.1 Description of the populations surveyed in 2009

Important note: Direct comparison of the population data between sites needs to take account of the site specific characteristics of the populations studied. All of the population statistics are influenced by the physical characteristics of the defined collection areas; these include wave exposure, food availability, many habitat features and the size of the collection area established. Thus a lower number of dogwhelks collected at one site compared to another may be unrelated to the abundance of dogwhelks generally at those locations. Also, many wave sheltered sites like those in Sullom Voe tend to have smaller populations of dogwhelks than many open coast sites. The proportion of juveniles is also influenced by the habitat characteristics (e.g. availability of suitable crevices), so that some sites always have relatively few juveniles. Shell height statistics (maximum, minimum, median and mean) are greatly influenced by the wave exposure – animals at the more wave exposed sites typically have smaller shells. Most of the following analyses therefore describe the changes at individual sites and compare trends between the sites.

Populations of dogwhelks with a large range of sizes and ages were present at all of the survey sites. The range of shell sizes present in each collected sample was always at least 14mm (maximum height – minimum height in a single sample). The smallest range was present in the sample from Easterwick (site 1), one of the furthest sites from the terminal, which had notably reduced population in 2009. The largest range (30mm) was present at East of Ollaberry (site 5) with 195 animals spread from 8mm to 37mm.

At a few sites the numbers of juveniles <16mm collected from the population study areas were very low; and they were absent at one site (Northward). However, thin edged shells were present in larger numbers at those sites (a minimum of 14 collected in the standard search time). At both Mavis Grind (site 9) and The Kames (site 12), where it used to be very difficult finding sufficient juveniles for the imposex analysis samples, there were large numbers of juveniles in the normal sampling areas.

The abundance of dogwhelks was approximated by calculating the number of dogwhelks collected per minute of sampling. Table 5 gives values for the numbers of total dogwhelks and numbers of juveniles (<16 mm) collected per minute at each site. The abundance of total dogwhelks during the 2009 survey ranged from 4.8 dogwhelks per minute at Norther Geo (site 20) to 82 dogwhelks per minute at The Brough (site 19). However, values above 50 per minute must be interpreted with caution because they indicate a large population where the collection rate is limited more by the pick-up speed of the collector than the real abundance. The highest abundance of juveniles (5.5 per minute) was from Tivaka Taing (site 7). The lowest abundance of juveniles was at Northward (site 11) (zero, as noted above), but there were eight other sites where collection rates were less than 1 juvenile per minute of search. The average abundance of dogwhelks was 20.5 per minute for Sullom Voe sites (7 to 12) and 35.3 per minute for sites outside the Voe. The values for juveniles were 0.9 per minute and 1.8 per minute, respectively.

Table 5 Comparison of summary data from population studies in August 1991, 2001, 2007 and 2009. 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. 2009 values in ***bold*** *or underlined indicate notable* ***increases*** *or decreases compared with 2007.*

	1991					2001				
Site	**No./min**	**Juvs/min**	**Mean**	**Median**	**Min**	**No./min**	**Juvs/min**	**Mean**	**Median**	**Min**
1	47.6	2.6	21.8	23	9	18.6	1.0	21.8	23	6
2	47.3	7	25.5	30	9	56.7	5.7	20.3	30	8
3	39.6	7.2	21.3	25	7	47.4	2.0	25.0	25	8
4	22.6	7.2	20.8	28	9	17.0	4.8	28.9	28	5
5	27.8	1.2	28.3	30	8	49.4	12.8	24.9	32	11
6	23.2	5.8	23.2	29	9	53.8	4.2	27.4	29	9
7	81	18	23.3	28	8	36.3	5.3	23.4	28	8
8	25.6	0.2	26.6	27	15	41.6	0.6	25.0	27	11
9	6.8	0.2	28.9	30	15	34.8	1.4	27.5	32	5
10	21.8	0.2	29.6	30	16	28.4	0.4	29.2	30	11
11	41.8	0.75	27	28	13	24.5	1.5	27.5	29	9
12	10.2	0	30.6	31	23	12.3	3.4	20.3	29	7
13	26.2	5.6	24.2	29	8	41.8	6.8	24.9	30	5
14	46	5.4	29	33	6	20.0	1.0	27.4	33	9
15	40.2	1.6	23.9	25	12	66.0	2.8	23.4	27	8
16	28.6	1.4	27.8	30	12	29.4	2.0	27.4	30	10
17	37.5	3.75	24.7	29	8	42.5	1.5	27.5	29	10
18	37	9.2	23.8	30	9	17.6	6.4	22.2	32	6
19	56	2	22.7	23	10	68.0	0.5	23.4	24	15
20	26.4	4	20.2	22	8	24.8	3.8	20.3	23	8

	2007					2009				
Site	**No./min**	**Juvs/min**	**Mean**	**Median**	**Min**	**No./min**	**Juvs/min**	**Mean**	**Median**	**Min**
1	34.4	1.4	22.5	23	10	34.6	0.2	22.2	23	14
2	50.3	3.7	27.8	30	10	55.7	3.0	27.2	30	10
3	56.0	4.6	24.0	25	9	49.4	2.8	24.5	25	10
4	5.2	0.6	22.0	26	13	5.6	**2.6**	17.1	26	8
5	26.4	3.0	26.9	30	9	39.0	4.2	27.1	30	8
6	37.4	1.8	27.1	30	9	43.0	1.8	27.2	29	9
7	41.5	1.5	27.3	29	12	45.0	**5.5**	25.4	28	7
8	22.8	0.8	24.7	28	13	24.6	0.4	25.4	27	13
9	12.2	0.0	28.0	31	16	9.4	0.2	27.4	30	12
10	21.2	2.2	26.0	31	8	12.2	0.2	27.3	30	13
11	36.3	0.8	25.2	30	10	17.3	0.0	24.2	29	18
12	37.8	2.2	26.2	30	13	28.4	1.8	26.9	29	10
13	22.6	0.8	24.7	28	13	25.4	1.4	26.3	29	8
14	14.0	0.2	32.5	35	15	**28.2**	0.6	32.2	34	11
15	58.6	4.6	24.3	26	7	52.4	3.0	24.1	26	9
16	24.2	2.2	24.4	30	11	23.2	0.8	26.6	29	10
17	47.0	9.0	24.7	29	8	46.0	2.0	25.0	29	11
18	33.0	4.4	25.2	32	7	43.0	0.8	29.1	31	12
19	-	-	-	-	-	**82.5**	1.0	23.9	25	12
20	-	-	-	-	-	4.8	0.6	20.8	23	12

4.2.2 Temporal changes in the dogwhelk populations up to 2009

Results from surveys in previous years, starting in 1991, have highlighted a number of features in dogwhelk populations present at some study sites, primarily in Sullom Voe, which would be considered abnormal in a well developed and un-stressed population. These abnormal features have included low juvenile abundances, large minimum shell heights, abnormal size-class distributions and fluctuating size-class distributions. The most distinctive abnormalities in the size-class distributions (e.g. histograms in Appendix 2 from 1991 at The Kames) have been where the adult sizes are skewed towards the larger individuals, suggesting that recruitment of young animals has been reduced and the population is dominated by old survivors. Large fluctuations in the size-class distribution at a site suggest that the population is not stable, due to abnormal patterns of survival and recruitment. These characteristics 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.

A slow recovery process, from the very poor conditions at the time of the first survey in 1991, has been described in previous reports; including an increase in the numbers of juveniles and improvements in the size class distribution of the populations at sites in Sullom Voe. However, large fluctuations still occur, there has been no uniform pattern to the improvements at each site and some populations have still shown notable declines over periods of the monitoring programme. It is apparent that other ecological factors are also influencing the recovery process. These are considered further below.

Trends and comparisons across all sites

Figures 8 and 9 summarise two of the key statistics from the dogwhelk population data. The histogram in Figure 8 shows that abundance of juveniles (<16mm) does vary considerably from survey to survey and that some years are characterised by higher juvenile abundances over many sites. Thus 1991 and 2001 were characterised by relatively high juvenile abundances outside Sullom Voe while 2007 and 2009 had generally lower juvenile abundances although site specific variation is also evident.

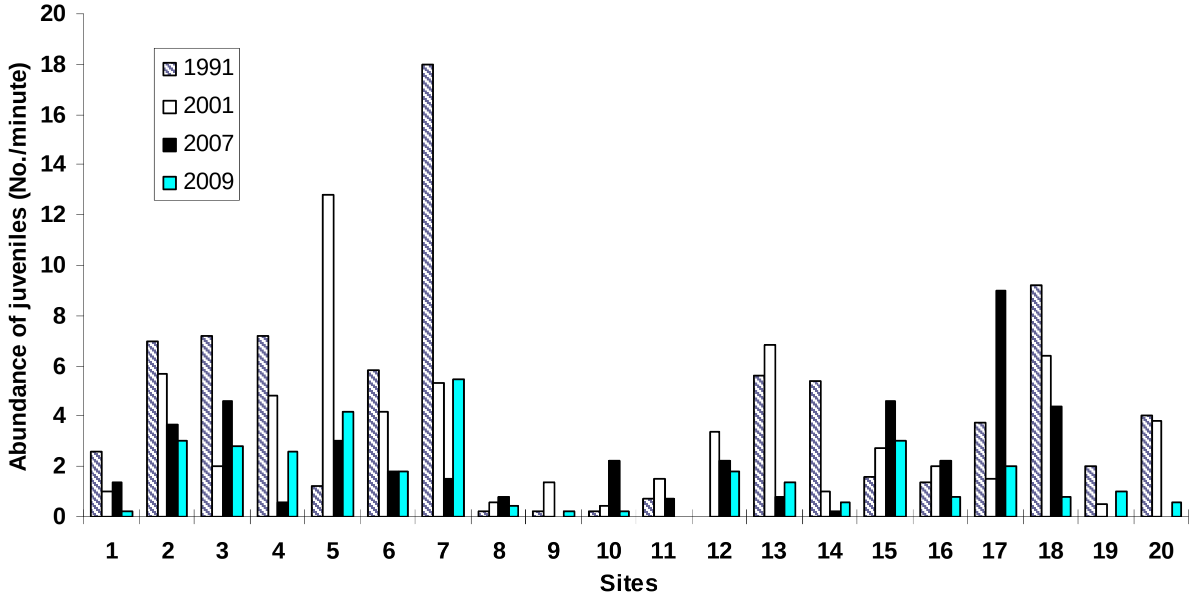


Figure 8 Comparison of juvenile dogwhelk abundances in 1991, 2001, 2007 and 2009 at the 20 monitoring sites

Figure 9 plots the differential in mean height between 2009 and the mean heights averaged over all the previous surveys. Notable reductions are shown, particularly at sites 4 (Scarf Stane) and 11

(Northward) where large proportions of the larger adults have gone, leaving apparently younger populations. Notable increases are also shown, particularly at site 18 (Little Roe) where there has been very good survival of the new adult recruits but production of juveniles was relatively poor. There was an overall decrease in mean height at the Sullom Voe sites (sites 7 to 12).

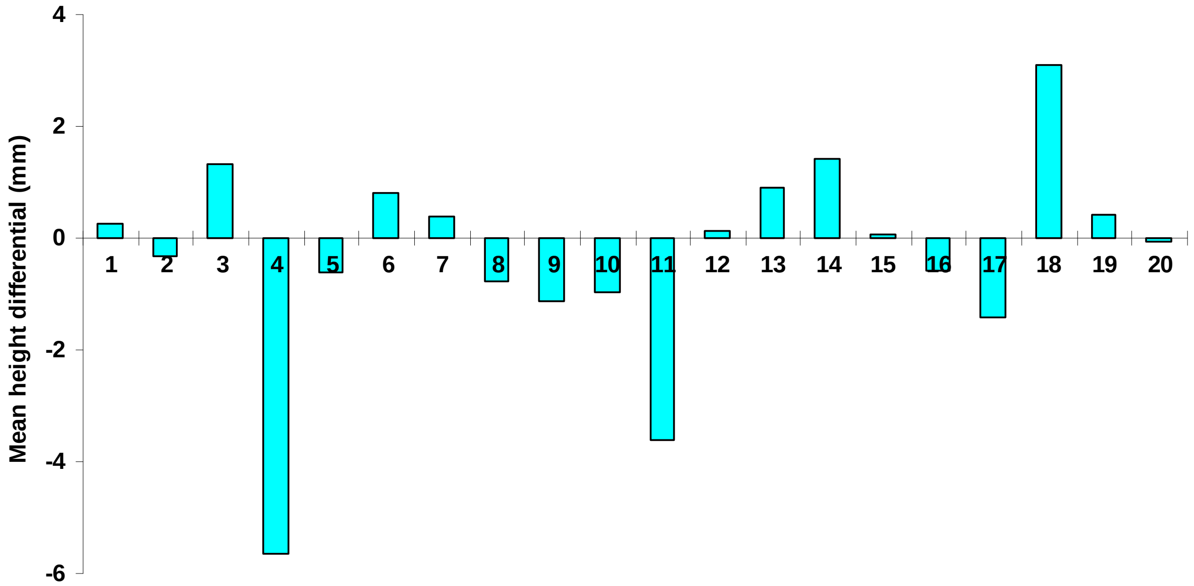


Figure 9 Mean height of dogwhelks in 2009 calculated as the differential to the average of mean heights (1991 to 2007), at the 20 monitoring sites

The ratio of juvenile to adult numbers can be used as an indicator of improved juvenile production, and hence of reproductive capacity of the dogwhelk populations (Table 6). Analysis of the 2009 data showed that this ratio decreased at a number of sites, both inside and outside the Voe, and that a notable increase was only seen at one site (site 4, Scarf Stane). This suggests an overall reduction in juvenile production which might mean that reproductive capacity has decreased.

Table 6 Comparison of juveniles / toothed adults ratio from population studies in 1995, 1997, 1999, 2001, 2004, 2007 and 2009. 2009 values in ***bold*** *or* <u>*underlined*</u> *indicate notable increases or decreases, respectively, compared with 2004.*

Site	1991	1997	1999	2001	2004	2007	2009
1	0.07	0.23	0.09	0.07	0.19	0.06	<u>0.01</u>
2	0.34	0.16	0.05	0.15	0.03	0.11	0.11
3	0.46	0.27	0.51	0.08	0.02	0.18	0.07
4	1.44	0.7	0.26	1.00	0.59	0.30	**6.50**
5	0.07	0.11	0.13	0.52	0.13	0.17	0.16
6	0.73	0.06	0.09	0.12	0.06	0.10	0.05
7	0.46	0.35	0.52	0.24	0.07	0.09	0.18
8	0.02	0.04	0.09	0.04	0.00	0.08	0.04
9	0.04	0.85	0.14	0.08	0.00	0.00	0.08
10	0.02	0.19	0	0.02	0.00	0.55	<u>0.05</u>
11	0.04	0.03	0.02	0.12	0.00	0.03	0.00
12	0	1.43	0.25	1.48	0.20	0.10	0.11
13	0.4	0.69	0.13	0.25	0.11	0.08	0.09
14	0.18	0.02	0.09	0.09	0.09	0.02	0.03
15	0.06	0.37	0.12	0.06	0.01	0.11	0.09
16	0.07	0.18	0.11	0.11	0.00	0.28	0.07
17	0.21	0.06	0.09	0.05	0.07	0.44	0.11
18	0.52	0.29	0.34	0.82	0.16	0.41	<u>0.03</u>
19	0.06	0	0.12	0.01	0.00	-	0.02
20	0.33	0.25	0.21	0.33	0.17	-	0.43

Sullom Voe sites (7 to 12)

The Kames (site 12) 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 in The Kames study area has increased considerably since then, particularly since 2004 (see Figure 10). When the site was established in 1991 there were not enough dogwhelks in the first defined area of shore so a second area, separated from the first by a ridge, was defined and the search time was effectively doubled (5 minutes in each area). The two areas, combined, became the study site for all subsequent surveys up to 2004. In 2007 the population had increased so much that it was decided to drop one of the areas and search for only 5 minutes and this was repeated in 2009. Abundances in 2009 appear to have dropped slightly from those recorded in 2007, but that level of natural fluctuation is not unexpected and there may be a period of stabilisation as the population adjusts to the available food source.

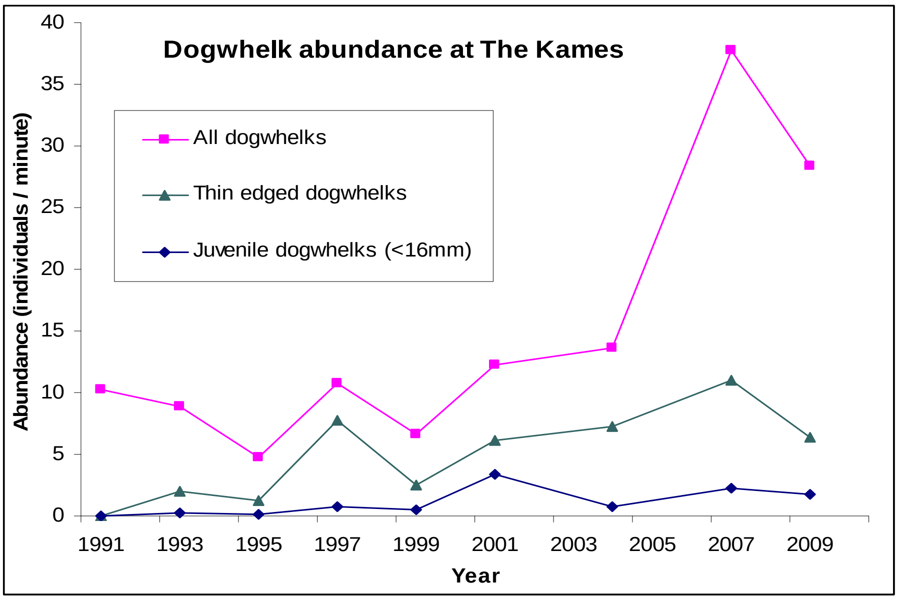


Figure 10 Temporal changes in abundance of dogwhelks at The Kames

Information on dogwhelk populations from the associated rocky shore transect surveys (see Moore, 2009) have also shown a gradual return of dogwhelks, particularly at The Kames transect site, 200m south of the dogwhelk site. Dogwhelks disappeared from that transect in 1991 and then reappeared in 2006, but they have still not reached the abundances that were typically present before the TBT contamination. An annual search between the terminal jetties, a further 600m south has not found any dogwhelks since the mid 1980s.

The population at Mavis Grind (site 9) also showed notable increases in juveniles and a rapid increase in adults, up to 2001. However, in 2004 and subsequent surveys the population has progressively decreased (Figure 11, top left) and is now similar to the size it was in the early 1990s, although juvenile abundances in 2009 were still larger than they were in 1991. 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. It is hoped that the removal of dogwhelks for imposex analysis from the boulder shore is not influencing recruitment to the population study area.

Some similarities to the Mavis Grind population changes have also been found at Voxter Ness (site 10) (Figure 11, top left), with an initial increase followed by a decline and total abundance was lower in 2009 than it was in 1991. In 2004 the population was very small and fluctuated up and down considerably in the last two surveys. Juveniles were still present in moderate numbers in 2009. It seems unlikely that there is much migration of dogwhelks in and out of the population study area as the site consists of a bedrock outcrop separated from the main shore by a steep sided gully at low tide level. The sampling area for the imposex analysis is over 40m away.

A variety of changes and notable fluctuations are also evident in the dogwhelk populations from all of the other Sullom Voe sites (sites 7 to 11; Figure 11). Whether these are associated with the reproductive stress caused by imposex, it seems likely that other ecological factors may have at least as much effect and that they vary on a site specific basis.

Yell Sound sites

Outside Sullom Voe the dogwhelk populations at most sites show much less variability in their size frequency distributions, with relatively large numbers of individuals and well formed peaks present in the adult sizes. Large fluctuations in abundance do occur (see Figure 11) particularly the juvenile (<16mm) abundances, which were relatively low at many sites in 2009. However, abundances of thin edged shells, which will include some 1 year old animals, fluctuate less erratically and suggest that 2009 was not unusual. Populations at four sites in Yell Sound deserve further analysis:

Site 20 (Norther Geo) is tucked away at the back of a small bay on NW Yell, surrounded by high cliffs, and exposed to any large swells that come from the north. While the study site provides habitat that is apparently suitable for dogwhelks, it is small in extent and very isolated from any other suitable habitat, and dogwhelks are very sparse in the surrounding area. The sample for imposex analysis is collected over a large area in an adjacent bay, and it can take an hour to find a sufficient number. Thus, the study population is unlikely to receive much recruitment from external sources and is showing signs of stress. Abundances have dropped considerably since 1997 (Figure 11, top right). This decline is not due to TBT or any other known pollutant.

Site 4 (Scarf Stane) has been discussed in previous reports because of an unexpected rise in the levels of imposex between 1997 and 2001, followed by a gradual decline but a persistently raised VDSI compared to other Yell Sound sites until 2009. It has been suggested in previous reports that this may be due to TBT contamination associated with the large fishing vessel on the Collafirth pier. The dogwhelk population has also shown a decline in abundance and juvenile abundances were very low in 2007 (Figure 11). In 2009 the population was still very low (Figure 11, top right) but there was a notable improvement in juvenile abundance. The population study area at Scarf Stane is often, but not always, dominated by fucoid algae which hides the dogwhelks and slows the pick-up rate. To a certain extent this will affect comparability with those years where the dogwhelks are more conspicuous, but the condition of the site has not been recorded each year. In 2009 the site was dominated by a dense low turf of fucoid sporelings and after the standard 5 minutes search it was decided to continue collecting, in separate bags, until no more dogwhelks could be found. This took an additional 13 minutes for the two collectors and produced an additional 73 dogwhelks; compared to 28 from the standard 5 minutes. A histogram of size class distribution for the combined data shows similar characteristics to the histogram from the standard search (Appendix 2), but shows more clearly that the adult population is not large but is producing large numbers of juveniles. It also shows that the adult size distribution has a normal shape. It is concluded that the population is no longer showing signs of reproductive stress.

Site 3 (Billia Skerry) and Site 14 (Grunna Taing, aka Mossbank) are also of interest because the imposex data for those sites were raised above the normal low levels (see Section 4.1). Population data for site 3 does show a drop in abundance of adults and juveniles from 2007 to 2009, but the values are still within the normal range for the site and the size class histogram shows a very normal distribution for the adults. The site is isolated from human activities and there are no known sources of TBT nearby. Population data for site 14 gives no suggestion of reproductive stress and abundance values were all higher in 2009 than 2007 (Figure 11, bottom right). The data for both sites will be inspected closely again after the next survey.

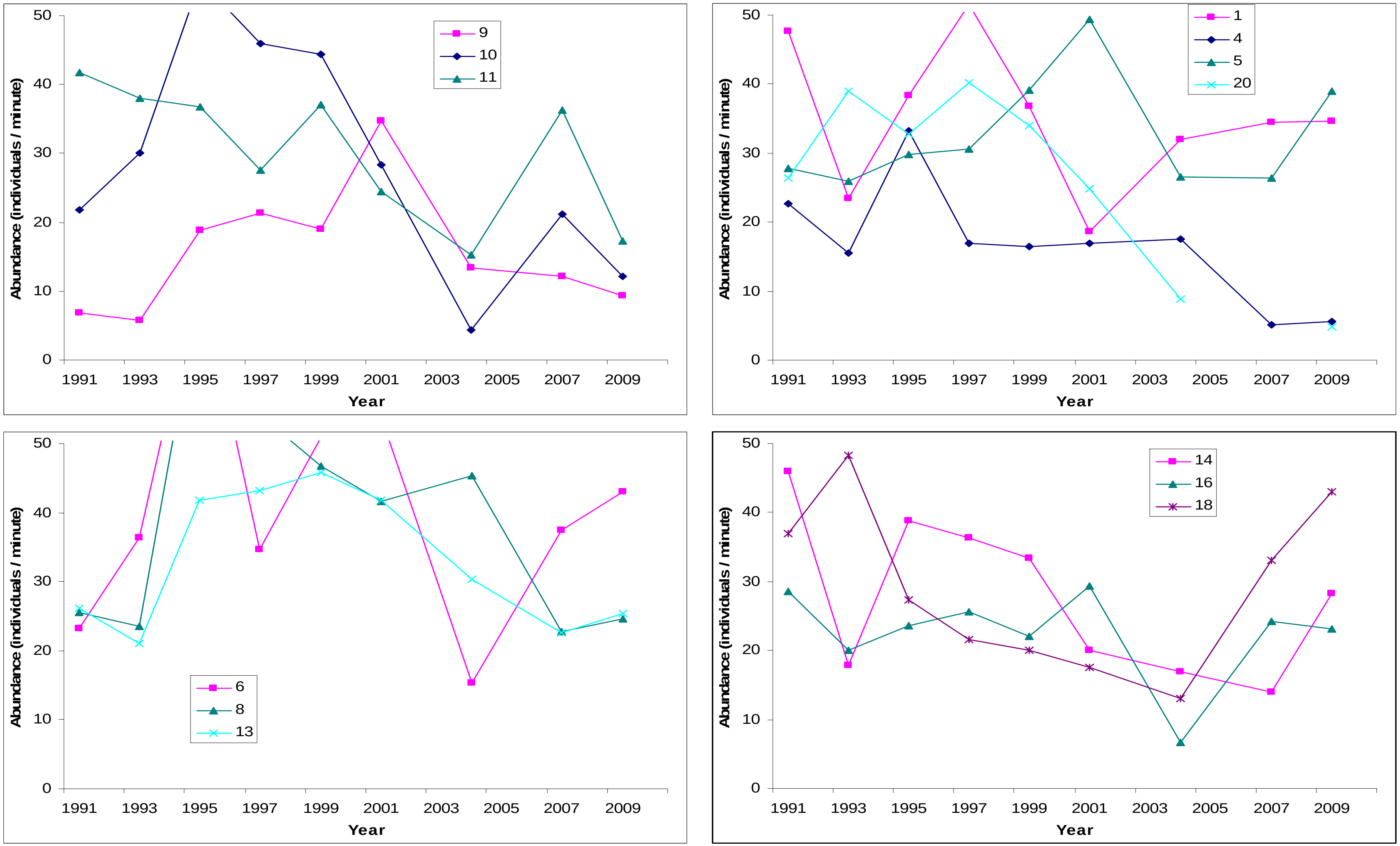


Figure 11 Temporal changes in abundance of dogwhelks (all sizes) at selected sites, in regional groupings. Graphs cut-off at 50 / minute because values above this indicate a large population where the pick-up rate is biased by the collector and not limited by real abundance.

5 Discussion and conclusions

5.1 Assessment of imposex data against OSPAR assessment criteria

In order to aid environmental assessments, the Oslo and Paris Commission (OSPAR) have derived a set of biological effect assessment criteria for TBT, based on the development of imposex in gastropod species (OSPAR, 2004). For dogwhelks, these criteria are based on VDSI, and the values chosen relate to effects on the reproductive capability of females in the populations and the effects expected from exposure to TBT concentrations in water equivalent to the Environmental Assessment Criteria (EAC). The VDSI values used to discriminate 6 assessment classes (A-F) and the effects that these values relate to are given in Table 7. The VDSI data from the 2009 survey were assessed against the criteria presented in Table 7 and the results are shown in Figure 12.

Temporal changes over the monitoring programme are given in Table 8. There are a number of changes that have occurred since the last survey in 2007. Due to very small increases in VDSI (to above 0.3) at some outlying sites, 2 sites have shown loss of OSPAR Classification status from A to B (sites 1, 16). Three sites within Sullom Voe (8, 9, 11) have improved status from D to C and one site (10) an improvement from C to B. Outside the Voe, improvements in classification from C to B have occurred at sites 4, 6 and 18. Of greatest concern was site 14 (Mossbank / Grunna Taing) which as a result of substantial increase in VDSI of adults has changed from class B to class C.

Table 7 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	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	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	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	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	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	VDSI = -	The populations of the more sensitive gastropod species, such as *Nucella lapillus* and *Ocinebrina aciculata*, are absent/expired.

Figure 12 Assessment of VDSI data from adult dogwhelks (Nucella lapillus) sampled from sites around Sullom Voe and Yell Sound in 2009. Data are presented in accordance with OSPAR assessment classes A-D (See Table 7).

Table 8 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
1	19.0	-	-	A	A	A	A	B	A	B	A	B
2	13.6	-	-	B	B	B	B	B	A	A	B	B
3	10.4	C	C	C	C	B	B	B	B	B	B	B
4	9.5	C	C	C	C	C	C	D	D	D	C	B
5	5.7	C	C	C	C	C	C	C	B	B	B	B
6	3.5	D	D	D	C	D	D	D	D	C	C	B
7	2.3	D	D	D	D	D	D	D	D	D	C	C
8	1.3	D	D	D	D	D	D	D	D	D	D	C
9	8.5	D	D	D	D	D	D	D	D	D	D	C
10	6.3	D	D	D	D	D	D	D	D	D	C	B
11	3.3	D	D	E	D	D	D	D	D	D	D	C
12	0.6	E	E	E	E	E	D	D	D	D	C	C
13	3.5	D	D	D	D	D	D	D	D	D	C	C
14	10.5	-	-	D	B	C	C	C	B	B	B	C
15	14.2	-	-	C	B	B	B	B	B	B	B	B
16	11.0	-	-	C	B	B	B	B	B	B	A	B
17	8.9	C	C	C	B	B	B	B	B	B	B	B
18	4.5	D	D	D	D	D	C	C	C	C	C	B
19	14.5	-	-	C	B	B	B	B	B	B	-	B
20	20.6	-	-	B	B	A	A	B	A	A	-	A

5.2 Reproductive capacity of Sullom Voe and Yell Sound dogwhelks

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). The population data also show that juveniles are being produced in large numbers and size class distribution of the adult populations are normal and stable at most sites. At sites 3 and 14, increases in VDSI and RPSI however, cause concern and suggest that there may be transient local factors at play that have resulted in increased TBT exposure. Site 14 is quite close to a small harbour and there is strong evidence from the juveniles sampled from site 3 that the cause for the increase in imposex is recent and on-going. Population data are so far showing no clear signs of an impact, but will be closely examined in future surveys.

The imposex condition of the dogwhelk population at Scarf Stane (site 4) has now improved after showing deterioration in previous surveys since 1995, presumably also due to a transient local source of TBT. The population study found that the numbers of dogwhelks were still low but that production of juveniles was now very good and recovery is clearly well underway.

The population at Norther Geo (site 20) has declined considerably since 1997 and may no longer be viable. This decline is not linked to TBT, imposex or any other known pollutant, but may be a feature of its isolation from other extant populations.

The higher RPSI and VDSI values of *N. lapillus* populations in Sullom Voe relative to those of the dogwhelk populations in Yell Sound indicate that the Sullom Voe populations continue to be more impacted by TBT released from around the oil terminal. Imposex continues to develop in dogwhelks that have recently recruited to the Sullom Voe populations as the juveniles are less than 2 years old, demonstrating that low levels of TBT contamination must still be present, possibly in subtidal sediments which are known to be a potential long-term source of contamination (see Section 2). However, the results of the current 2009 survey show a marked improvement in levels of imposex at sites within the Voe since the 2007 survey. The RPSI and VDSI measurements at sites within the Voe indicate that these populations have good reproductive potential, with no recorded sterile females in the populations. The degree of imposex in populations of dogwhelks from the boundary sites (6, 13 and 18) is continuing to decline and these populations continue to have a good reproductive potential, with no sterile individuals found in the August 2009 survey. The population data confirm that juveniles are being produced at all sites and show that the size class distribution of the adult populations are close to normal distribution at many of the Sullom Voe sites.

The population at the Kames, which is closest to the terminal and was the worst affected, has improved considerably since the start of the programme and its viability is no longer threatened. The continued presence of juvenile and sub-adult dogwhelks at that site reflects the lack of sterile females found there during the last few surveys and the continued decrease in VDSI and RPSI noted during the current survey. It is nevertheless clear that they have not yet returned to pre-impact conditions. Data from the rocky shore transect monitoring programme (Moore, 2009) shows that the dogwhelk population at The Kames is still low compared to that present in the years pre-TBT and they are still completely absent between the Sullom Voe terminal jetties.

Populations at most sites in the Voe are also still fluctuating greatly and abundances of adults and juveniles at some sites were lower in 2009 than in 2007. While the effects of imposex will have a lasting effect on the populations (the dogwhelks live for 5 to 10 years, there may still be some sterility remaining and even low levels of imposex will reduce reproductive capacity) it is suggested that this does not adequately explain the levels of fluctuation observed. It seems likely that effects of other ecological factors on recruitment and survival of dogwhelks in Sullom Voe may now be at least as important as the impacts of TBT. Distinguishing any further improvements that are due to the declining imposex may be more difficult.

The natural levels of fluctuations in dogwhelk populations is often high on any rocky shore, but populations on wave sheltered shores are often on the edge of their natural habitat range and are more likely to have seasons of poor recruitment and/or poor survival. The abnormal features of the Sullom Voe populations, including low juvenile abundances and fluctuating size-class distributions, may therefore be close to the natural condition, presumably worsened by imposex. This might have been apparent if the dogwhelk population monitoring had been started before the onset of TBT contamination or if reference monitoring sites had been established in similar sheltered sites to those monitored in Sullom Voe, but where imposex was at background levels. Scarf Stane (site 4) would have made a good reference site, as it is relatively wave sheltered compared to the other sites in Yell Sound, but imposex levels have been considerably raised. It is suggested that one or two sheltered populations, remote from potential sources of TBT, are located, established as reference sites and added to the monitoring programme.

This series of surveys of dogwhelk imposex in Sullom Voe 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. Monitoring should continue to chart the course of the recovery following the recent IMO ban on exposed TBT based paints on hulls of large vessels. It is recommended that the surveys continue to be carried out at an interval of every two to three years.

6 References

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

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

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

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

Bryan, G.W., Gibbs, P.E., Hummerstone, L.G. and Burt, G.R. (1986). The decline of the gastropod Nucella lapillus around south-west England: evidence for the effect of tributyltin from anti-fouling paints. *J. mar. biol. Ass. UK, 66, pp 611-640.*

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

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

Gibbs, P.E., Bryan, G.W., Pascoe, P.L. and Burt, G.R. (1987). The use of the dogwhelk, Nucella lapillus, as an indicator of tributyltin (TBT) contamination. *J. mar. biol. Ass. UK, 67, pp 507-523.*

Gubbins M.J., O'Reilly M., McIlroy L., Thain J., Davies I.M. 2004. A decade of UK organo-tin specific biological effects monitoring – Trends, ecological quality assessment and future monitoring requirements. ICES CM 2004/Z:06, 17 pp.

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

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

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

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

Moore, H.B. (1936). The biology of *Purpura lapillus*. I. Shell variation in relation to the environment. *J. mar. biol. Ass. UK, 21, pp 61-89.*

Moore, J.J. (1990). *Surveys of Rocky Shores in the Region of Sullom Voe, Shetland, August 1990.* A report to the Shetland Oil Terminal Environmental Advisory Group from the Field Studies Council Research Centre.

Moore, J.J. (2007). *Survey of the rocky shores in the region of Sullom Voe, Shetland, August 2007*. A report to SOTEAG from Aquatic Survey & Monitoring Ltd., Cosheston, Pembrokeshire. 28 pp + v.

Moore, J.J. (2009). *Survey of the rocky shores in the region of Sullom Voe, Shetland, August 2009*. A report to SOTEAG from Aquatic Survey & Monitoring Ltd., Cosheston, Pembrokeshire. 29 pp + v.

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

OSPAR (2002). Revised technical annex 3 of the OSPAR guidelines for contaminant-specific biological effects monitoring (TBT-specific biological effects monitoring). Annex 10, Summary Record, *ASMO*, 2002, 18 pp.

OSPAR (2004). Proposal for assessment criteria for TBT-specific biological effects. ASMO 04/3/3. *OSPAR Environmental Assessment and Monitoring Committee, Stockholm*, 29 March – 2 April 2004.

Spence, S.K., Bryan, G.W., Gibbs, P.E., Masters, D., Morris, L. and Hawkins, S.J. (1990). Effects of TBT contamination on Nucella populations. *Functional Ecology 1990, 4, pp 425-432.*

Taylor, P.M.H., Moore, J.J., Bailey, S.K. and Davies, I.M. (1992). *Survey of dogwhelk, Nucella lapillus, population structure and imposex in the vicinity of Sullom Voe, Shetland.* A report to SOTEAG from FSCRC and SOAFD. Report No. FSC/RC/28/91. pp 23 plus appendices.

Watanabe, N., Sakai, S. and Takatsuki, H. (1995). Release and degradation half lives of tributyltin in sediment. *Chemosphere*, **31**: 2809-2816.

Appendix 1 Field log of rocky shore monitoring surveys in Sullom Voe 31st July – 13th August 2009

Field Log

Survey Team: Jon Moore (JM), Aquatic Survey & Monitoring Ltd., Cosheston
Christine Howson (CH), Aquatic Survey & Monitoring Ltd., Ormiston
Gordon Wilson, SVT Environmental Advisor (5th August)
Dave Manson, SVT Assistant Environmental Advisor (6th August)

(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 (Fri)

Weather:	Wet and windy
am	CH one-way hire car to Aberdeen from Ormiston
1430	Flight to Scatsta from Aberdeen
1600	Pick up PPE from Oil Pollution Base Check into Westayre B&B
eve	Dinner at Busta House

1 Aug (Sat)

Weather:	Wet and windy in morning; drier and brighter in afternoon
Low tide:	0.88m @ 13:20
am	Shetland Amenity Trust – Marine Identification course
pm	Leebitten shore (Sandwick) – Marine Identification course
eve	Dinner at Gurkha's Kitchen, Lerwick

2 Aug (Sun)

Weather:	Mostly dry and bright with light winds
Low tide:	0.81m @ 14:20
am	Shetland Amenity Trust – Marine Identification course
pm	Whiteness Voe & Weisdale Voe shores – Marine Identification course
eve	Dinner at The Raba, Lerwick

3 Aug (Mon)

Weather:	Mostly dry and bright with light/moderate southerly winds
Low tide:	0.73m @ 15:00
am	Oil Pollution Base – meet Alex Thomson - branch induction and sort out equipment etc. Survey planning and preparation
1250	Pollution Base – take boat out and head over to Gluss Isle
1330-1430	Survey Gluss Island East transect site (3.4)
1445-1545	Survey Grunn Taing transect site (4.1)
1600-1650	Survey The Kames transect site (4.3)
1730	Return to Pollution Base
eve	Dinner at St Magnus Bay Hotel

4 Aug (Tue)

Weather:	Strong southerly winds all day, but dry and bright.
Low tide:	0.63m @ 15:40
am	Survey planning and preparation. Data entry and photo collation.
1245	Drive to Pollution Base. BP staff take us into SV terminal and out to Calback Ness
1400-1455	Survey Roe Clett transect site (2.3)
1515-1610	Survey S. of Skaw Taing transect site (5.1)
1620-1700	Survey Skaw Taing dogwhelk site (13)

1730-1800	Survey Orka Voe Bund
1800	BP staff pick us up and take us back to SV terminal main gate
eve	Dinner at Busta House

5 Aug (Wed)

Weather:	Dry and bright, often sunny, with force 5 southerly winds
Low tide:	0.54m @ 16:10
am	Survey planning and preparation. Data entry and photo collation.
1330	Pollution Base – meet Gordon Wilson (SVT Environmental Advisor), take boat out and head over to west side of Sullom Voe
1415-1500	Survey Noust of Burraland dogwhelk site (8)
1500-1545	Survey Noust of Burraland transect site (3.3)
1600-1650	Survey Grunn Taing dogwhelk site (6)
1720-1750	Survey Tivaka Taing dogwhelk site (7)
1810-1840	Survey Northward dogwhelk site (11)
1730	Return to Pollution Base – look after dogwhelks
eve	Dinner at Pierhead restaurant, Voe

6 Aug (Thu)

Weather:	Dry and sunny, with force 4 southerly winds
Low tide:	0.36m @ 04:40; 0.48m @ 16:50
am	Survey planning and preparation. Data entry and photo collation.
1330	Pollution Base – meet Dave Manson (SVT Assistant Environmental Advisor), take boat out and head up Yell Sound
1500-1540	Survey Norther Geo dogwhelk site (20)
1600-1700	Survey Easterwick dogwhelk site (1)
1740-1830	Survey Billia Skerry dogwhelk site (3)
1930	Return to Pollution Base – look after dogwhelks
eve	Dinner at Busta House

7 Aug (Fri)

Weather:	No wind and lots of midges all day. Morning dry but cloudy & dull; afternoon starting wet but becoming sunny later.
Low tide:	0.30m @ 05:20; 0.44m @ 17:20
0430	Drive to Mavis Grind
0500-0600	Survey Mavis Grind transect site (5.5)
0540-0705	Survey Mavis Grind dogwhelk site (9)
0730	Pollution Base – package up dogwhelks for flight to Aberdeen
0845	Return to Westayre. Rest, photo and data collation, survey preparation etc.
1300	Drive to Pollution Base. Rearrange dogwhelks travel on flight from Sumburgh airport.
1500	Head out in boat
1530-1615	Survey W. of Mioness transect site (1.1)
1625-1715	Survey S. of Swarta Taing transect site (3.5)
1740-1810	Survey Fugla Ayre transect site (6.1)
1820-1845	Brief survey of shore affected by October 2008 oil spill
1900	Return to Pollution Base
eve	Fish supper

8 Aug (Sat)

Weather:	Early morning dry but cloudy & dull with no wind and lots of midges. Afternoon brighter with force 4 south east winds.
Low tide:	0.29m @ 05:50; 0.42m @ 17:40
0415	Drive to Pollution Base. BP staff take us into SV terminal

0515-0600	Survey Jetty 3 transect site (5.2)
0620-0700	Survey Jetty 2 transect site (6.2)
0730	Return to Westayre. Rest, photo and data collation, survey preparation etc.
1330	Pollution Base – take boat out and head down Voe
1610-1700	Survey Voxter Ness dogwhelk site (10)
1640-1740	Survey Voxter Ness transect site (4.6)
1800-1845	Survey Scatsta Ness (cleared) transect site (6.12)
1850-1920	Survey Scatsta Ness (uncleared) transect site (6.13)
1930	Locate and collect sample of asphalt pavement from *Esso Bernicia* spill, for hydrocarbon analysis by MScan
1945	Return to Pollution Base – look after dogwhelks
eve	Dinner at Busta House

9 Aug (Sun)

Weather:	Morning dry and bright with light winds. Afternoon cloudy with force 4 south west winds, decreasing later.
Low tide:	0.30m @ 06:20; 0.43m @ 18:20
0600	Drive to Lunna Ness
0650-0750	Survey Riven Noust transect site (2.9)
0845	Return to Westayre. Rest, photo and data collation, survey preparation etc.
1530	Pollution Base – take boat out and head down Voe
1620-1720	Survey Orfasey dogwhelk site (15)
1730-1815	Survey The Helliack dogwhelk site (16)
1825-1905	Survey Uynarey dogwhelk site (17)
1920-2000	Survey Little Roe dogwhelk site (18)
2030	Return to Pollution Base – look after dogwhelks
eve	Dinner at Busta House

10 Aug (Mon)

Weather:	Morning dull and raining with light breeze. Afternoon mostly bright with force 4 northerly wind, dropping later.
Low tide:	0.35m @ 06:50; 0.48m @ 18:50
0600	Drive to Vidlin
0640-0725	Survey Kirkabister transect site (6.11)
0755-0830	Survey Vidlin Ness transect site (3.8)
0915	Return to Westayre. Rest, photo and data collation, survey preparation etc.
1530	Pollution Base – take boat out and head up Yell Sound
1615-1650	Survey The Brough dogwhelk site (19)
1750-1900	Survey E. of Ollaberry dogwhelk site (5)
1915	Collect dogwhelks sample from Skaw Taing dogwhelk site (13)
1930-2035	Survey The Kames dogwhelk site (12)
2045	Return to Pollution Base – look after dogwhelks
eve	Dinner at Busta House

11 Aug (Tues)

Weather:	Mostly bright with light breeze during day; evening overcast with some rain and light southerly breeze.
Low tide:	0.42m @ 07:20; 0.54m @ 19:20
0830	Pollution Base – package up dogwhelks for flight to Aberdeen
1000	Return to Westayre. Rest, photo and data collation, survey preparation etc.
am/pm	Lerwick – visit SNH
1600	Drive to North Roe

1710-1930	Survey Burgo Taing transect site (3.12)
1750-1820	Survey Burgo Taing dogwhelk site (2)
1825-1905	Survey N. Burra Voe transect site (6.14)
eve	Dinner from Indian takeaway in Brae

12 Aug (Wed)

Weather:	Mostly bright with light breeze; some rain showers
Low tide:	0.53m @ 08:00; 0.62m @ 20:10
0700	Drive to Colla Firth
0740-0820	Survey Scarf Stane dogwhelk site (4)
0835	Drive to Mossbank
0910-1000	Survey Grunna Taing (Mossbank) dogwhelk site (14)
1015	Pollution Base – package up dogwhelks for flight to Aberdeen
1130	Return to Westayre. Rest, photo and data collation, etc.
pm	Burra Isles
eve	Dinner at Bistro, Lerwick

13 Aug (Thurs)

1030	Pollution Base & SV Terminal – drop off passes and equipment
1130	Drive to Scatsta airport
1315	Flight to Aberdeen
pm	CH takes hire car back to Edinburgh; JM takes flight back to Bristol

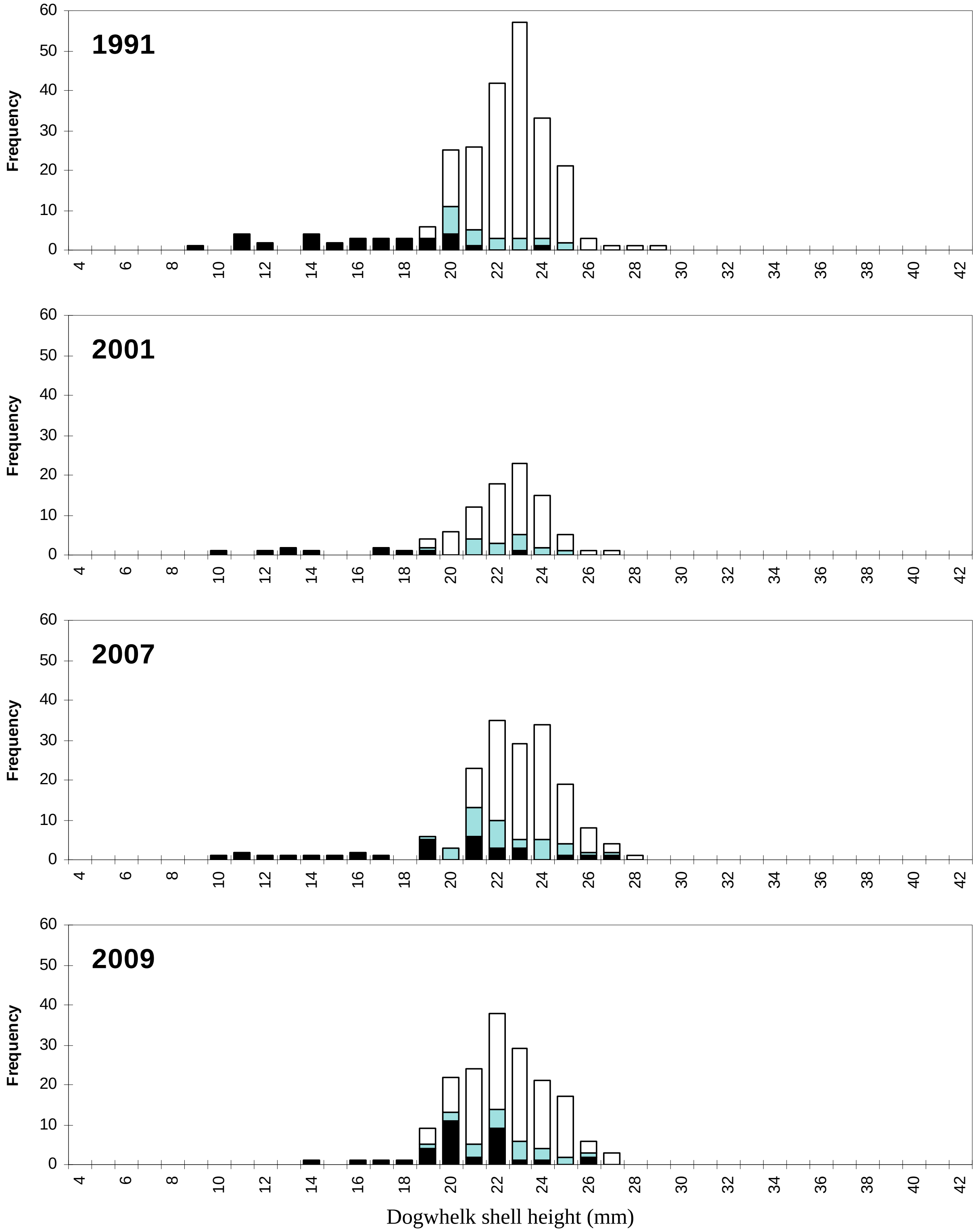
Jon Moore, 13 August 2009
Aquatic Survey & Monitoring Ltd.
Ti Cara, Cosheston, Pembroke Dock, SA72 4UN

Appendix 2 Site descriptions and size class histograms from 1991, 2001, 2007 and 2009

1 Easterwick

Wave exposed shore at the back of a small bay. The area of search is on steep broken bedrock and includes a deep fissure on one side. The shore is dominated by barnacles and the rock in the search area is often partially obscured by the ephemeral red alga *Porphyra*.

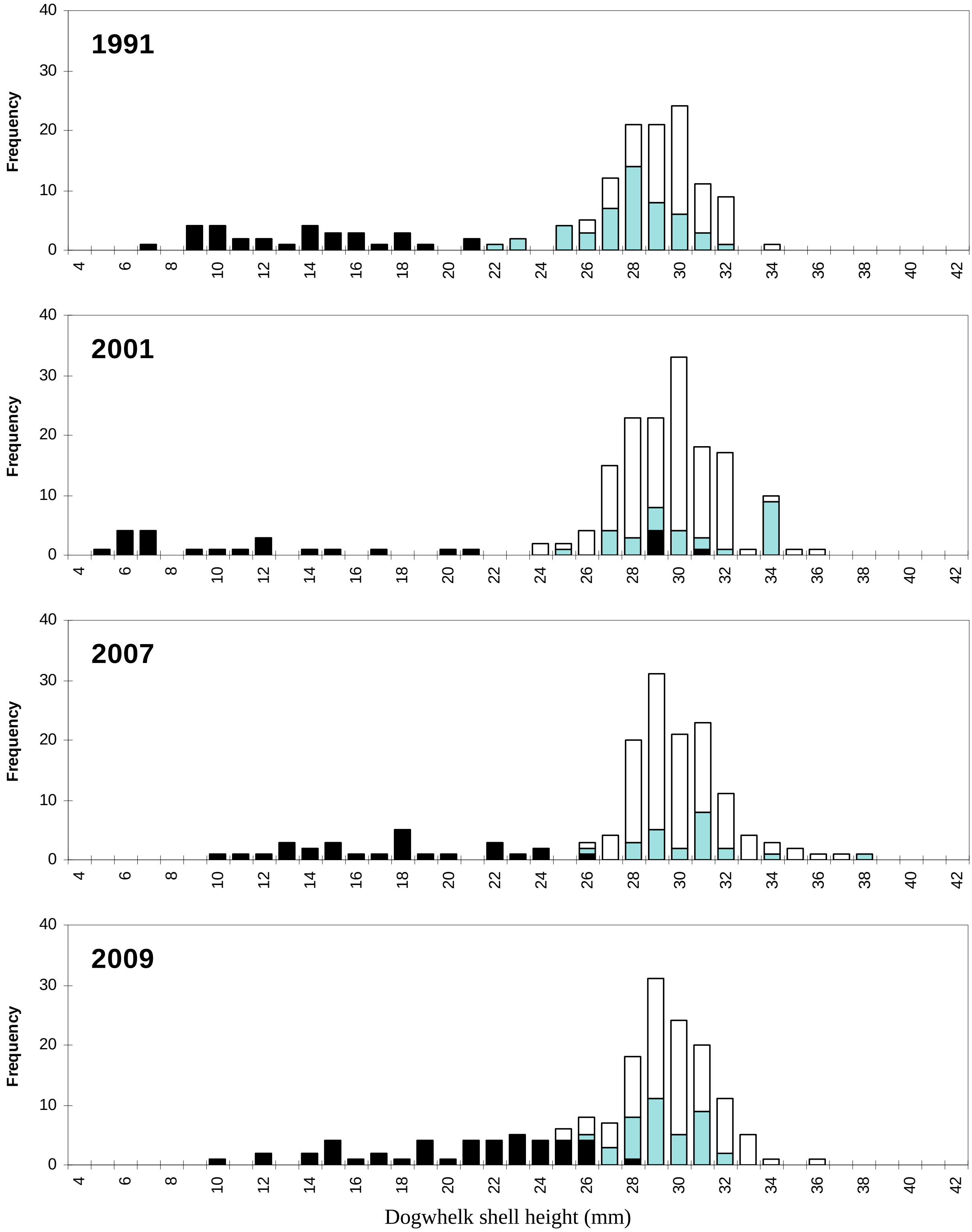
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



2 Burgo Taing

Wave exposed shore at the entrance to Burra Voe. The area of search is on a ridge of broken bedrock with numerous shallow crevices. Barnacles dominate with occasional fucoid algae present on the middle and lower shore.

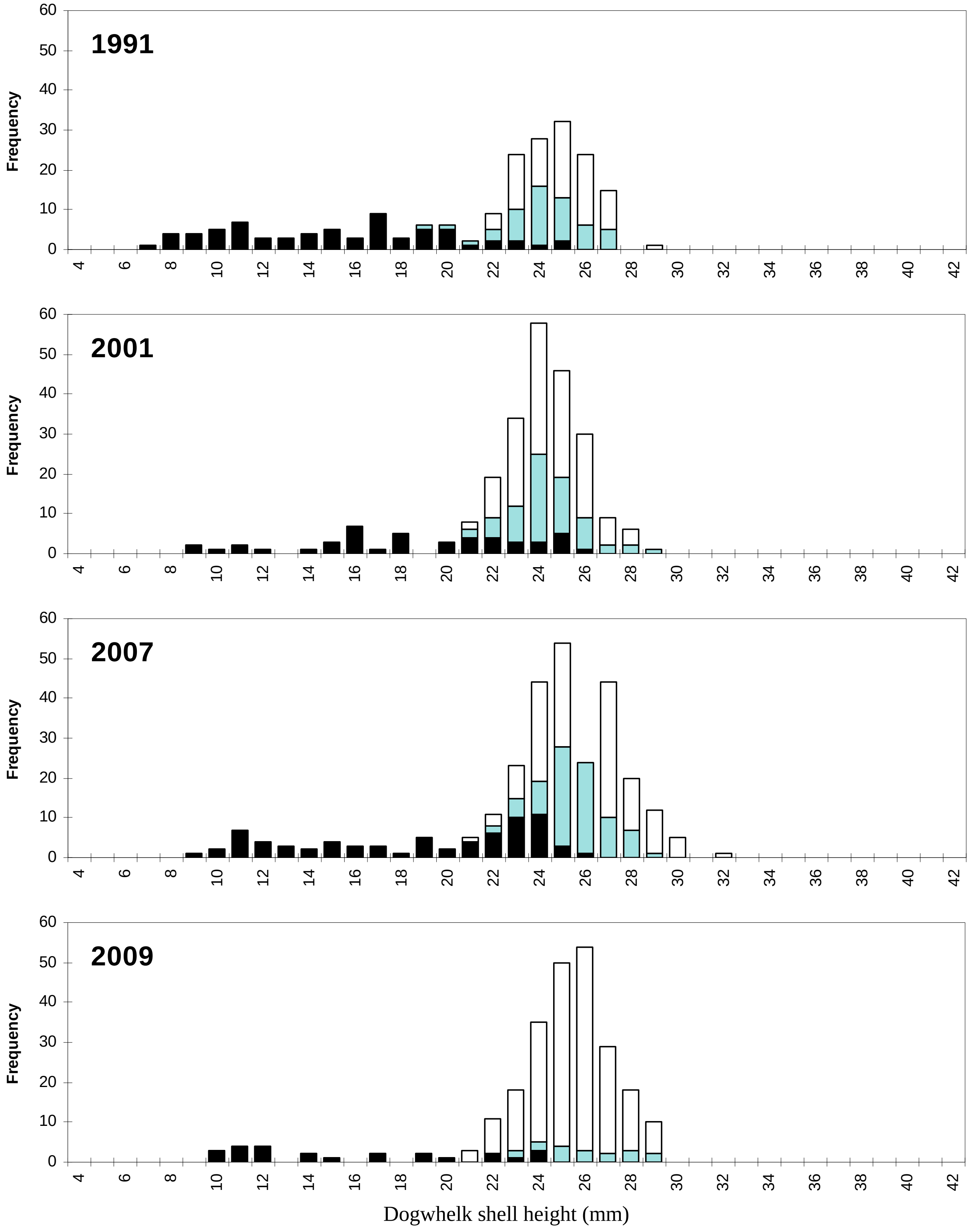
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



3 Billia Skerry

Wave exposed shore. The area of search consisted of bedrock with numerous shallow crevices. Barnacles dominate the shore with *Mytilus edulis* in the middle and lower shore crevices. *Porphyra* often forms a distinct band on the upper middle shore.

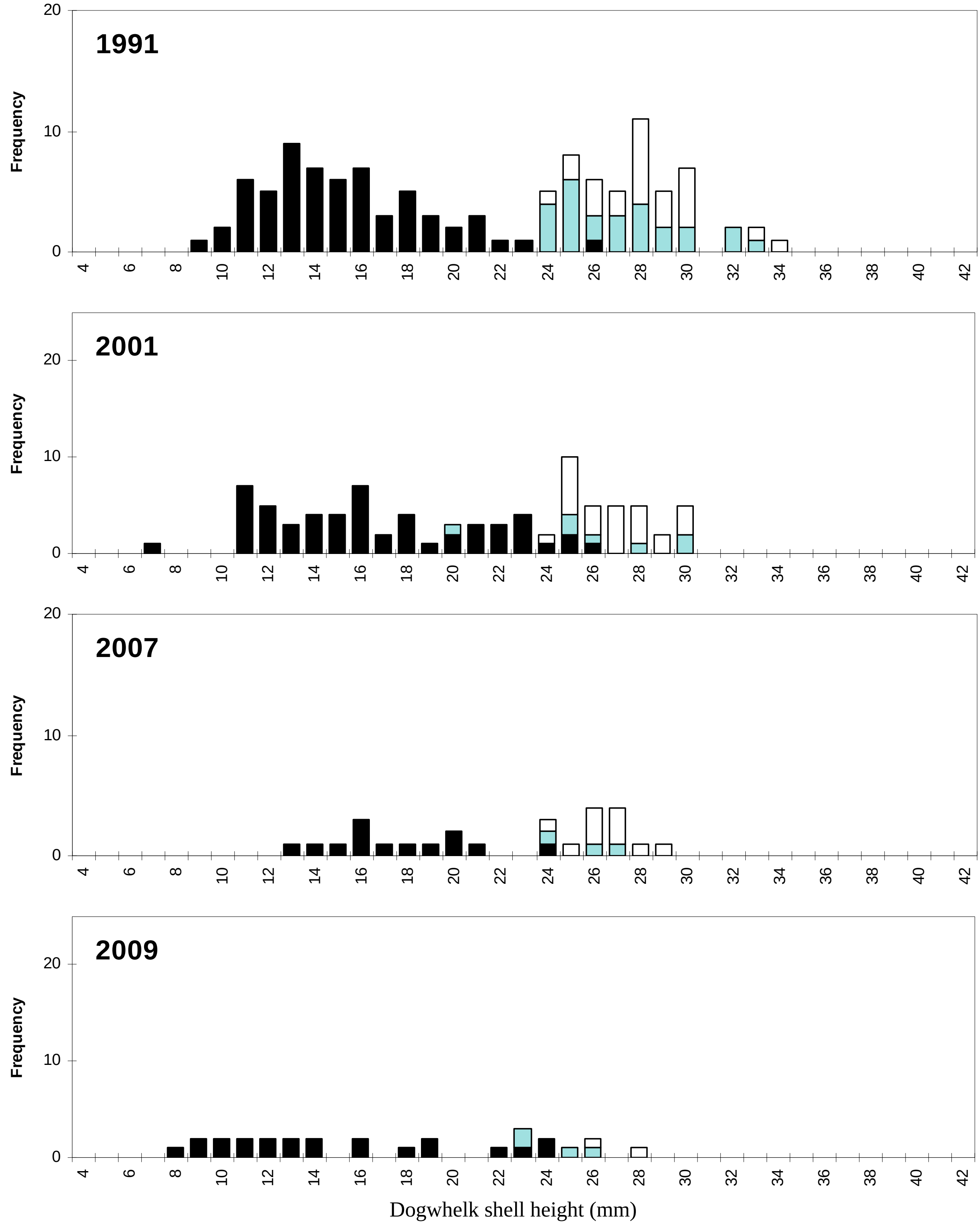
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



4 Scarf Stane

Wave sheltered shore at the back of a large bay. The area of search consists of an isolated outcrop of broken bedrock and boulders. There are limited crevices, but numerous under-boulder niches. The middle shore is dominated by fucoid algae with abundant barnacles.

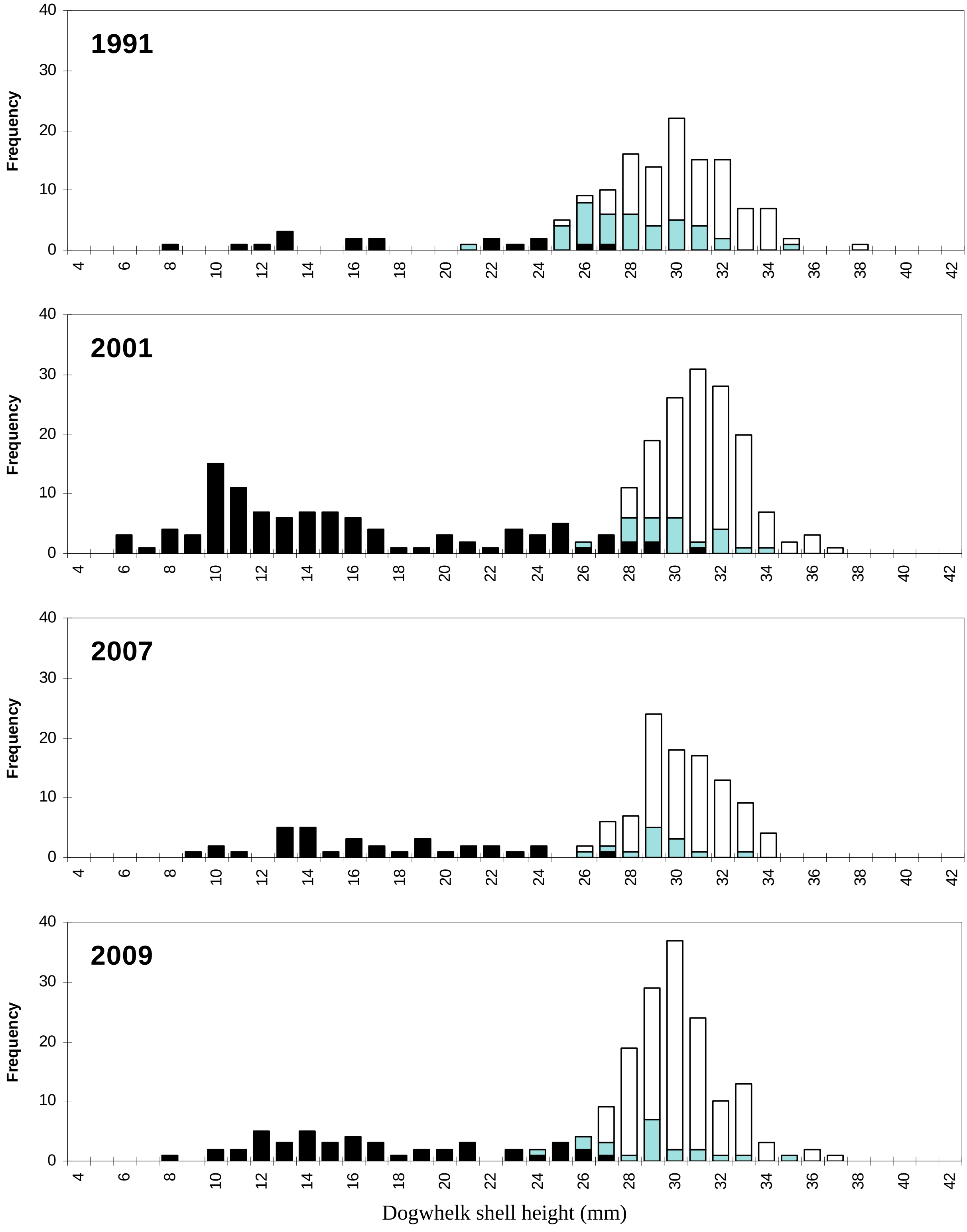
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



5 East of Ollaberry

Moderately wave exposed shore on the north side of the bay. The area of search consists of bedrock with some crevices. Barnacles dominate with *Himanthalia elongata* frequent on the lower shore.

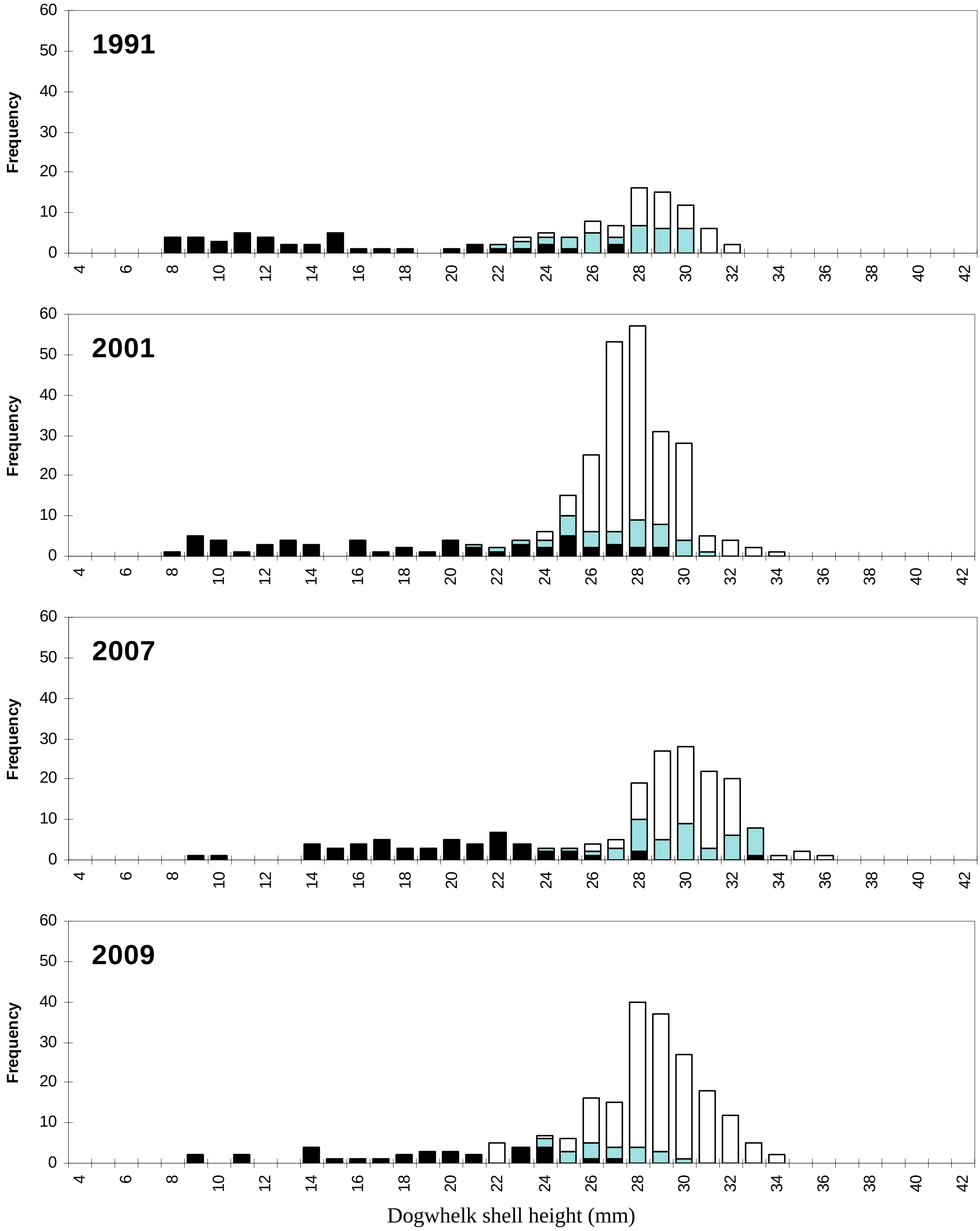
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



6 Grunn Taing

Moderately wave exposed shore on the north side of the bay. The area of search consists of bedrock with some shallow crevices, with the inclusion of one large boulder. Fucoid algae dominate the middle shore, with common/abundant barnacles in patches.

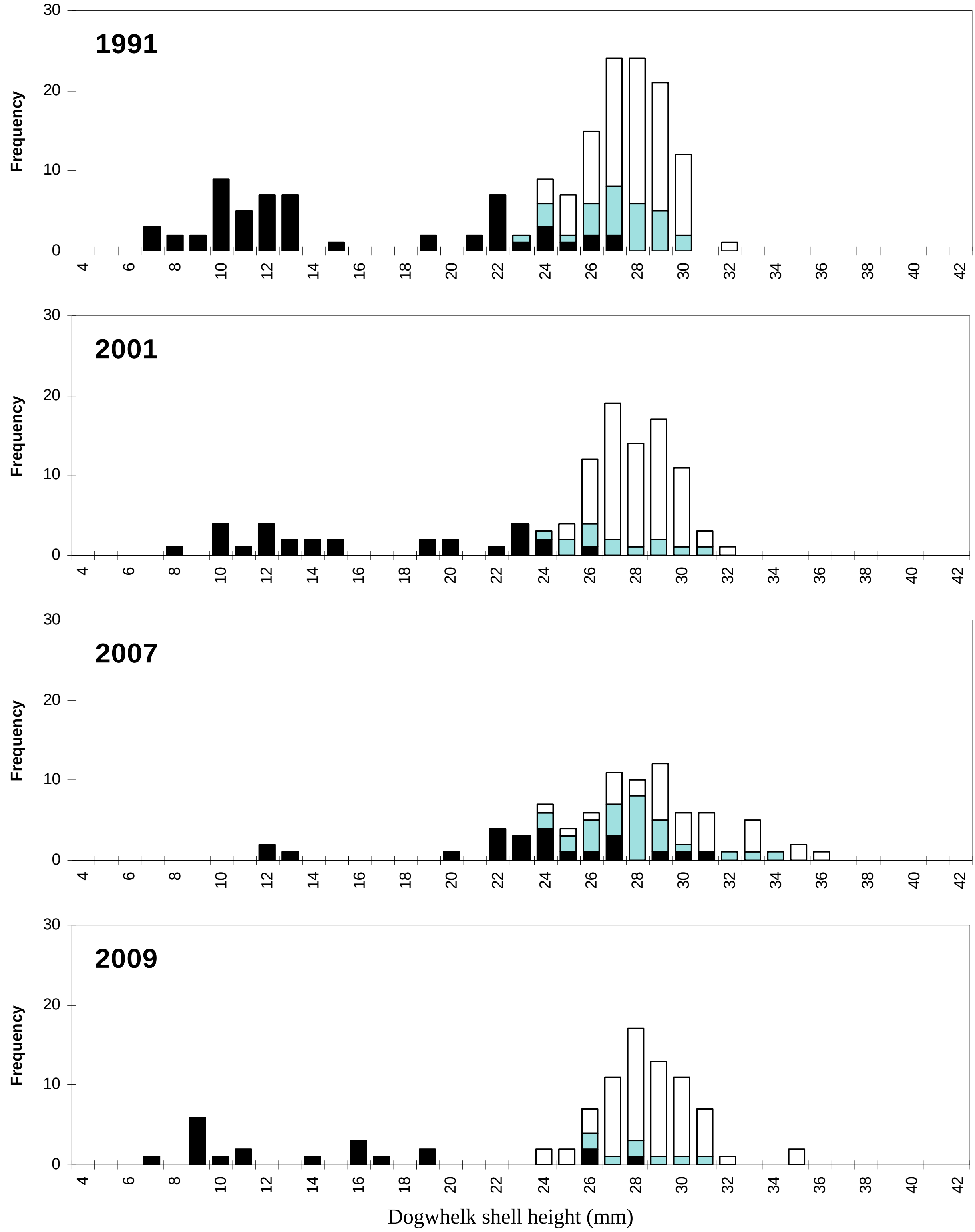
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



7 Tivaka Taing

Moderately wave exposed shore. The area of search consists of bedrock with numerous shallow crevices. Barnacles dominate with *Fucus serratus* present on the lower shore.

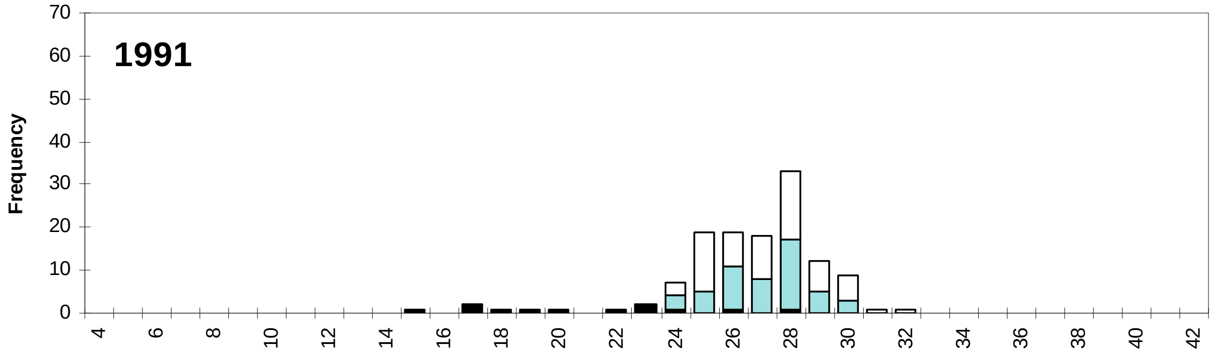
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults

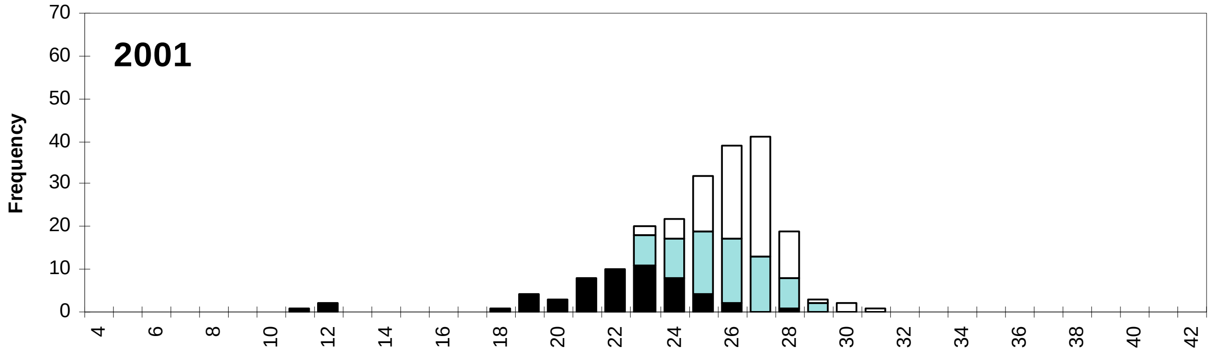


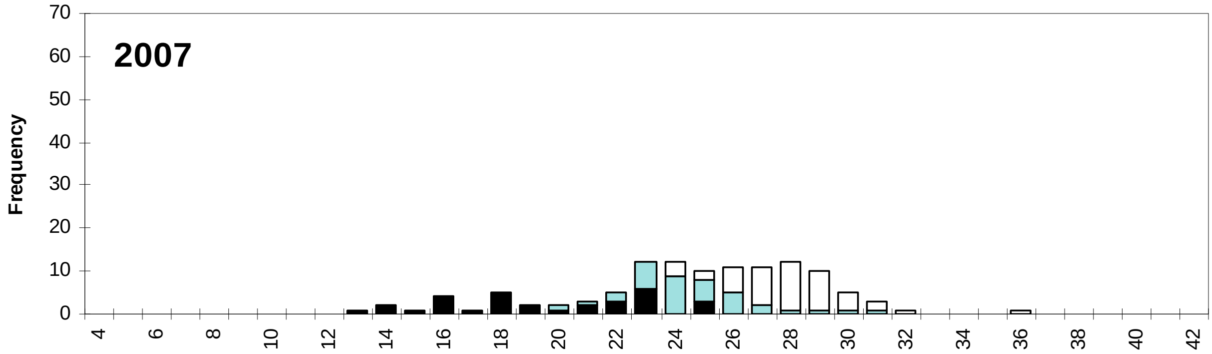
8 Noust of Burraland (Blanches Geo)

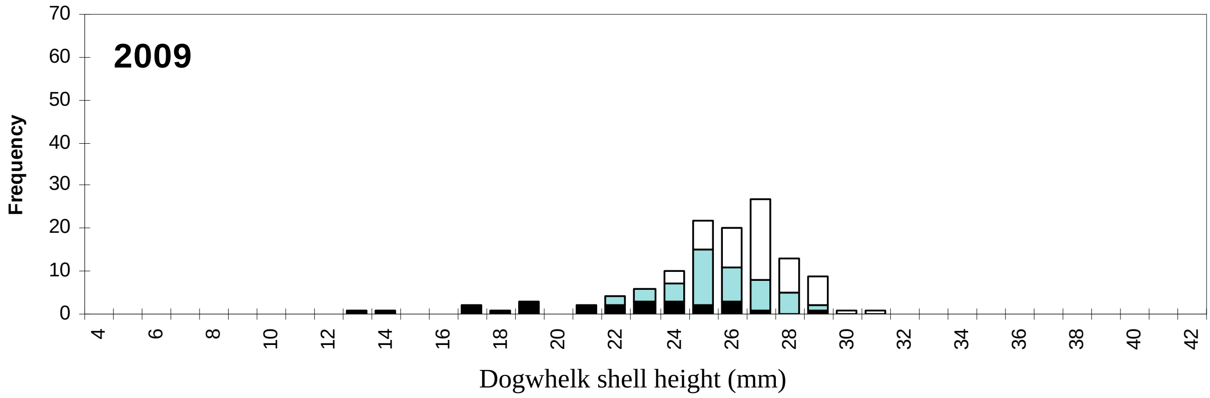
Wave sheltered shore. The area of search consists of bedrock with numerous shallow crevices, and some small boulders and cobbles at the base of the bedrock. Fucoid algae dominate with abundant barnacles on the upper middle shore.

Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults





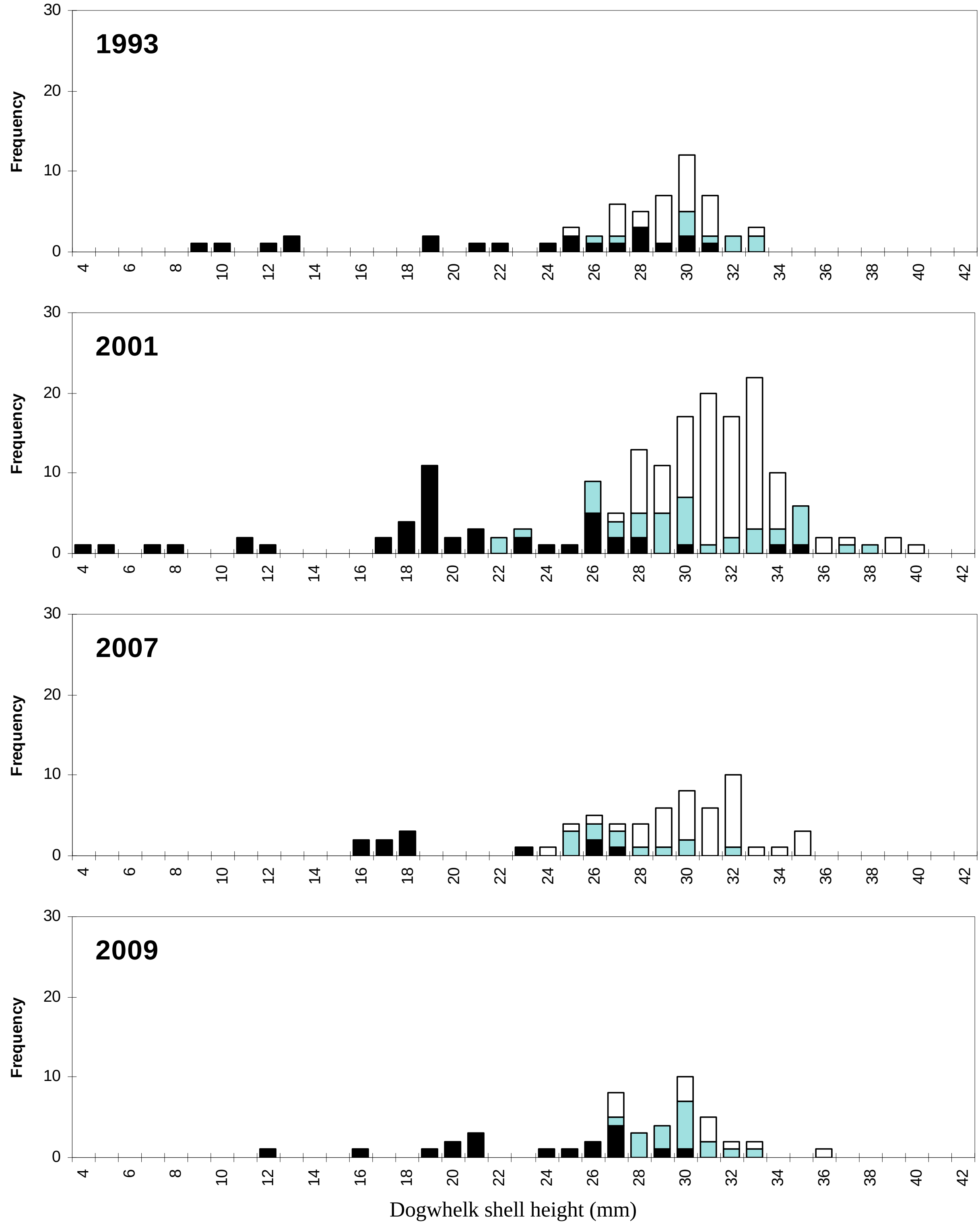




9 Mavis Grind

Very sheltered bedrock shore with some crevices. Fucoid dominated (primarily *Ascophyllum nodosum*) with abundant/common barnacles on the lower shore. The area of search was changed (by about 20m) after the 1991 survey due to a lack of dogwhelks.

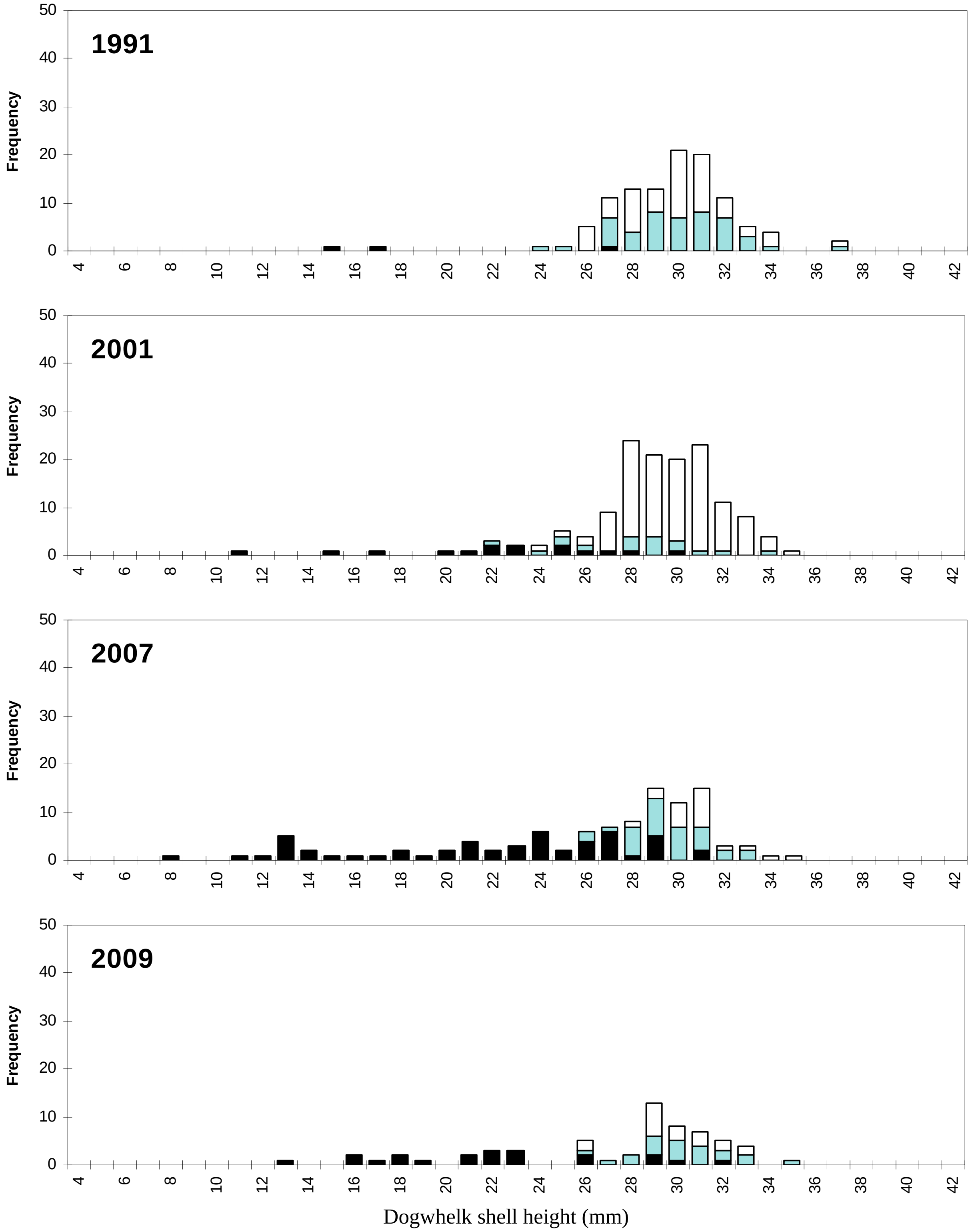
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



10 Voxter Ness

Wave sheltered shore. The area of search consists of bedrock with some shallow crevices. Barnacles dominate the middle shore with *Mytilus edulis* superabundant on the lower shore.

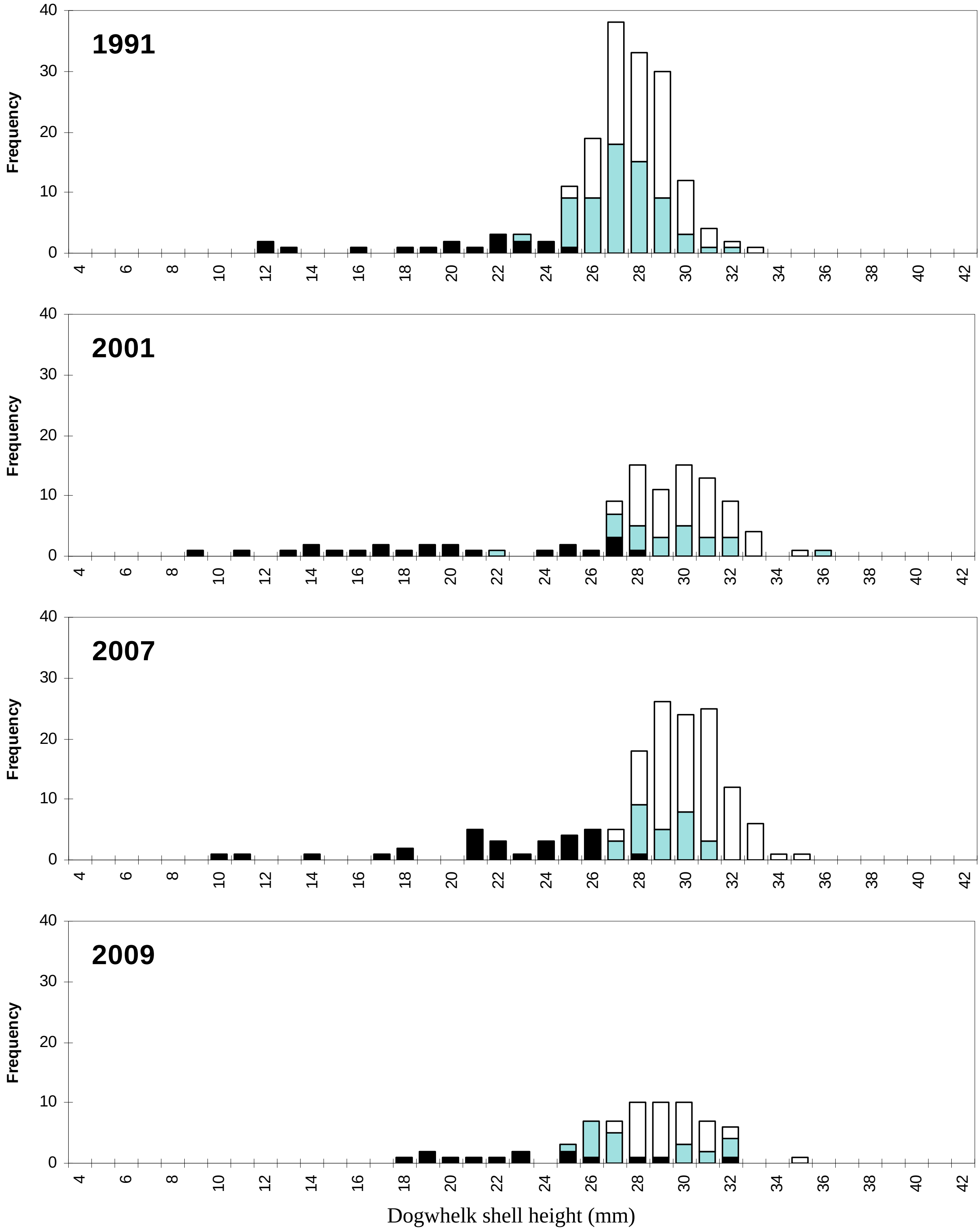
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



11 Northward

Wave sheltered shore. The area of search is on an isolated outcrop of bedrock and boulders with some crevices. Barnacles dominate with fucoids on the middle and lower shore, including patchy *Ascophyllum nodosum*.

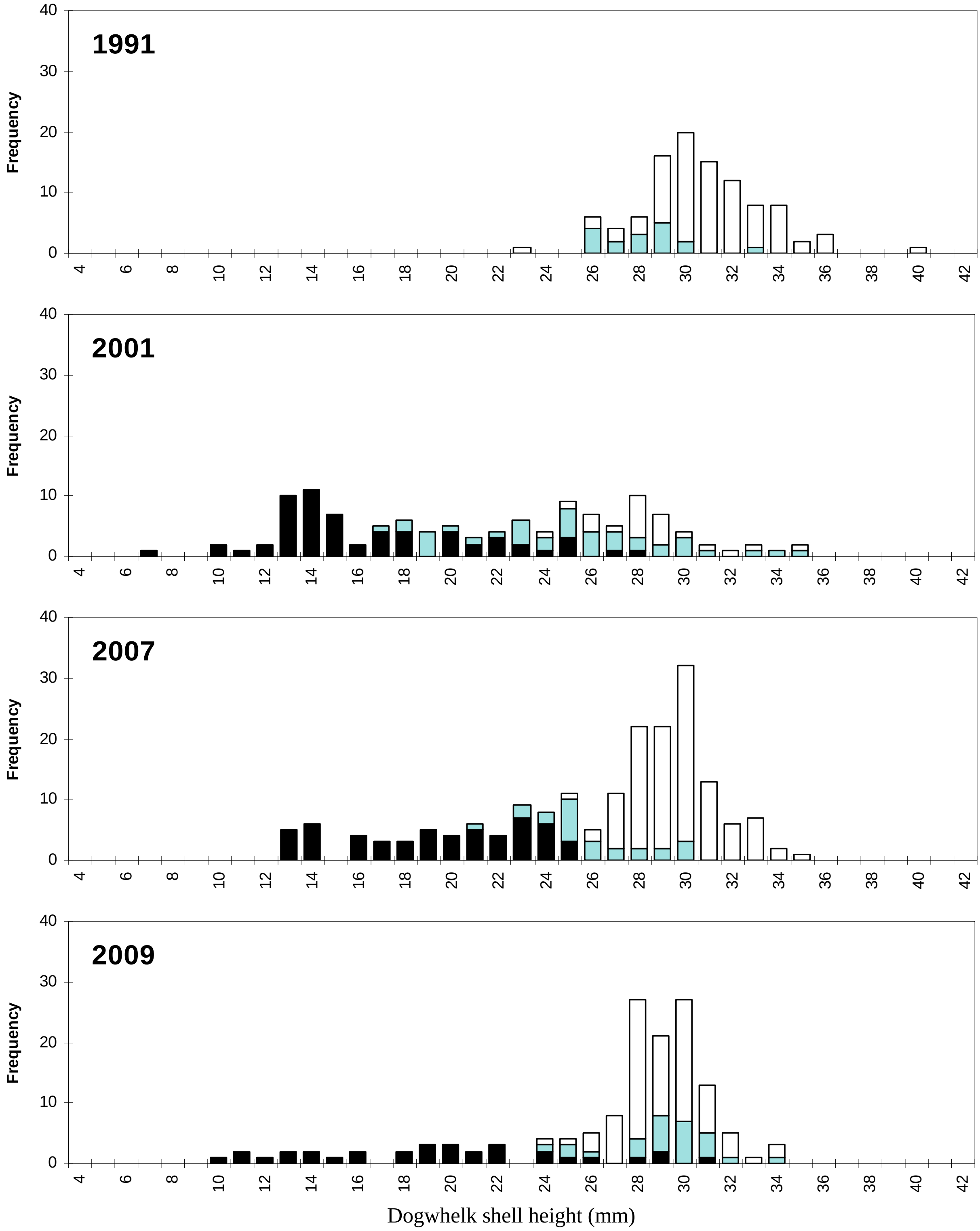
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



12 The Kames

Moderately wave exposed shore. The area of search was greater than other sites due to low dogwhelk numbers. The search area consists of bedrock with shallow crevices dominated by barnacles and some fucoid algae.

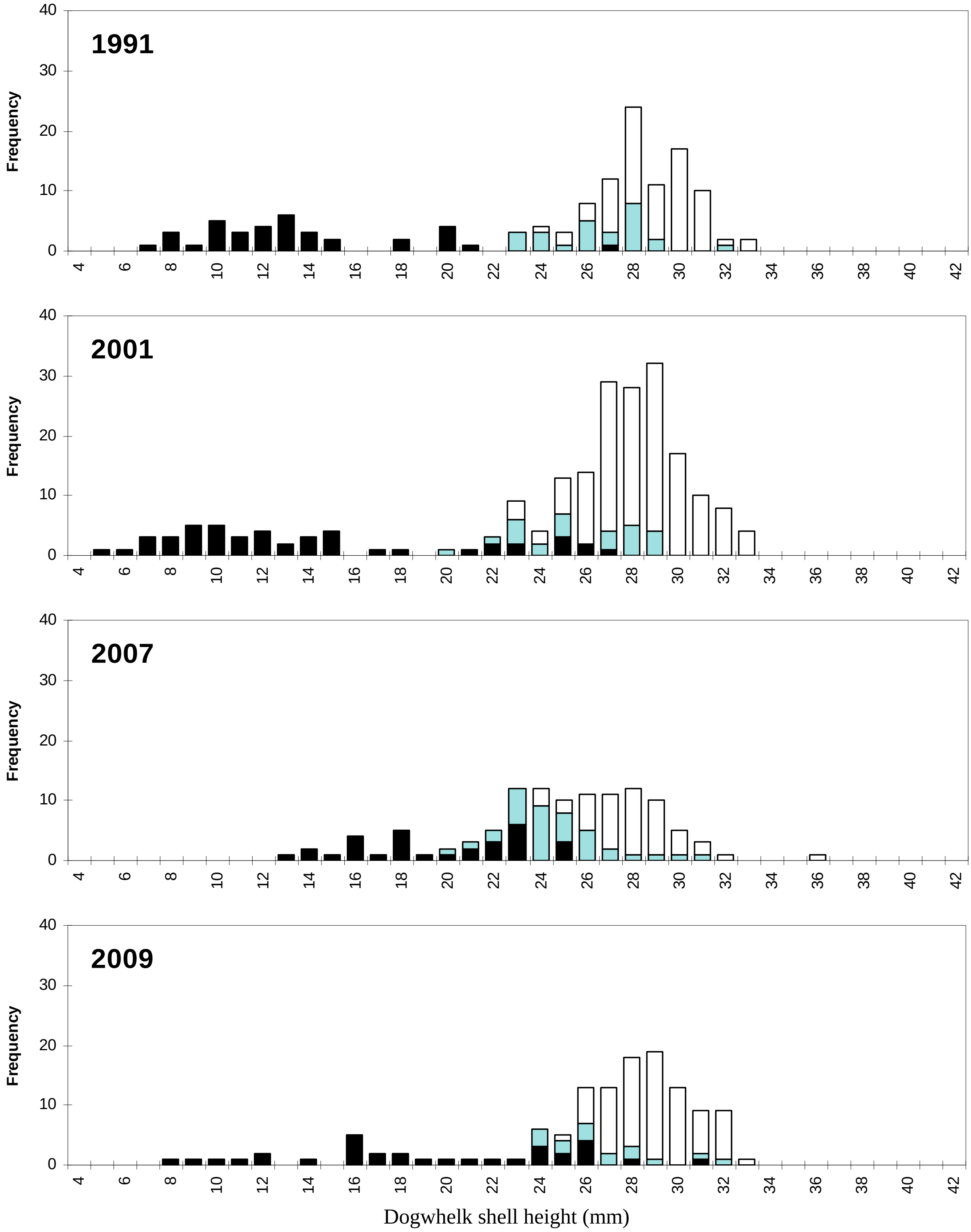
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



13 Skaw Taing

Wave exposed shore on the steep east side of a long ridge. The area of search consists of bedrock with numerous crevices. Barnacles dominate with some lower shore *Himanthalia elongata*.

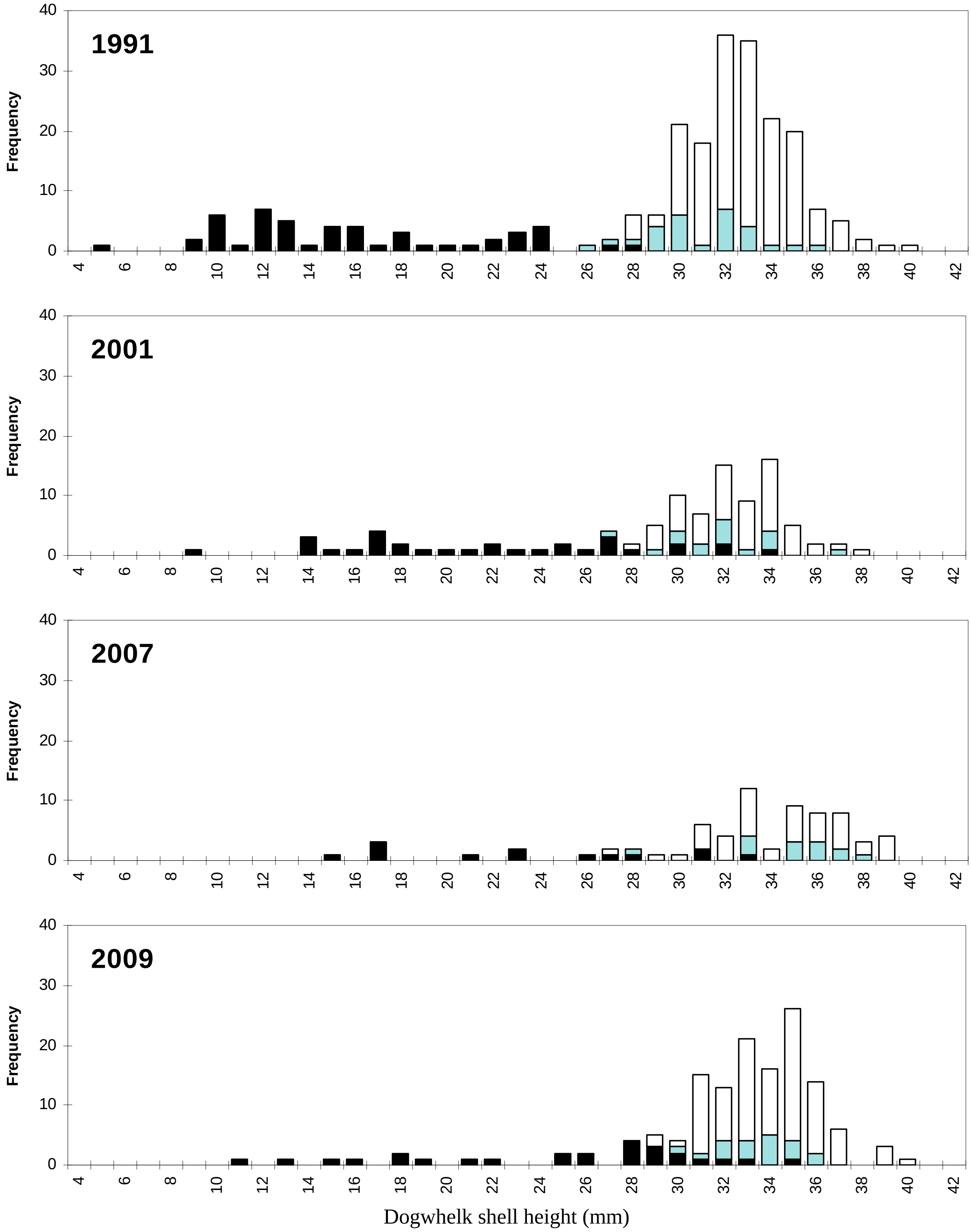
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



14 Mossbank (Grunna Taing)

Moderately wave exposed shore. The area of search consists of broken bedrock with numerous crevices. Barnacle dominate with patchy fucoids on the middle shore.

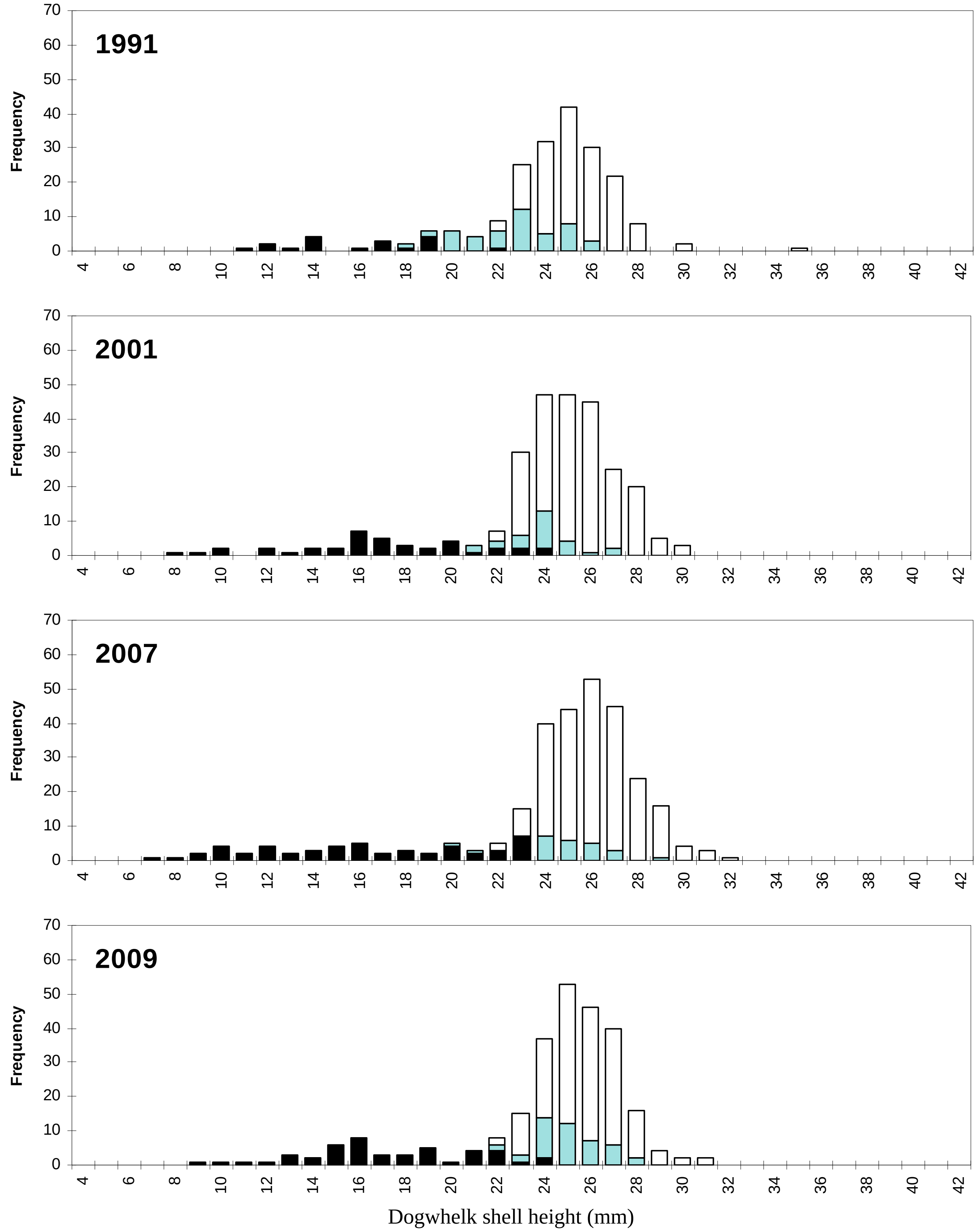
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



15 Orfassey

Wave exposed shore on the east side of the island. The area of search consists of bedrock with narrow crevices. Barnacle dominate the shore.

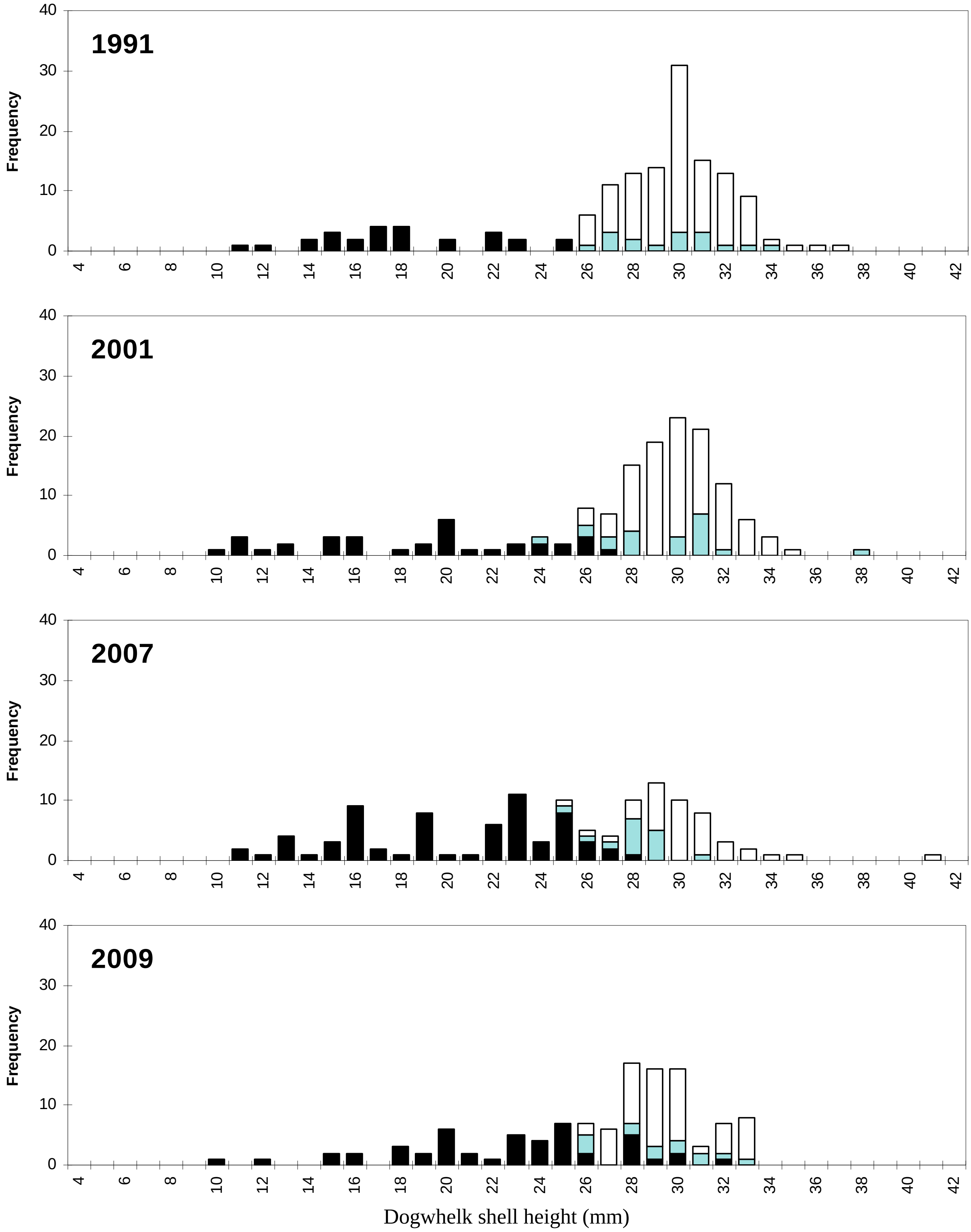
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



16 Samphrey (The Helliack)

Wave exposed shore on the northern tip of the island. The area of search consists of bedrock with shallow crevices and one large fissure. Barnacle / limpet dominated shore.

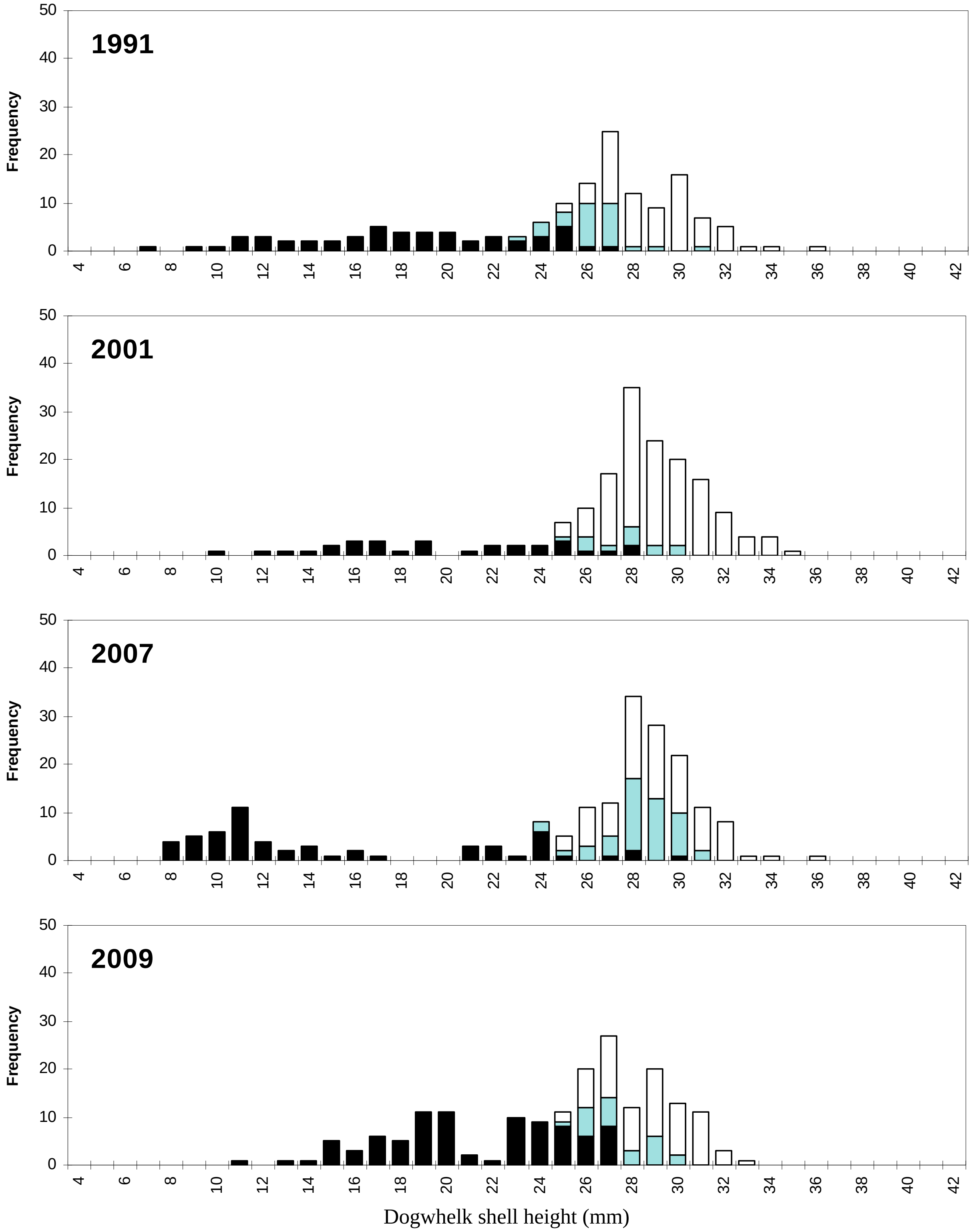
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



17 Uynarey

Wave exposed shore on the east side of the island. The area of search consists of bedrock with numerous narrow crevices. Barnacle / limpet dominated shore.

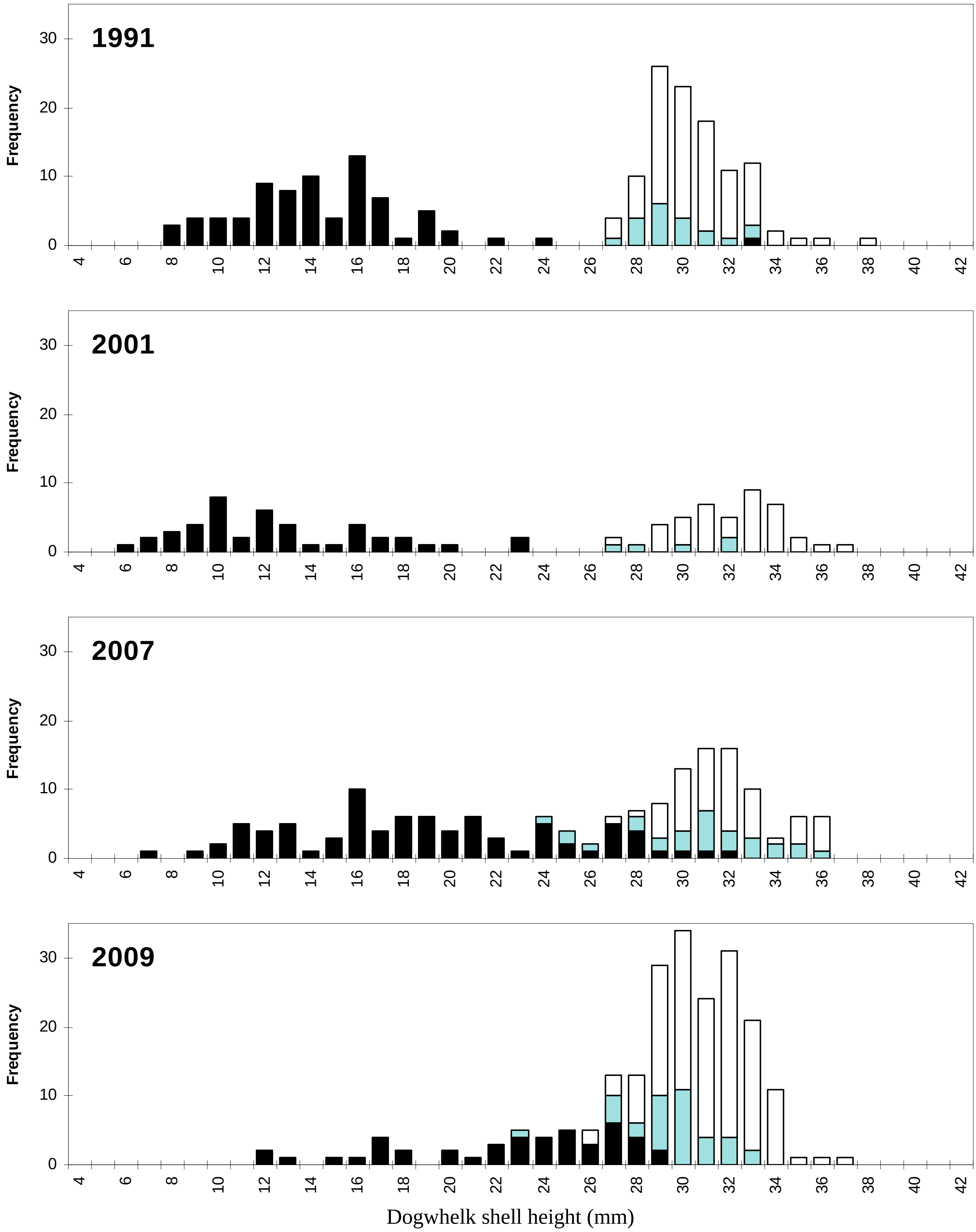
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults



18 Little Roe

Wave sheltered shore. The area of search consists of bedrock with shallow crevices. Fucoid algae dominate with abundant barnacles on the upper middle shore.

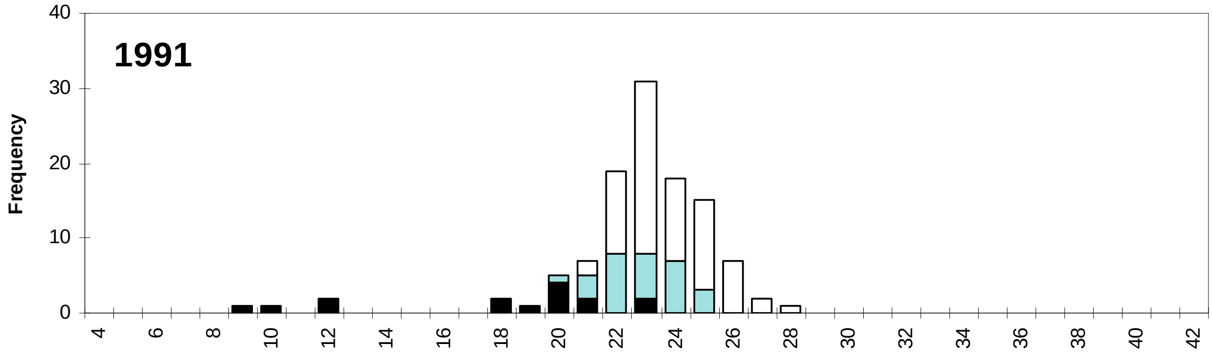
Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults

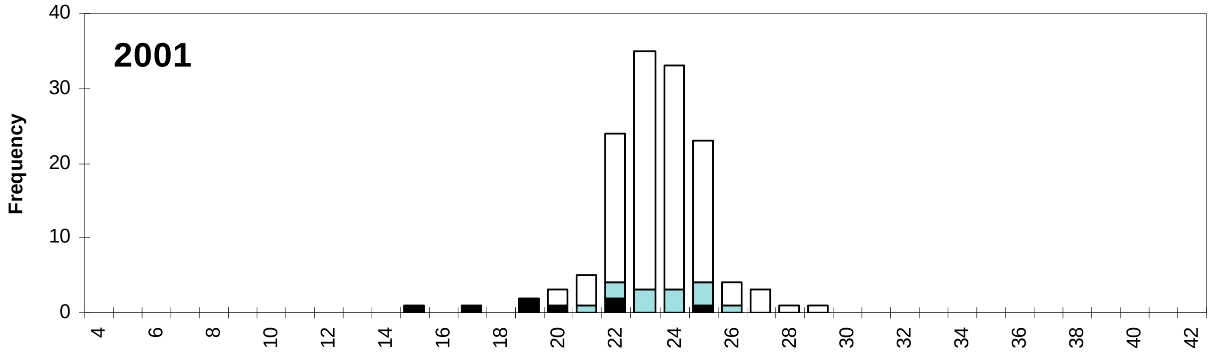


19 The Brough

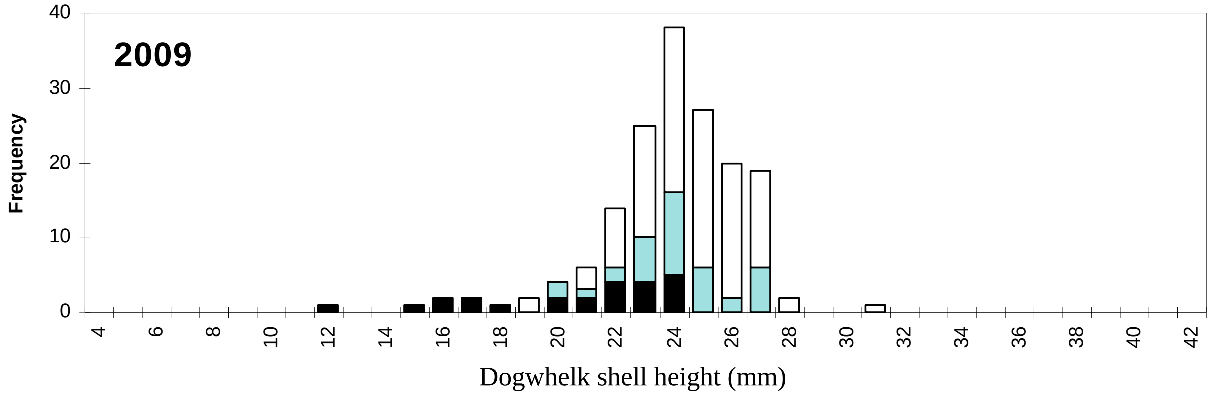
Very wave exposed shore. The area of search consists of bedrock with extremely numerous narrow crevices. Barnacle dominated with *Mytilus edulis* in the middle and lower shore crevices.

Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults





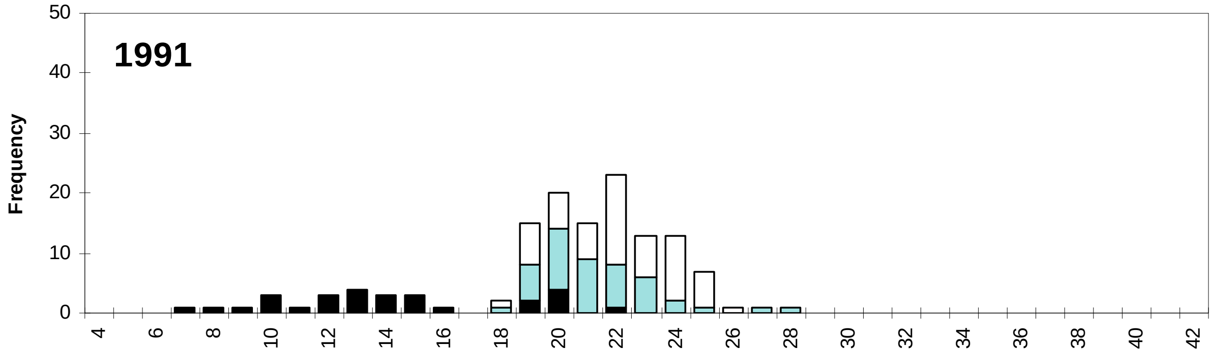
2007: no data due to rough sea conditions

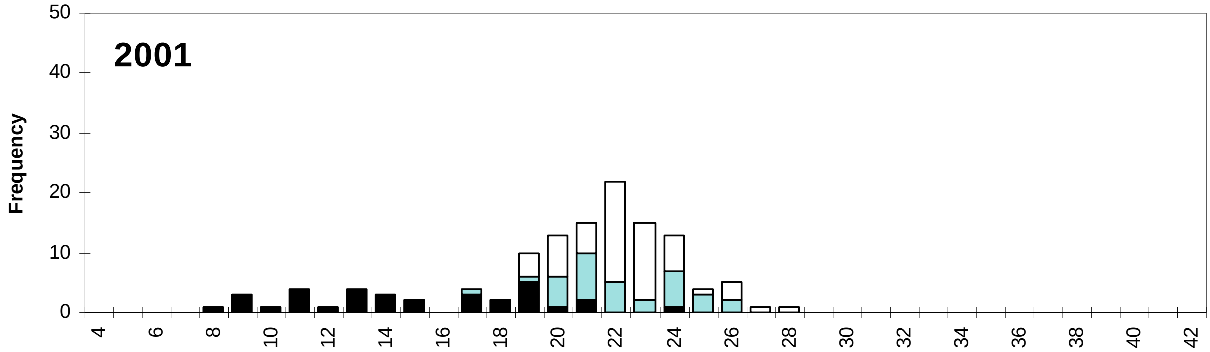


20 Norther Geo

Wave exposed shore at the back of a large geo. The area of search consists of bedrock with shallow crevices. Barnacle dominated with *Mytilus edulis* in middle and lower shore crevices.

Dark shading:	thin shell edge, juveniles and first years
Medium shading:	thick edge, second year dogwhelks and young adults
Light shading:	toothed shell, mature adults





2007: no data due to rough sea conditions