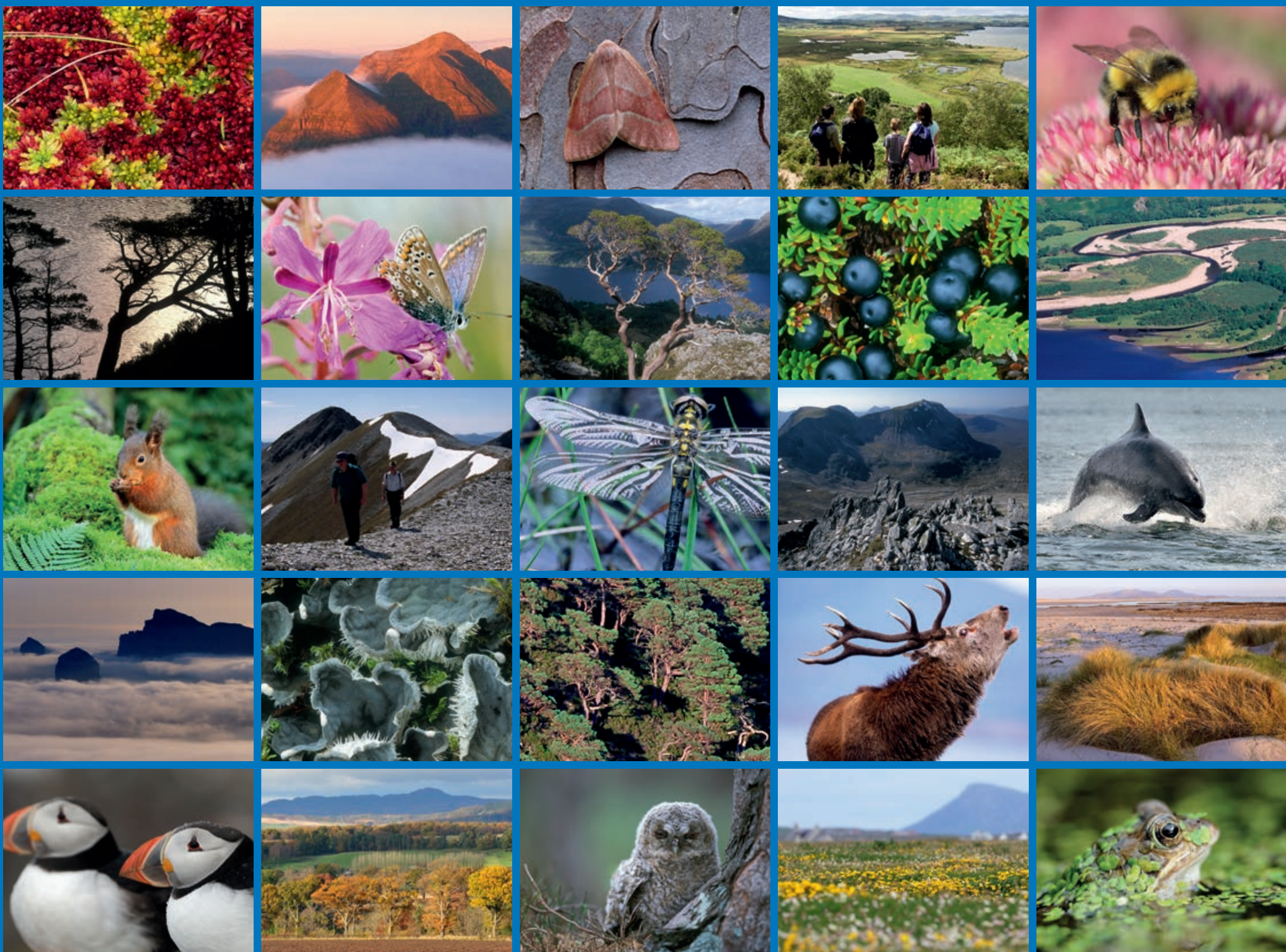
Scottish Natural Heritage
Research Report No. 1156

The current status of serpulid reefs, horse mussel beds and flame shell beds in Loch Creran SAC and MPA



RESEARCH REPORT

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The current status of serpulid reefs, horse mussel beds and flame shell beds in Loch Creran SAC and MPA

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RESEARCH REPORT

Summary

The current status of serpulid reefs, horse mussel beds and flame shell beds in Loch Creran SAC and MPA

Research Report No. 1156
Project No: 116868
Contractor: Heriot-Watt University
Year of publication: 2020

Keywords

benthos; monitoring; condition; reefs; flame shell; SAC; MPA; SCM

Background

The Loch Creran SAC was established to afford protection for the marine feature reefs, which includes the biogenic sub-features serpulid reefs and horse mussel beds, as well as the bedrock reefs of the loch. An aim of the current study was to carry out site condition monitoring (SCM) of the biogenic sub-features of the SAC, in order to identify any possible deterioration in the condition of the reefs feature and to form a judgement on its current condition. Loch Creran is also designated as a Marine Protected Area (MPA), conferred to protect the flame shell beds and geodiversity features. A further aim of the study was to assess the current condition of the flame shell bed feature.

Main findings

– Widespread fragmentation and marked reduction in tube occupancy of the serpulid reefs of the loch are reported to have taken place between 2005 and 2014-19, with loss of habitat estimated at around 20%. It is proposed that a phase of reef degradation without compensatory replenishment forms part of a long-term, natural cycle.

– Horse mussel beds covering a total area of 30 ha have been mapped, representing the biotopes **SS.SBR.SMus.ModHAs** and **SS.SBR.SMus.ModT**.

– Localised reductions in horse mussel density were recorded in three of the beds between 2005 and 2018, with evidence of long-term, poor recruitment in the most extensive, upper basin bed.

– Only slight changes in species composition and diversity of the community associated with horse mussels were recorded over the years 2005 - 2017.

– Temporal changes in the horse mussel beds were consistent with natural temporal variation.

– In view of the decline in the condition of the sub-feature serpulid reefs, the condition of the reefs feature has been referred to the category Unfavourable Declining.

- Three flame shell beds covering a total area of 35 ha have been mapped. An increase in the recorded extent of the habitat between 2012 and 2017-18 was due to the increase in spatial spread of survey sites.

- Mean byssal coverage of the sea bed (a proxy for flame shell abundance) and diversity values of the associated biota of the flame shell habitat were similar in 2012 and 2017-18 and the feature was considered to be in Favourable Condition.

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Acknowledgements

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1. INTRODUCTION

Loch Creran lies 12 km to the north of Oban on the west coast of Scotland (Figure 1). It was designated a Special Area of Conservation (SAC) under the EC Habitats Directive (92/43 EEC) in 2005 in order to protect its qualifying feature, reefs. The SAC extends to the mouth of the loch (Figure 1) and includes the subtidal area to MLWS. The reefs feature (listed in Annex 1 of the Habitats Directive) comprises rocky and biogenic reefs, the latter including serpulid reefs (mass aggregations of the serpulid worm, *Serpula vermicularis*) and beds of the horse mussel, *Modiolus modiolus*. The loch harbours the greatest known development of the rare *S. vermicularis* reef habitat in the world (Moore *et al*., 1998).

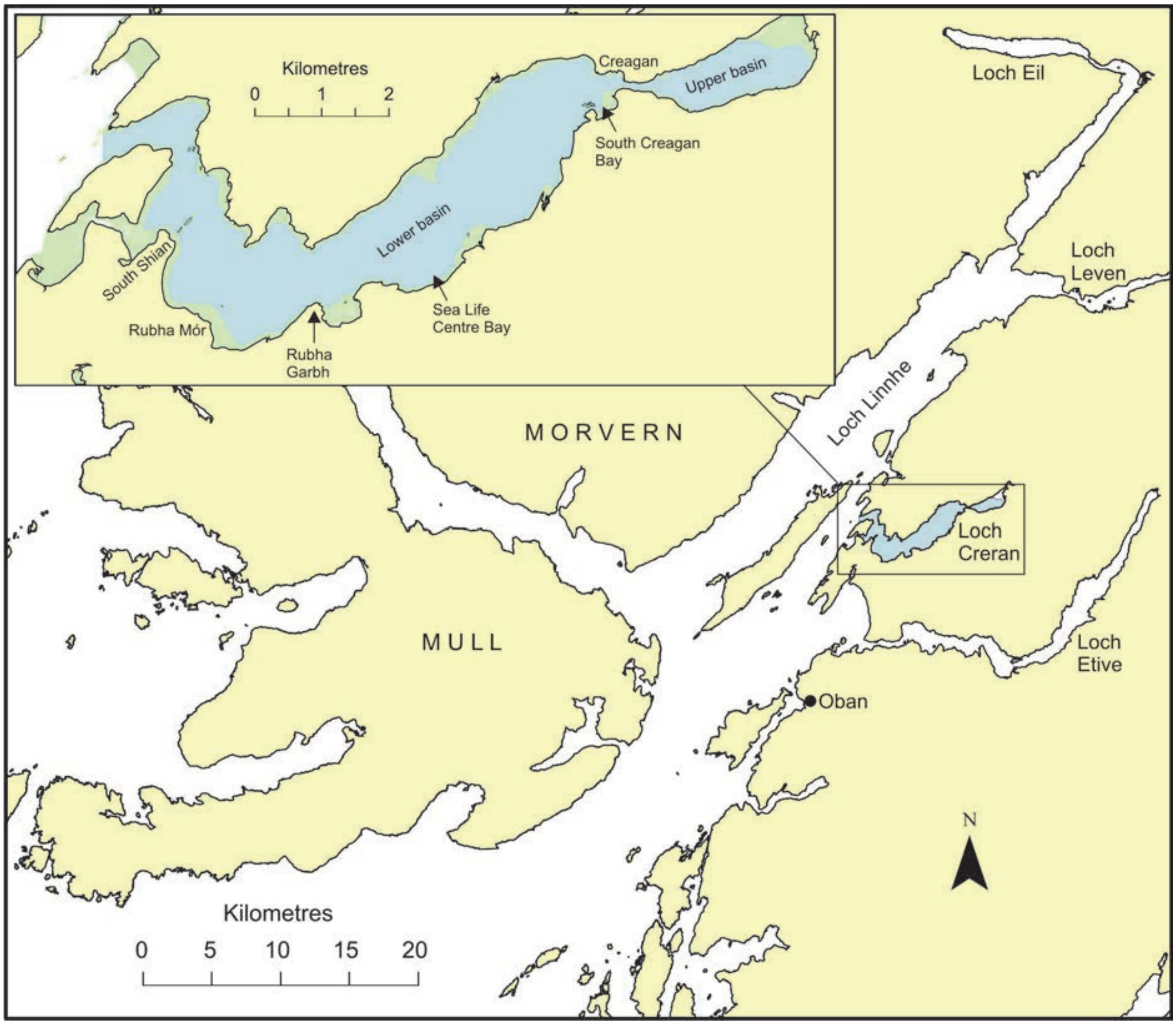

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Figure 1. Location of Loch Creran on the west coast of Scotland, with inset showing detail of the loch. Loch Creran SAC and MPA in blue.

In 2014 Loch Creran was also designated as a Marine Protected Area (MPA) under the Marine (Scotland) Act 2010, with the same geographical coverage as the SAC. The MPA protected features include beds of the flame shell, *Limaria hians*, and the geodiversity feature Quaternary of Scotland.

One aim of the current investigation was to carry out site condition monitoring (SCM) of Loch Creran in order to assess the condition of the biogenic reefs of the SAC. A further aim was to assess the current status of the flame shell bed habitat in the loch. The proposition in the project brief was that the condition assessment of serpulid reefs could be largely based on collation of recent, existing work. While this expectation was exceeded, it did provide some limitation on the scale of the current field investigations.

1.1 Condition Monitoring of Loch Creran SAC

In order to ensure a uniform approach to the monitoring of the condition of features, guidance has been drawn up on the general approach to be taken in condition monitoring (Joint Nature Conservation Committee, 2006). Thus, for the purposes of monitoring, each feature is represented by a series of attributes, which are measurable indicators of the condition of the feature at the site. For each attribute (e.g. extent of a habitat or presence of representative/notable biotopes), a target is set which is considered to correspond to the favourable condition of the feature.

In the case of the Loch Creran SAC the Annex I 'reef' feature falls under the Common Standards Monitoring guidance produced for littoral and inshore sublittoral rock habitats (Inter-Agency Marine Monitoring Group, 2004). The Inter-Agency Marine Monitoring Group (*ibid*.) lists the attributes of these habitats and corresponding targets that should form the basis of the site condition monitoring (Table 1).

Table 1. Site attributes that should be utilised to define the condition of littoral and inshore sublittoral rock features in site condition monitoring (Inter-Agency Marine Monitoring Group, 2004). The use of the first three attributes is mandatory; otherwise attributes are discretionary.

Attribute	**Target**
Extent	No change in extent of intertidal rock or inshore sublittoral rock.
Biotope composition	Maintenance of the variety of biotopes identified for the site, allowing for natural succession or known cyclical changes.
Distribution of biotopes. Spatial arrangement of biotopes at specified locations	Maintain the distribution/spatial arrangement of biotopes, allowing for natural succession or known cyclical changes.
Extent of sub-feature or representative/notable biotopes	No change in the extent of the biotope(s) identified for the site, allowing for natural succession or known cyclical changes.
Presence of representative/notable biotopes	Maintain the presence of the specified biotope, allowing for natural succession or known cyclical changes.
Species composition of representative/notable biotopes	No change in biotope quality due to change in species composition or loss of notable species, allowing for natural succession or known cyclical changes.
Presence and/or abundance of specified species	Maintain presence and/or abundance of specified species. Absence of the specified species (such as an undesirable/non-native species).

1.2 Previous studies

A number of previous surveys of the protected features of the loch have been carried out. Connor (1990) reported on MNCR phase 2 surveys (Hiscock, 1996) at 10 subtidal sites in 1989 including examples of serpulid reefs and *Modiolus* beds. The distribution of the serpulid reef habitat was examined by diving in 1994 (Moore, 1996; Moore *et al*., 1998) and broadscale mapping of the biotopes of the loch, including serpulid and horse mussel habitats, carried out by Black *et al*. (2000) using an acoustic ground discrimination system (AGDS) supported by grabs, diver and video observations. Moore *et al.* (2003) measured the percentage cover of serpulid reefs at locations off Rubha Mór and Rubha Garbh in 2000 - 01 using a video transect technique. Mair *et al.* (2000) studied the abundance, distribution, population structure and associated community of a *Modiolus* bed in the upper basin of the loch in 1999.

A baseline for site condition monitoring of the loch was established in 2005 (Moore *et al*., 2006). The extent and distribution of serpulid reefs was determined from observations by diver along 110 transects around the loch. Detailed studies were also performed at four of the major serpulid reef sites in the loch. Here, distribution was examined with sidescan sonar, reef density by video and the community of organisms associated with the habitat by diver survey of the reefs themselves and of the surrounding sediment. The distribution and abundance of *Modiolus* was examined along seven relocatable transects and, at one of the major mussel beds, the size structure of the population and associated community surveyed. The serpulid reef results from the 2005 study are further analysed in Moore *et al.* (2009).

Other, largely unpublished sidescan sonar surveys of the loch concentrating on the serpulid reefs have been undertaken by Heriot-Watt and St Andrews Universities in 2003, 2004 and 2005 using a towed sonar fish and by Heriot-Watt University in 2007 and 2009 using a Remus 100 AUV. The 2004 and 2005 results have been partly presented by Moore *et al.* (2006) and the AUV results are presented in part and discussed in the current report. Sidescan surveys of most of the loch were carried out in 2002 and 2004 by Fournier *et al*. (2010), who used supervised classification of the mosaicked imagery to map the serpulid habitat.

Marked deterioration in the condition of the serpulid reefs became evident in 2013 following diving work by Heriot-Watt University at several locations previously supporting pristine reef habitat, with extensive areas reduced to reef rubble. Since then two sonar surveys have taken place. A multibeam survey was carried out off Rubha Mór by the British Geological Society in 2014 (H. Stewart, pers. comm.) but this failed to resolve the microtopography of the seabed to the level where reef material could be reliably detected. A 2015 sidescan sonar survey of the principal reef areas within the loch commissioned by SNH and carried out by Geosurv Ltd. (2015) produced considerably better discrimination of seabed detail and this imagery has been utilised extensively in the current report.

Work by Heriot-Watt University over the winter of 2014/15, chiefly in the form of an undergraduate dissertation, aimed to assess the extent and possible cause of reef damage (Tulbure, 2015). A quantitative comparison of the percentage of broken reef material from areas within the principal reef site locations, Rubha Mór, South Shian, Sea Life Centre Bay and South Creagan Bay, using video from the 2005 SCM survey and new video material, revealed marked increases in broken material at all sites.

In order to identify spatial patterns in reef damage and to link these with possible causative factors, reef condition was assessed within the coastal serpulid reef band at 28 sites around the periphery of the lower basin of the loch. At each site reef material within four replicate areas of approximately 3 x 3 m was assessed by recording the percentage cover of upright and fallen/broken reef material, as well as the maximum reef height and water depth. No correlations were observed between a derived measure of exposure and either damaged reef or reef height.

There has been only one previous survey of the flame shell beds of the loch (Moore *et al*., 2013). The survey validated the presence of beds off South Shian and off Creagan and mapped their distribution.

As well as the above surveys there have been many biological studies carried out on the protected features of the loch, several of which are particularly relevant to the current project.

Growth and population structure have been studied by Comely (1978) for M*odiolus modiolus* at Creagan in 1974 - 76, and for *Limaria hians* off South Shian by Trigg (2009) in 2006 - 07. For *Serpula vermicularis* in the loch, Chapman *et al.* (2007) has examined settlement in 2000 - 01, and Hughes *et al.* (2008) growth in 2004 - 05. A study of serpulid tube bioerosion in the loch (Hughes, 2011) also included data on serpulid recruitment. The community associated with the South Shian *Limaria* bed has been studied by Trigg in 2006 - 07 (Trigg, 2009; Trigg *et al*., 2011), while equivalent studies on the serpulid reefs of the loch include Chapman *et al*. (2012) in 2001 and Poloczanska *et al.* (2004) in 2003. In 2012 - 14 Cook (2016) investigated the potential for restoration of serpulid reefs in the loch through deployment of a range of colonisation substrates.

2. METHODS

2.1 Serpulid reefs

2.1.1 Morphometric analysis of serpulid reefs

The analysis was undertaken to facilitate comparison of results from studies of the serpulid reefs of Loch Creran where different measures of serpulid reef size have been employed. For example height is used in the current study, width by Connor (1990) and area by Moore (1986), Moore *et al*. (2006) and in the current study.

Thirty-three reefs of *Serpula vermicularis* spanning a broad size range were measured *in situ* in 2001 off Rubha Mor. Using a metre rule divers measured the maximum height, maximum width (major axis) and maximum width perpendicular to the major axis (minor axis) of well-formed, intact reefs. Ten of these reefs subsequently provided the source material for an investigation into the associated fauna of reefs (see Chapman *et al*., 2012). From the width measurements plan area was derived using an ellipsoidal model. The relationships between area, maximum height and maximum width were modelled using regression analysis employing polynomial and power functions.

2.1.2 MNCR phase 2 survey video analysis

No MNCR phase 2 surveys of the serpulid reef habitat were conducted as part of the current project, although some analysis of previous video footage collected during MNCR phase 2 surveys along 25 m transects at four sites in 2005 was performed, as well as analysis of video footage collected along the same four transects in 2014 during the study by Tulbure (2015). The locations of the four sites are shown in Figure 2 and details provided in Table 1.1 (Annex 1). Video sample collection involved a diver with hand-held video camera slowly zigzagging along a transect band approximately 4 m either side of the transect line to obtain representative footage of the habitat and characterisation of the biota. Further details on equipment and methodology are available in Moore *et al.* (2006) and Tulbure (2015).

The video samples were used to identify gross change in the physical integrity of the reefs and to illustrate the change in habitat by means of representative frame grabs. Where possible the condition in both years was quantified in terms of the parameters used in the main transect condition survey (section 2.1.3, Figure 3).

2.1.3 Transect condition survey

The condition of the serpulid reef habitat in the lower basin of Loch Creran was assessed by diver along 40 transects over the period 13/06/2017 to 28/01/2019 (Figure 2). The work was not carried out within the same year as it also formed a component of a temporal study into the potential spread of *Didemnum vexillum* in the loch. Two transect configurations were employed. At 15 sites measures of reef condition were obtained along two parallel 20 m long transects 10 m apart (termed 'paired transects'). The locations of these sites were chosen to provide good coverage of historically rich serpulid habitat and in some cases to groundtruth 2015 sidescan imagery (Geosurv, 2015). The diver swam along a bearing for 20 m using a metre rule to aid distance determination, recording condition metrics within a band approximately 4 m wide. At the end of the transect the diver turned right and swam along a bearing at 90° to the initial bearing for a distance of 10 m. This was followed by the start of the second 20 m long transect which followed a reciprocal bearing to that of the first transect. To simplify navigation all transects ran either north then south, or west then east, depending upon which option better followed the depth contours in the area.

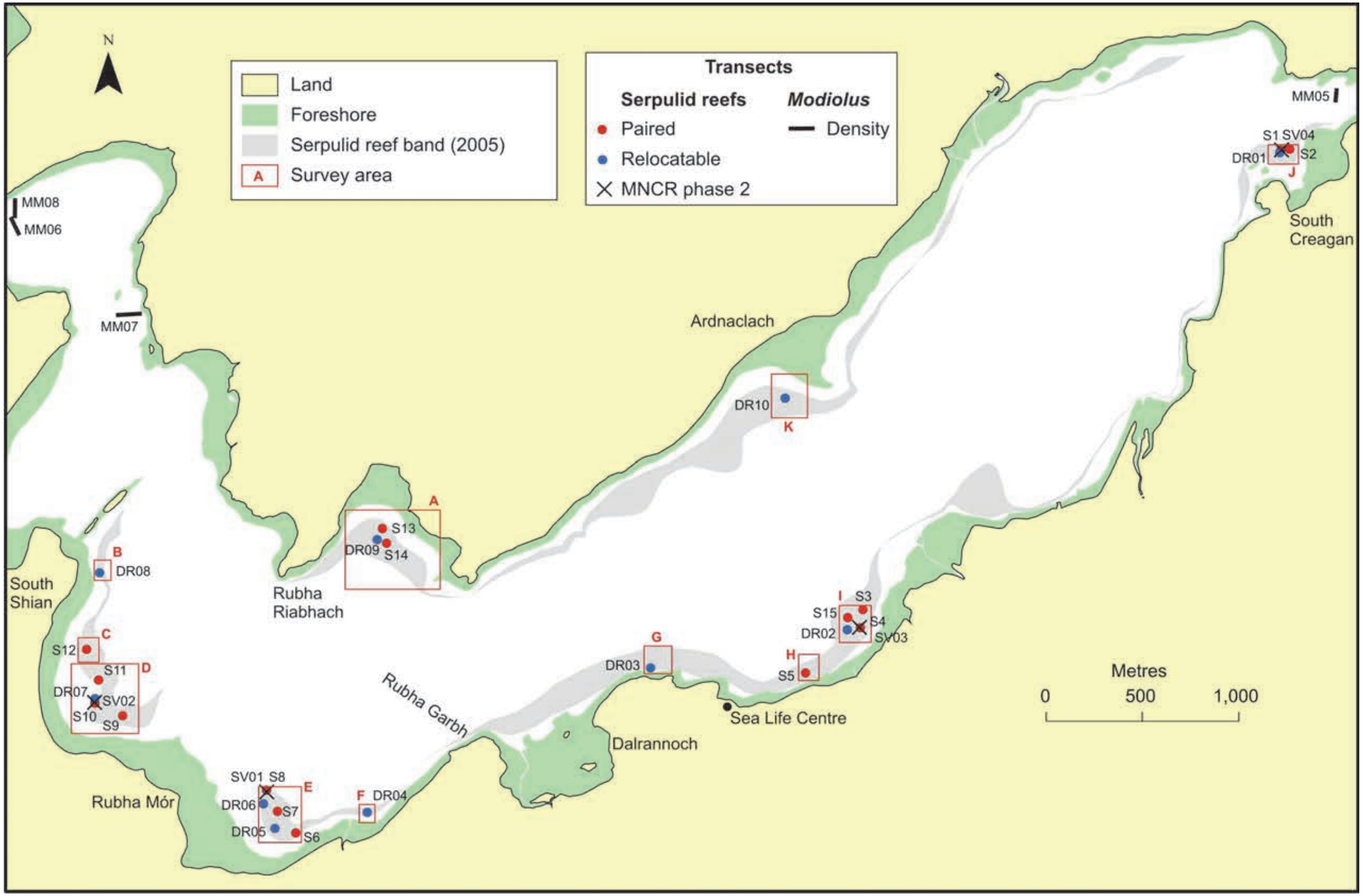

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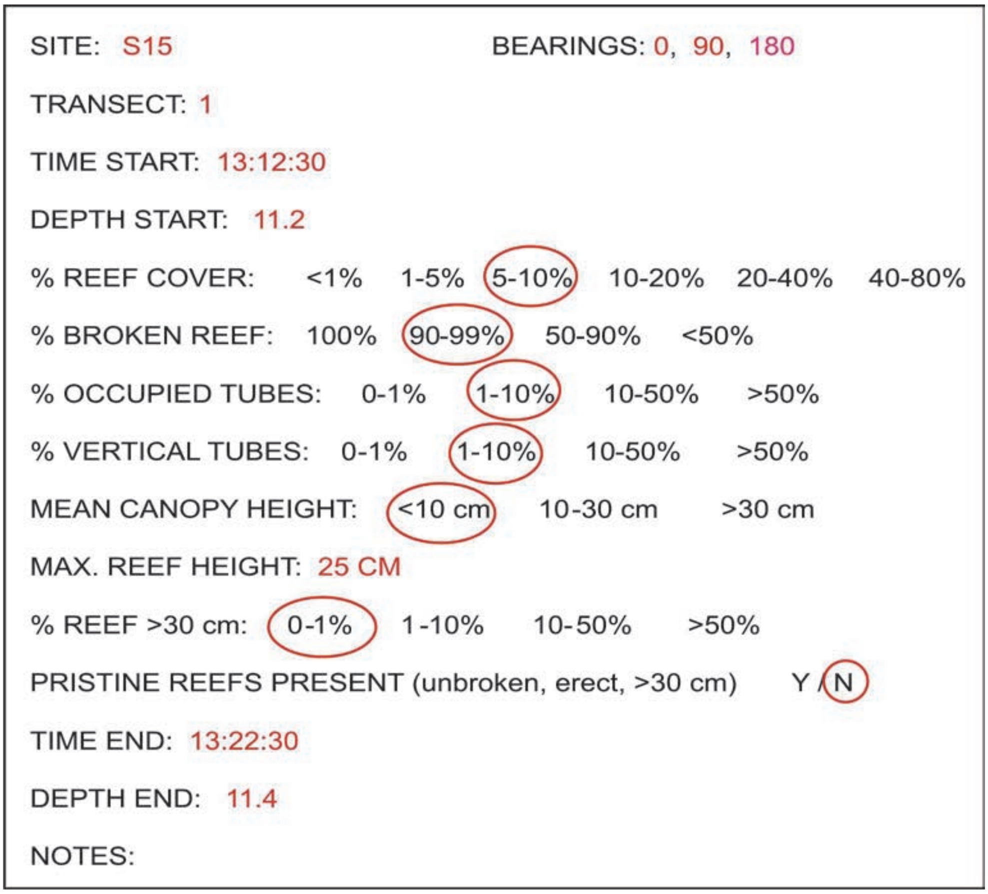
Figure 2. Location of serpulid reef condition transects and Modiolus transects in the lower basin of Loch Creran, with distribution of serpulid reef band in 2005 (Moore et al., 2006). Red boxes (A - K) delineate areas illustrated and analysed in detail in section 3.1.2.2.

The total area surveyed at each site was approximately 160 m^2. If it was found that the start of the first transect was located in a patch atypical of the locality (e.g. potentially impacted by moorings) slight adjustment to the start position was made. The diver towed a surface buoy furnished with a dGPS data logger storing dGPS signals at 3 s intervals. To avoid inaccuracy due to layback, the diver pulled the buoy into an overhead position and recorded the time at the start and end of each transect, as well as the depth. Other parameters recorded along each transect are included on the *proforma* used (Figure 3). Note that pristine reefs are defined in this study as unbroken, erect reefs of at least 30 cm in height.


SITE: S15 BEARINGS: 0, 90, 180

TRANSECT: 1

TIME START: 13:12:30

DEPTH START: 11.2

% REEF COVER: <1% 1-5% 5-10% 10-20% 20-40% 40-80%

% BROKEN REEF: 100% 90-99% 50-90% <50%

% OCCUPIED TUBES: 0-1% 1-10% 10-50% >50%

% VERTICAL TUBES: 0-1% 1-10% 10-50% >50%

MEAN CANOPY HEIGHT: <10 cm 10-30 cm >30 cm

MAX. REEF HEIGHT: 25 CM

% REEF >30 cm: 0-1% 1-10% 10-50% >50%

PRISTINE REEFS PRESENT (unbroken, erect, >30 cm) Y / N

TIME END: 13:22:30

DEPTH END: 11.4

NOTES:

Figure 3. Example of completed serpulid reef condition transect reef proforma.

To avoid inter-worker variability, all reef condition surveys were undertaken by the same experienced surveyor (D. Harries), who was accompanied by a videographer recording the condition of the habitat within the same area.

The location of survey sites is illustrated in Figure 2 and details provided in Table 1.2 (Annex 1).

The same reef condition data and video footage were also obtained along ten relocatable 25 m long transects established for the *Didemnum vexillum* monitoring study in the lower basin of the loch (termed ‘relocatable transects’).

At each site a 25 m negatively-buoyant line marked with 1 m gradations (and labels showing distance every 5 m) was pegged out along the seabed. Sites were chosen to provide good geographical spread and high serpulid reef cover, although there was some geographical bias towards the south-west region of the loch where *D. vexillum* had been reported intertidally (Turrell *et al*., 2018). Most of the transects were straight, with the bearing of the transect being recorded. At some sites minor doglegs were introduced to maximise passage through reef material. In these cases addition pins were used to peg the line at deviation points and the bearing along each leg of the transect and tape positions were recorded. The depth at the transect start and end were recorded by diver, and the positions fixed by the surface vessel. The location of all monitoring sites is shown in Figure 2 and further details provided in Table 1.2 (Annex 1). Note that site codes for the paired transects sites are prefixed 'S', whereas the relocatable transects have the prefix 'DR'.

Reef condition assessment required a modified approach in the upper basin of Loch Creran, where reef density has historically been low and largely confined to an intermittent, narrow, peripheral band (Moore *et al*., 2006). Six sites were surveyed, representing all the locations where either medium (50 - 500 cm^2 plan area) or large (>500 cm^2 plan area) reefs were recorded in 2005 (Moore *et al*., 2006) (Figure 4). To maximise survey coverage of the reef habitat, at each site a diver zigzagged between the start and nominal end points (the latter aided by surface communication) employing a compass bearing indicating the overall direction of travel. The diver covered a specified depth range, which was slightly wider than the range over which reefs had been previously recorded in the location. Location fixes were provided by a towed dGPS logger which was pulled vertical and the time taken at the start and end of each swim. In addition, the following parameters were recorded on a *proforma* using the same categories as for the lower basin transect sites (Figure 3):

- % reef cover (maximum in area of approximately 5 x 5 m)
- % broken reef material
- % occupied tubes
- % vertical tubes
- mean reef canopy height (cm)
- maximum reef height (cm)
- presence of pristine reefs
- % reefs >30 cm in height
- presence of individual *Serpula vermicularis*
- presence of small reefs (<50 cm^2 plan area)
- presence of medium reefs (50 - 500 cm^2 plan area)
- presence of large reefs (>500 cm^2 plan area)

The diver surveyed an area within the range of visibility (c.3 m) either side of the direction of movement. The dive slate carried a template to aid assessment of the plan area of reefs and the diver carried a head-mounted HD GoPro video camera to record the survey. The location of all upper basin sites is shown in Figure 4 and further details provided in Table 1.4 (Annex 1).

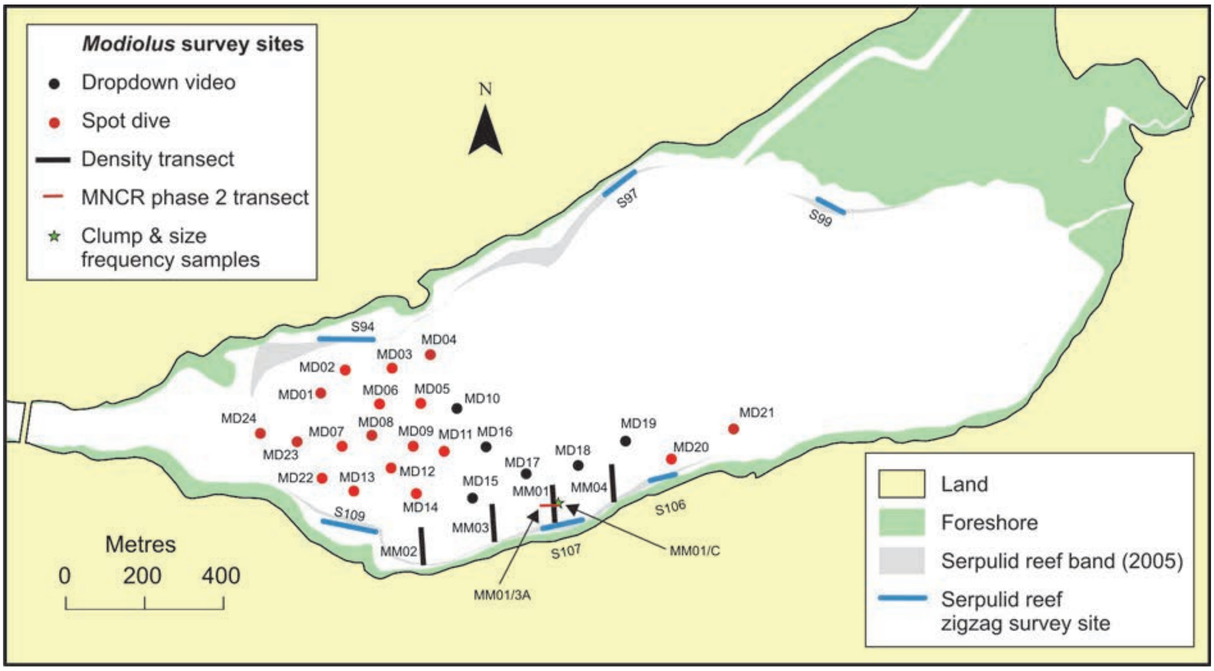


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Figure 4. Location of serpulid reef condition and <u>Modiolus</u> survey sites in the upper basin of Loch Creran, with distribution of serpulid reef band in 2005 (Moore <u>et al</u>., 2006). Lines include start and end positions of zigzag survey.

2.1.4 Single beam sonar survey

The effectiveness of single beam sonar in recording the height of reef material above the seabed was investigated during the period of the current survey (April 2017), although it was not integral to it and did not lie within the remit of the research contract. However, some of the preliminary results proved useful and so have been incorporated into this report. The study, including methodology, is described in Annex 5.

2.1.5 Serpulid reef colonisation study

The effectiveness of different substrates as materials for the restoration of serpulid reefs in Loch Creran was tested by Cook (2016) through the deployment of a range of experimental units on 27 March 2012 and subsequent monitoring of serpulid colonisation. Cook (2016) compared colonisation density on units of five types, each of which was replicated six times at his main study site in Sea Life Centre Bay:

- scallop shells in a loose pile
- scallop shells packed into a small, cylindrical net bag (1.5 cm mesh) with a height of c.12 cm and length of c.25 cm
- scallop shells in a large net bag (1.5 cm mesh) with a height of c.20 cm and length of c.30 cm
- cobbles (6.4 - 25.6 cm in diameter) in large net bag (1.5 cm mesh) of same dimensions as large scallop shell unit
- single boulder c.50 - 80 cm diameter

Cook (2016) also examined geographical variation in colonisation by deploying six replicates of the scallop shells in the large net bag treatment at five sites throughout the loch (Figure 5) on 27-28 March 2012 and monitoring subsequent colonisation. Two of these sites were in areas of historically dense serpulid reefs (Main site, Rubha Mór) and three were located in regions of the loch where reefs have been recorded as sparse or absent (Mussel Farm, Kelco, Upper basin).

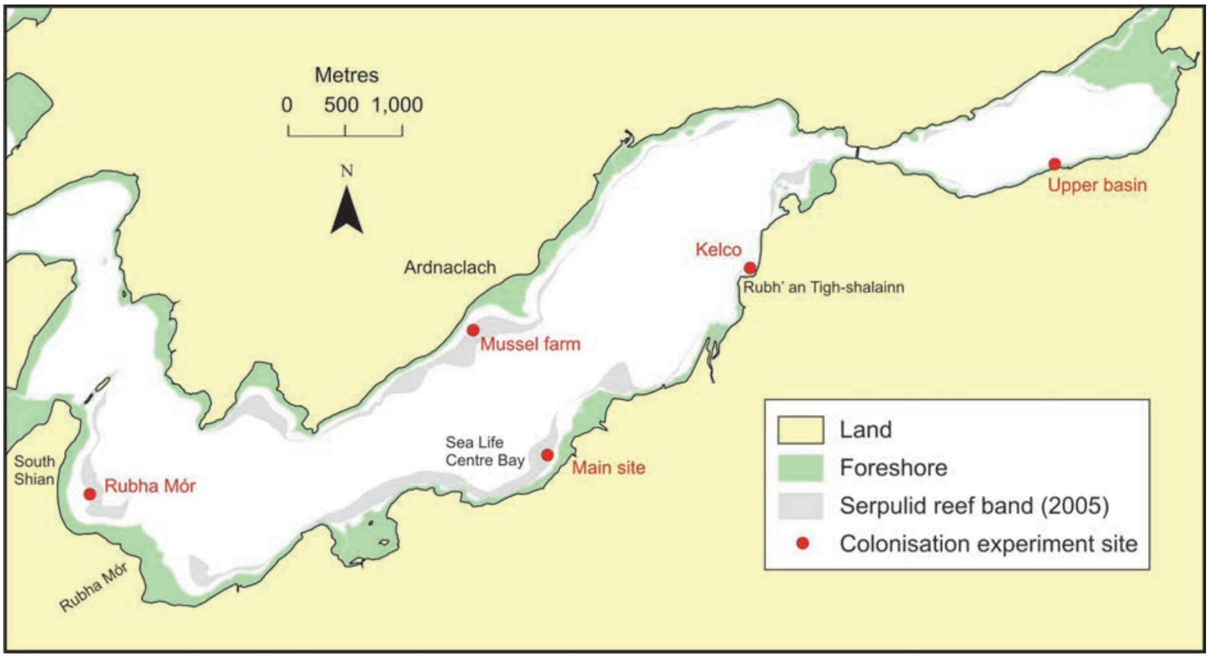

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Figure 5. Location of experimental serpulid reef colonisation sites.

Within the 2 year timescale of Cook's study it was only possible to monitor early colonisation of the substrates by serpulid juveniles, but the current programme afforded the opportunity to examine reef development 5 years post deployment.

On 13-15 June 2017 the degree of reef development was measured *in situ* by diver for replicates of all substrate types at all five locations (Table 2, Figure 5).

Table 2. Location of serpulid reef colonisation experiment sites.

Site	Location	Latitude	Longitude	Date
Main site	Sea Life Centre Bay	56.522850	-5.333150	13/06/2017
Upper basin	South coast, upper basin	56.547017	-5.262450	14/06/2017
Kelco	Rubh' an Tigh-shalainn	56.538067	-5.305250	15/06/2017
Mussel farm	Ardnaclach	56.532483	-5.344233	13/06/2017
Rubha Mór	North of Rubha Mór	56.518550	-5.397933	13/06/2017

For each replicate the maximum height of a *Serpula vermicularis* tube clump was measured using callipers and the approximate number of tubes in each clump and number of clumps counted. An assessment was made of the percentage cover of the substrate in plan view. Each unit was photographed using a wide-angle lens.

2.2 Flame shell beds

2.2.1 Distribution survey

The distribution of the flame shell bed habitat was examined along 23 diver transects in the vicinity of South Shian and Creagan Narrows during the period 2017 - 2019. Divers descended at selected coordinates and drifted or swam along a prescribed bearing for a prescribed distance, aided by mounting the compass on a 1 metre rule. Distances covered were mostly between 100 - 400 m. Spot records were taken at stations at approximately equal distance intervals along the transect (with a maximum of 11). Divers wore a head-mounted GoPro HD video camera.

Parameters recorded at each station using a *proforma* on a diving slate included the following:

- Depth (m)
- Bearing of the towed surface marker buoy (SMB)
- Time (hh:mm:ss)
- *Limaria* nest cover (%)
- *Limaria* nest thickness (cm)
- Live *Limaria* seen (yes/no)
- *Limaria* population density <1/0.1m^2 (yes/no)
- *Modiolus* density (SACFOR scale)
- Ophiuroid density (SACFOR scale)
- Algal turf coverage (%)
- *Laminaria hyperborea* density (SACFOR scale)
- *Saccharina latissima* density (SACFOR scale)
- Substrate description
- Notes on biota and any other comments

The logarithmic SACFOR density system is described in full by Hiscock (1996) but is defined for the above taxa recorded in this way in Table 3.

Table 3. SACFOR abundance scale for Modiolus modiolus and other relevant taxa

Category	**Code**	***Modiolus*, ophiuroids**	**Kelp**	
		Density	Density	% cover
Superabundant	S	>100 /m^2	10-99 /m^2	>80
Abundant	A	10-99 /m^2	1-9 /m^2	40-79
Common	C	1-9 /m^2	1-9 /10 m^2	20-39
Frequent	F	1-9 /10 m^2	1-9 /100 m^2	10-19
Occasional	O	1-9 /100 m^2	1-9 /1000 m^2	5-9
Rare	R	1-9 /1000 m^2	1-9 /10000 m^2	<5
Not seen	N			
Present	P			

The diver location was recorded by means of a surface dGPS logger unit attached to the SMB. Layback was calculated from the depth, as well as the SMB line length and bearing. Station details are provided in Table 3.1 (Annex 3) and their location illustrated in Figures 6 - 8.

The methodology was not designed to identify all biotopes present along the transects, although the data were subsequently employed to assign flame shell, horse mussel and ophiuroid biotopes.

The drift dive survey was supplemented by grab sampling at three sites around 500 m south of the southern boundary of the 2012 flame shell distribution polygon on 8th September 2017 (Figure 6). A single 0.1 m^2 van Veen grab sample was taken at each site and the number of *Limaria hians* retained on a 1 mm sieve counted. Sampling details are provided in Table 3.3 (Annex 3).

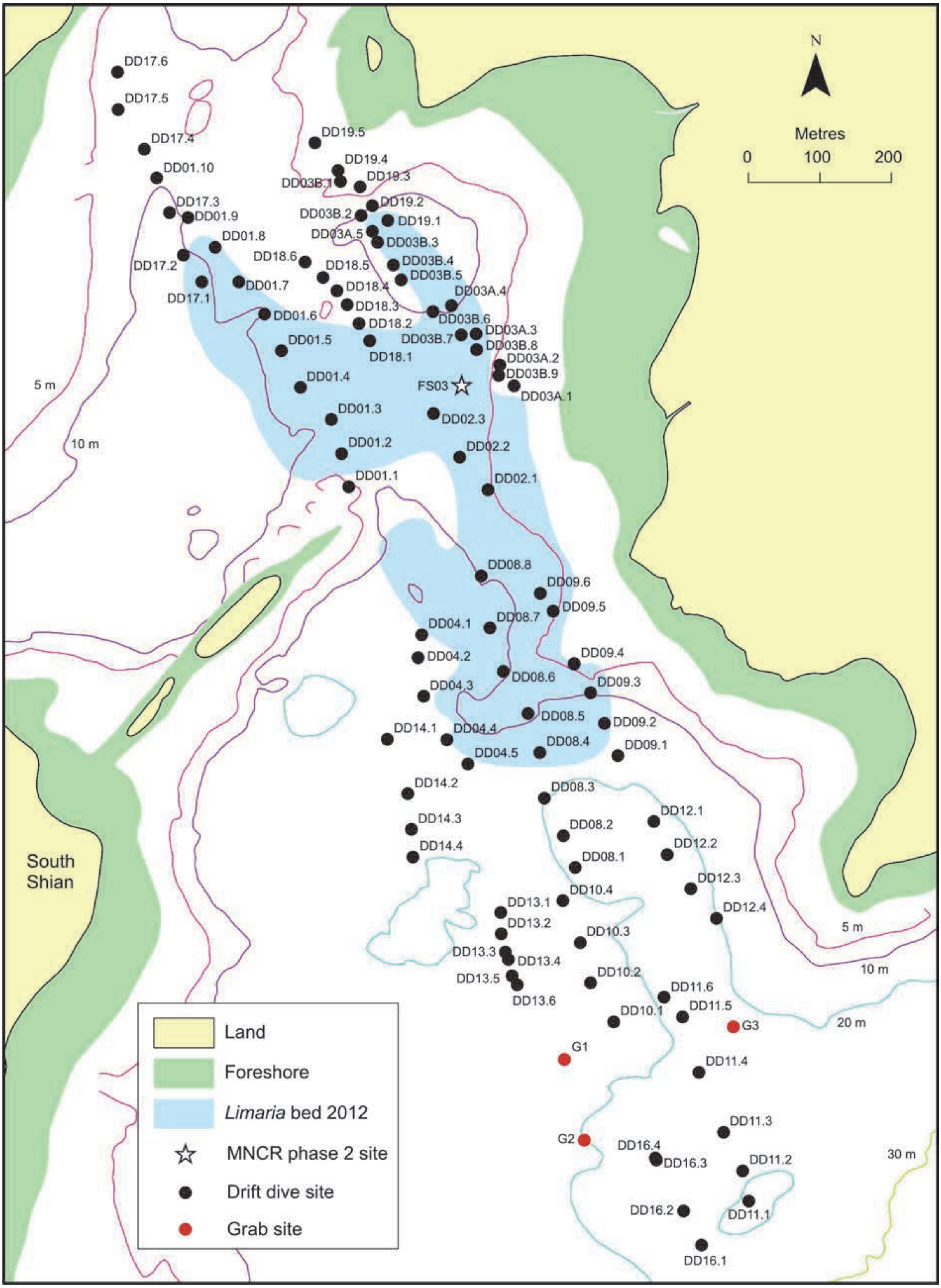

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Figure 6. Distribution of 2017/18 Limaria hians survey sites off South Shian. 2012 bed extent (Moore et al., 2013) also shown.

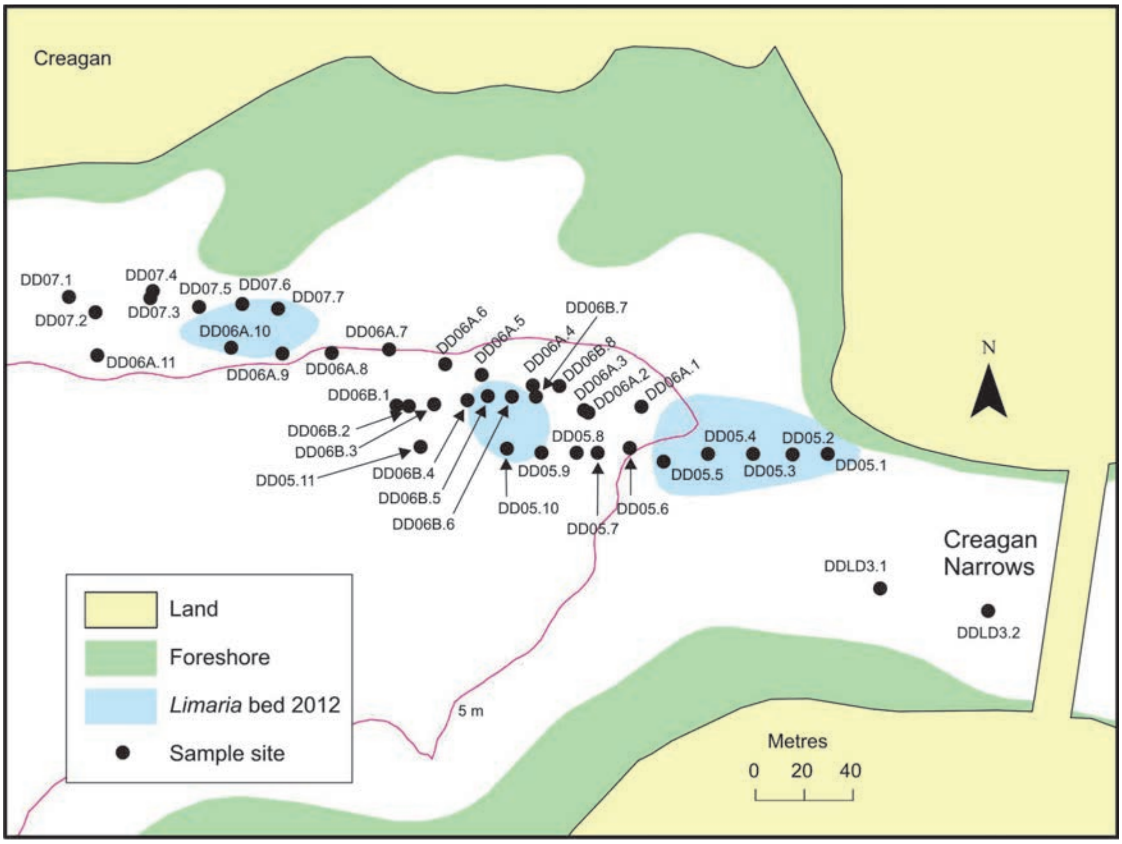

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Figure 7. Distribution of 2017/18 <u>Limaria hians</u> survey sites off Creagan. 2012 bed extent (Moore <u>et al</u>., 2013) also shown.

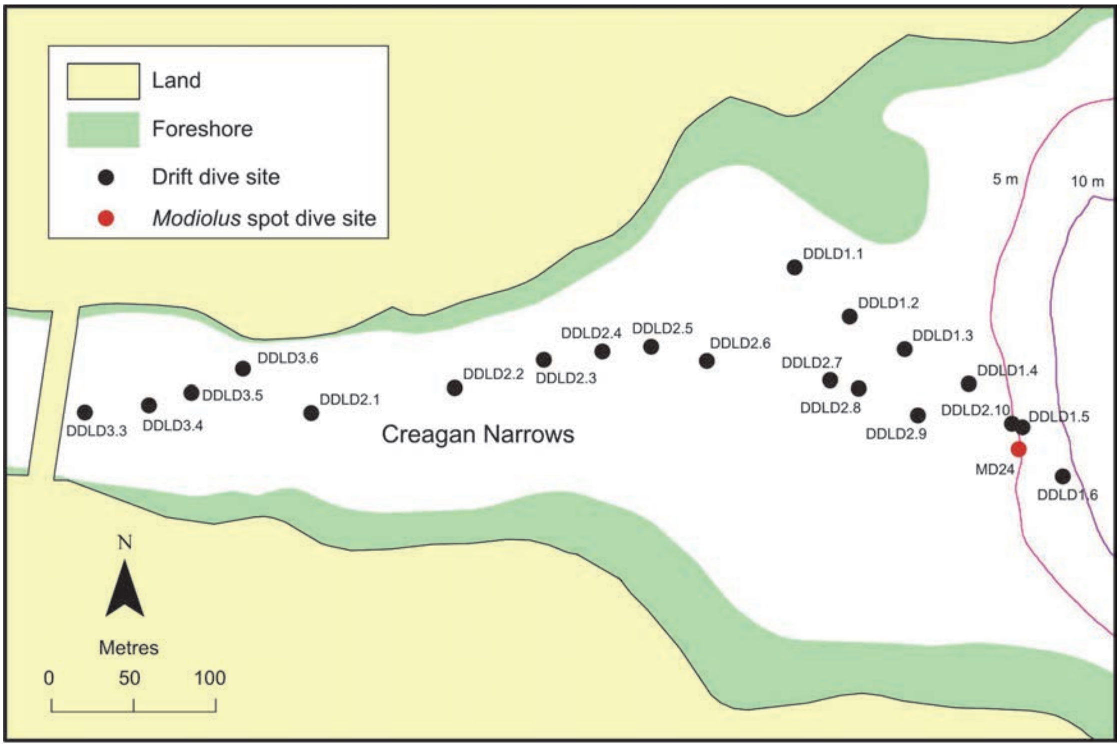

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Figure 8. Distribution of 2018/19 <u>Limaria hians</u> survey sites in the upper basin of Loch Creran.

2.2.2 MNCR phase 2 survey (site FS03)

The nature and condition of a characteristic, central region of the principal flame shell bed off South Shian was assessed by means of an MNCR phase 2 survey (Hiscock, 1996) along a 25 m transect ground tape within a band 4 m wide (site FS03, Figure 6, Table 4). Transect ends were permanently marked with steel pins driven into the seabed, the position and depth at both ends of the tape recorded and the bearing of the transect noted. Two surveyors recorded the presence and SACFOR abundance of epibiota, with collection of material for laboratory analysis where necessary. The transect band was videoed using a hand-held HD video camera. This involved the diver swimming along both sides of the transect ground tape recording characteristic footage of the habitat and referencing the tape periodically. The aim was to retain a visual record of the nature of the habitat and community and to provide material that could be used for supplementing the species inventory for the site and to aid in subsequent description of the habitat. Still photographs of the habitat and associated community were also taken for the same purpose using two digital SLR cameras with wide-angle and macro lenses.

Table 4. Details of MNCR phase 2 survey site FS03.

Date	Latitude start	Longitude start	Latitude end	Longitude end	Transect bearing (°T)	Depth at start (m)	Depth at end (m)
07/08/2017	56.530180	-5.391830	56.529995	-5.391611	147	7.8	7.5

Four replicate core samples (10.3 cm diameter to a depth of 20 cm) were collected for analysis of infaunal and epibiotic species composition, abundance and diversity. The core material was sieved using a 0.5 mm screen, with sievings retained in buffered 5% formalin.

The infauna retained by the sieve was analysed for species composition and abundance by Sue Hamilton (Edinburgh), with epibiota analysed by Colin Moore. From these data diversity measures were calculated using Primer software (Primer-E, Auckland, New Zealand).

2.3 Horse mussel beds

2.3.1 Distribution surveys

Recording the abundance of *Modiolus modiolus* formed a component of four surveys carried out between 2017 and 2018. SACFOR abundance (see Table 3) was assessed at all stations examined during the flame shell distribution survey off South Shian and in the vicinity of Creagan Narrows (section 2.2.1).

The abundance of *Modiolus* has been assessed at stations along four depth transects in the upper basin in 1999 (Mair *et al*., 2000) and 2005 (Moore *et al*., 2006). The fairly low mean *Modiolus* densities recorded on the four transects limits the potential for detecting temporal abundance changes, so in the current survey detailed quantitative monitoring in the upper basin of the loch was restricted to transect MM01, which supported the highest mean density in 2005 (Figure 4).

The inshore transect position was identified from relocation data provided in Moore *et al.* (2006) and a 120 m ground line, anchored and buoyed at the inshore end and marked in 20 m increments, ran out by boat along the previously recorded bearing of 0°T, with the offshore end also buoyed. Permanent relocation markers were established at approximately 20 m intervals, the precise distance along the ground line being adjusted to optimise agreement with the recorded positions and depths of the 2005 survey. The permanent marker consisted of blue 2 cm diameter polyethylene tubing which was hammered into the seabed. The depth and distance along the ground line of each station was recorded, as well as the position by means of a diver-towed dGPS data logger, with the time recorded once pulled overhead. At each station five randomly positioned 0.25 m^2 cross-strung quadrat placements were made on each side of the line and within each quadrat the number of cross-string intersections overlying living *Modiolus* recorded (as in all previous years), as well as the total number of *Modiolus*. Quadrats were strung at 10 cm intervals resulting in a total of 16 intersections.

The same methodology for detailed quantitative monitoring was also employed along transect MM05 off Creagan in the lower basin of the loch (Figure 2). This transect supported the highest densities of *Modiolus* in 2005 (Moore *et al*., 2006).

A rapid appraisal of *Modiolus* density was carried out along the other three previously surveyed upper basin transects and two lower basin transects (Figures 2, 4). The position of the offshore transect end was marked with a shot line and the surveyor swam inshore along the transect bearing, recording data at approximately 20 m intervals, aided by use of a metre rule. At each station *Modiolus* SACFOR abundance, substrate type, depth and time was recorded, with the position obtained from a towed dGPS logger, pulled overhead. The diver carried a helmet-mounted GoPro HD video camera. Following the failure to record *Modiolus* along transect MM06, an additional transect, MM08, was worked in the same vicinity (Figure 2).

Positional, temporal and other details of all transects worked are provided in Table 2.1 (Annex 2).

The geographical distribution of the upper basin bed and the abundance of *Modiolus* within it were surveyed by means of short (spot) dives at 16 sites and dropdown video at six deeper sites (Figure 4). The choice of site locations was aided by earlier biotope mapping of the loch (Black *et al*., 2000)

The dive survey was carried out in August 2018. At each site a shot line was dropped at the chosen position and a diver assessed *Modiolus* SACFOR density along a short 3 - 5 minute swim eastwards. Substrate type was also noted as well as depth and time at the start and end of the swim, with position recorded by means of an overhead dGPS data logger. The diver carried a head-mounted GoPro HD video camera. Site details are provided in Table 2.4 (Annex 2).

The dropdown video survey was undertaken in September 2018. The video system used consisted of an SD Panasonic NV-GS150 3 chip digital video camera within a Seapro housing held within a frame and illuminated by twin 100 watt lamps. A 100 m umbilical cable carried the video signal to a Sony Video Walkman for real-time observation and for recording. The frame also carried an HD GoPro video camera. At each station the camera system was deployed briefly (c. 5 minutes) from a drifting vessel, noting the times, depths and precise positions at the start and end of the drift. *Modiolus* SACFOR abundance, substrate type and biotope were recorded from analysis of the video footage. Site details are given in Table 2.6 (Annex 2).

2.3.2 MNCR phase 2 survey (site MM01/3A)

The nature and condition of an area characteristic of the *Modiolus* bed fringing the southern coastline of the upper basin of Loch Creran was assessed by means of an MNCR phase 2 survey (Hiscock, 1996). The same area had been previously surveyed in 1999 (Mair *et al*., 2000) and 2005 (Moore *et al*., 2006) as site MM01/3. As in previous years the survey was carried out close to site MM01/3 within a 50 m long transect band running east/west with the band width defined by the 12 and 15 m depth contours. The central point of the transect was marked with a shot line and 25 m ground tapes run out to the east and west. The position of the shot line was fixed from the surface vessel and the positions of the transect ends determined within ArcGIS 10.2. The transect position is shown in Figure 4, with details provided in Table 5.

*Table 5. Details of MNCR phase 2 survey site MM01/3A and Modiolus clump and size frequency site MM01/C. N/A = not applicable, * = maximum depth.*

	MM01/3A			**MM01/C**	
	West end	**Mid point**	**East end**	**Clumps**	**Size frequency**
Latitude	56.545896	56.545894	56.545895	56.54593	56.54593
Longitude	-5.269343	-5.268934	-5.268528	-5.268610	-5.268610
Depth below CD (m)	13.2	14.2	14.4	14.0*	15.5*
Transect bearing (°T)		87		N/A	N/A
Date		09/08/2017		09/08/2017	19/08/2018

Two surveyors recorded the presence and SACFOR abundance of epibiota, with collection of material for laboratory analysis where necessary. The transect band was videoed using a hand-held HD video camera. This involved the diver swimming along both sides of the transect ground tape recording characteristic footage of the habitat and referencing the tape periodically. The aim was to retain a visual record of the nature of the habitat and community and to provide material that could be used for supplementing the species inventory for the site and to aid in subsequent description of the habitat. Still photographs of the habitat and associated community were also taken for the same purpose using two digital SLR cameras with wide-angle and macro lenses.

To supplement the *in situ* recording of the community, clumps of live *Modiolus* shells were collected by diver for laboratory identification and enumeration of the associated biota. Four replicate clumps were taken from site MM01/C, close to the MNCR survey site (Figure 4, Table 5). For standardisation of clump size, as in previous surveys the aim was to select clumps that could just fit within a 5 litre sample bucket, although the size was constrained by the limited availability of large clumps.

The clump material was sieved using a 0.5 mm screen, with sievings retained in buffered 5% formalin. The infauna retained by the sieve was analysed for species composition and abundance by Sue Hamilton (Edinburgh), with epibiota analysed by Colin Moore. From these data diversity measures were calculated using Primer software (Primer-E, Auckland, New Zealand).

At the same site six 0.25 m^2 quadrats were cleared by diver of all live *Modiolus* visible and shell material, which was returned to the surface for size frequency analysis. The length, height and breadth of all identifiable live shells was measured using Vernier callipers and these shells returned alive to the seabed. The shell material was examined in the laboratory for *Modiolus* juveniles, whose dimensions were measured.

In this report all positions are given using the WGS84 reference system and were obtained using differential GPS. All depths are given in relation to chart datum.

3. RESULTS

3.1 Serpulid reefs

3.1.1 Serpulid reef morphometrics

The dimensions of 33 serpulid reefs recorded in 2001 in terms of maximum height, maximum width (major axis) and maximum width perpendicular to the major axis (minor axis) are provided in Table 1.6 (Annex 1). There is a strong relationship between height and plan area, the latter based on an ellipsoidal model (Figure 9) and also between area and maximum width (Figure 9). Using these relationships it is possible to derive maximum height and maximum width categories equivalent to the three reef sizes employed in the 1994 (Moore, 1996) and 2005 (Moore *et al.*, 2006) surveys, that were based on plan area (Table 6). These will be used later in this report.

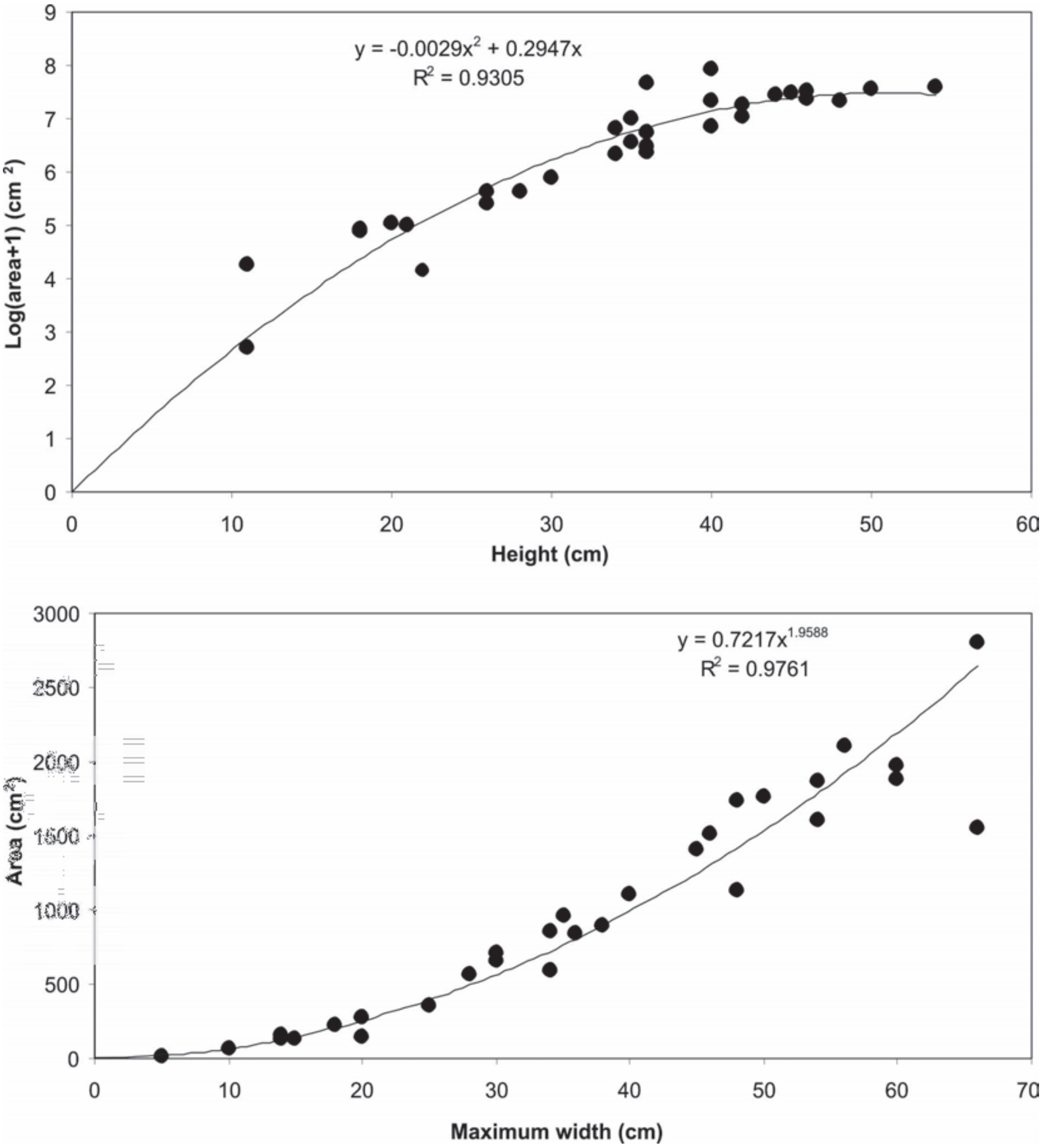

Figure 9. Relationship between plan area and maximum height (upper graph) and plan area and maximum width (lower graph) for 33 serpulid reefs from Loch Creran. Fitted curves and coefficients of determination (R^2) also shown.

Table 6. Equivalence of serpulid reef size categories based on area, height and width.

	Small reef	Medium reef	Large reef
Plan area (cm^2)	<50	50 - 500	<500
Maximum height (cm)	<16	16 - 30	>30
Maximum width (cm)	<9	9 - 28	>28

3.1.2 Serpulid reef condition

The results from analysis of data collected along reef condition survey sites are described here. This includes MNCR phase 2 transect sites, paired and relocatable transects in the lower basin and zigzag survey sites in the upper basin.

For most of the transects their location is shown in relation to georectified, mosaicked side scan sonar imagery derived from surveys in 2004 or 2005 by St. Andrews and Heriot-Watt Universities (Moore *et al*., 2006) and in 2015 by Geosurv Ltd. (2015). It should be noted that significant discrepancies were identified in the location of identifiable seabed target features between sonargrams from the different surveys, probably resulting chiefly from errors in towfish layback and distortion from the mosaicking process. For example, the positions of the two mooring blocks shown in the 2004 image (Figure 18) and in the equivalent 2015 image (Figure 17) differ by 6 m and 20 m. Whilst the latter figure is fairly exceptional, this issue should be borne in mind when interpreting the imagery. It should also be recognised that whilst typical, serpulid reef, sonar signatures can be clearly seen on much of the imagery, some of the texture visible on the sonargrams are artefacts, probably chiefly resulting from erratic tow fish movement and mosaicking. This includes the linear smudging visible, for example, in Figure 17.

On several of the figures in this section the transects from the current survey are also shown in relation to nearby serpulid reef transects examined in 1994 (Moore *et al*., 1998) and in 2005 (Moore *et al*., 2006). The 1994 positions are imprecise due to Selective Availability GPS degradation and so have been adjusted to better match the bathymetric contours. The start and end positions of the 2005 transects employed dGPS.

3.1.2.1 MNCR phase 2 transects

South Shian (Figure 10)

In 2005 the area displayed a rich serpulid reef habitat with a reef cover of around 20% in the form of reef and reef clusters (including probably ring reefs) separated by areas of muddy sand displaying little evident serpulid reef or tube rubble. A low proportion of the reef material (<50%) in the form of reefs or parts of reefs had fallen over but the tubes had generally reorientated growth vertically and maintained a high occupancy (>50% overall). The overall canopy height of the reefs appeared to exceed 30 cm and many reefs appeared markedly taller. Pristine reefs were common.

In 2014 there was clear visual evidence of reef degradation (90 - 99% broken reef material). Although patches of muddy sand were still discernible, the reef material was more dispersed, having collapsed to the extent that individual reefs were no longer identifiable. The fragmented reef material occupied around 50% of the seabed to an average height of less than 10 cm, although occasional reef segments still supported clusters of inhabited, vertically-orientated tubes (overall 1 - 10% occupied) with some clusters possibly attaining a height of around 20 - 30 cm. No pristine reefs were observed. Assessment of the temporal change in biota of such a cryptic habitat based on video material alone is difficult to confidently achieve, although there appeared to be a reduction in epibiotic diversity and a severe reduction in the abundance of *Ophiothrix fragilis* as well as *Serpula vermicularis*.

Figure 10. Representative screen grabs from video taken along MNCR phase 2 transect SV02 off South Shian in 2005 (left) and 2014 (right).

Rubha Mór (Figure 11)

The 2005 habitat at Rubha Mór was similar to that at South Shian, although with a higher density of reef material (c.40% cover). Most of this appeared to reach heights of at least 30 cm and included some considerably taller reefs. There was some broken reef material (<50%) largely in the form of large, collapsed reef segments that were still densely occupied by living worms with vertically-orientated tubes extending to heights of at least 30 cm in places. Overall tube occupancy was high (>50%). Pristine reefs were common. Between reefs the patches of muddy sand contained little rubble in the form of reef tube clumps, although appeared to contain a significant amount of small broken tube sections.

In 2014 there was no longer any evidence of intact reefs. The habitat consisted of patches of collapsed, broken reef material (around 50% cover), very largely unoccupied by worms, although small groups of inhabited tubes arose from the distal ends of some of the clumps (1 - 10 % tube occupation). Sparse small clusters of tubes possibly attained heights of around 30 cm, although the overall height of the reef material was probably less than 10 cm. No pristine reefs were observed. Much of the muddy sand between the concentrations of reef material contained high levels of comminuted tube fragments. As at South Shian, the gross reduction in the abundance of *Serpula vermicularis* appeared to be accompanied by much lower numbers of *Ophiothrix fragilis*, as well as by an impoverished hydroid population. By contrast high densities of ascidians, particularly *Ascidia mentula*, were present in 2014. This species was also present in 2005 but its density was difficult to gauge in such a cryptic habitat.

Sea Life Centre Bay (Figure 12)

In 2005 reef density here was noticeably lower than at South Shian or Rubha Mor. The survey site consisted largely of muddy sand with a fairly dense cover of pebbles (c.30%) with patches of serpulid reefs (5-10%). The site had evidently been subject to damage resulting from the presence of mooring tackle in the form of ground chains and rope used for temporary moorings for salmon cages. Although broken reef material probably accounted for <50% of the total, there were significant quantities of unoccupied reef rubble spread over the sediment patches. Many large reefs were present, including pristine examples. Some collapse of larger reefs was evident, although many of the component segments were tall (>30 cm) and of high tube occupancy. Overall reef height was probably >30 cm and occupancy >50%.

The density of reef material was similar in 2014 (5-10%), although its form was different, consisting almost entirely of collapsed material (50-90% broken) resulting in a reduced overall reef canopy height (10 - 30 cm). However the distal ends of many of the collapsed sections continued to be densely occupied by living worms (10 - 50% overall), several of which attained heights probably exceeding 30 cm. The sedimentary areas appeared to have changed in composition. Stone density seemed to have markedly decreased, possibly resulting from greater siltation. Some small patches with around 30% pebble cover remained and the sediment was augmented with comminuted shell/tube material and scattered reef rubble. The lack of lighting in the 2014 video footage makes objective commenting on any change in the epibiota difficult.

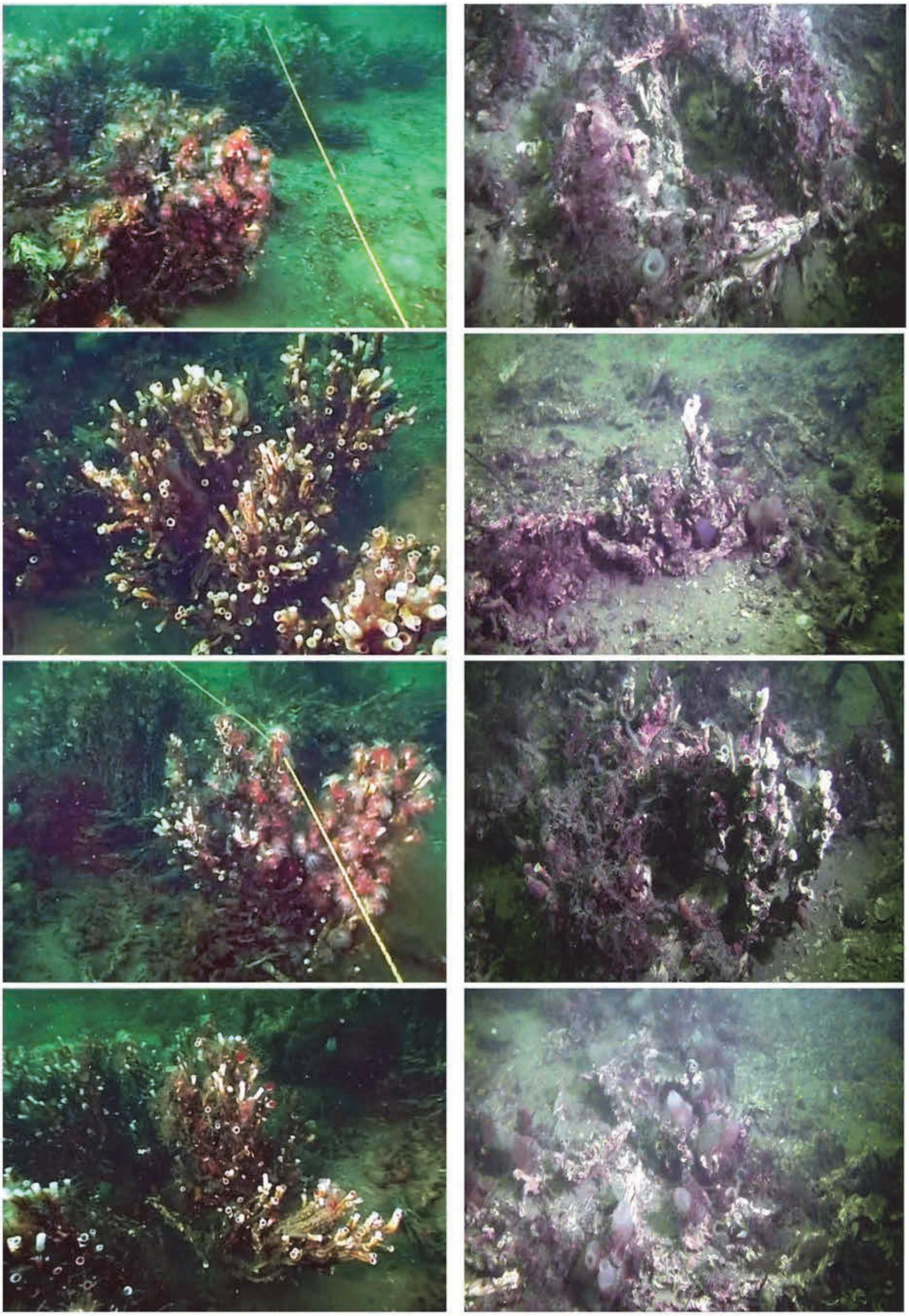

Figure 11. Representative screen grabs from video taken along MNCR phase 2 transect SV01 off Rubha Mór in 2005 (left) and 2014 (right).

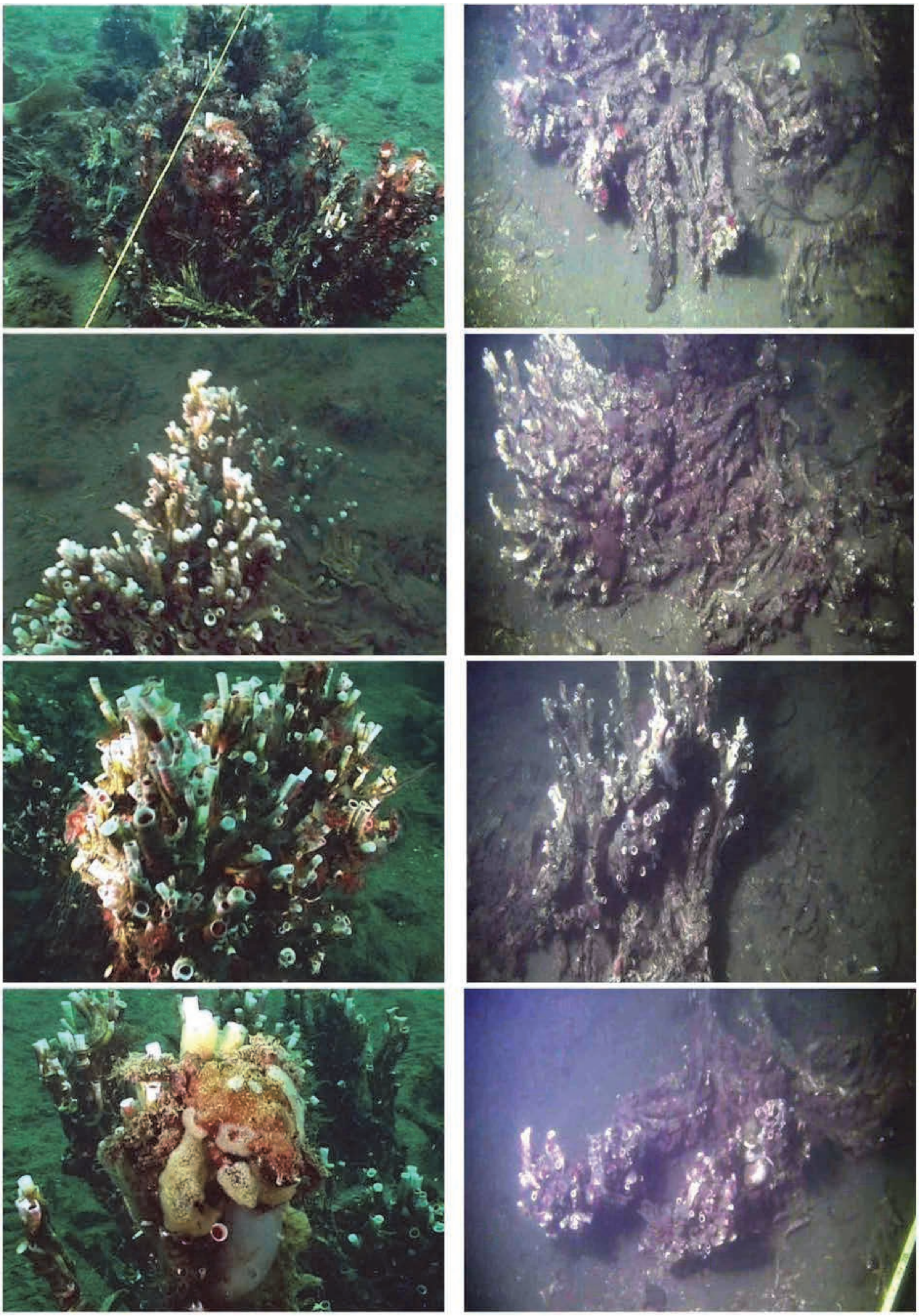

Figure 12. Representative screen grabs from video taken along MNCR phase 2 transect SV03 in Sea Life Centre Bay in 2005 (left) and 2014 (right).

South Creagan (Figure 13)

South Creagan supported the lowest reef cover amongst the 2005 sites (1 - 5%). Reefs were mostly arranged in clumps, widely separated by areas of muddy sand with comminuted serpulid tube/shell material and scattered gravel, shells and sparse boulders, with few fragments of dead reef rubble. The reefs were largely unbroken (>50%), included many pristine examples, and displayed an overall canopy height of >30 cm and high tube occupancy (>50%).

The serpulid reefs in 2014 had become extensively damaged. Areas of historic reefs were discernible but they had all collapsed (100% broken), with much of the material extensively fragmented and apparently supporting few live worms (<1% occupancy). Overall height of this reef material was <10 cm, although occasional tube clumps rose to around 25 cm. Between the collapsed reef patches, the muddy sand sediment was similar to that in 2005, although the there was a higher presence of dead reef rubble. The epibiotic diversity appeared to be reduced in 2014, although the absence of video lighting complicates the comparison.

Condition parameters for all four transects in both survey years are summarised in Table 7.

Table 7. Serpulid reef condition parameters recorded for MNCR phase 2 transect sites in 2005 and 2014. The condition score system was developed from analysis of the data from the paired and relocatable transect survey and is described in section 3.1.2.2 (1 = largely undamaged reefs, 8 = largely unoccupied rubble).

Transect	Year	Location	% reef cover	% broken reef	% occupied tubes	Canopy height (cm)	Pristine reefs	Condition score
SV01	2005	Rubha Mór	50	<50	>50	>30	YES	1
SV01	2014	Rubha Mór	50	100	1 - 10	<10	NO	7
SV02	2005	South Shian	20	<50	>50	>30	YES	1
SV02	2014	South Shian	50	90 - 99	1 - 10	<10	NO	7
SV03	2005	Sea Life Centre Bay	5 - 10	<50	>50	>30	YES	1
SV03	2014	Sea Life Centre Bay	5 - 10	50 - 90	10 - 50	10 - 30	NO	4
SV04	2005	South Creagan	1 - 5	<50	>50	>30	YES	1
SV04	2014	South Creagan	1 - 5	100	0 - 1	<10	NO	8

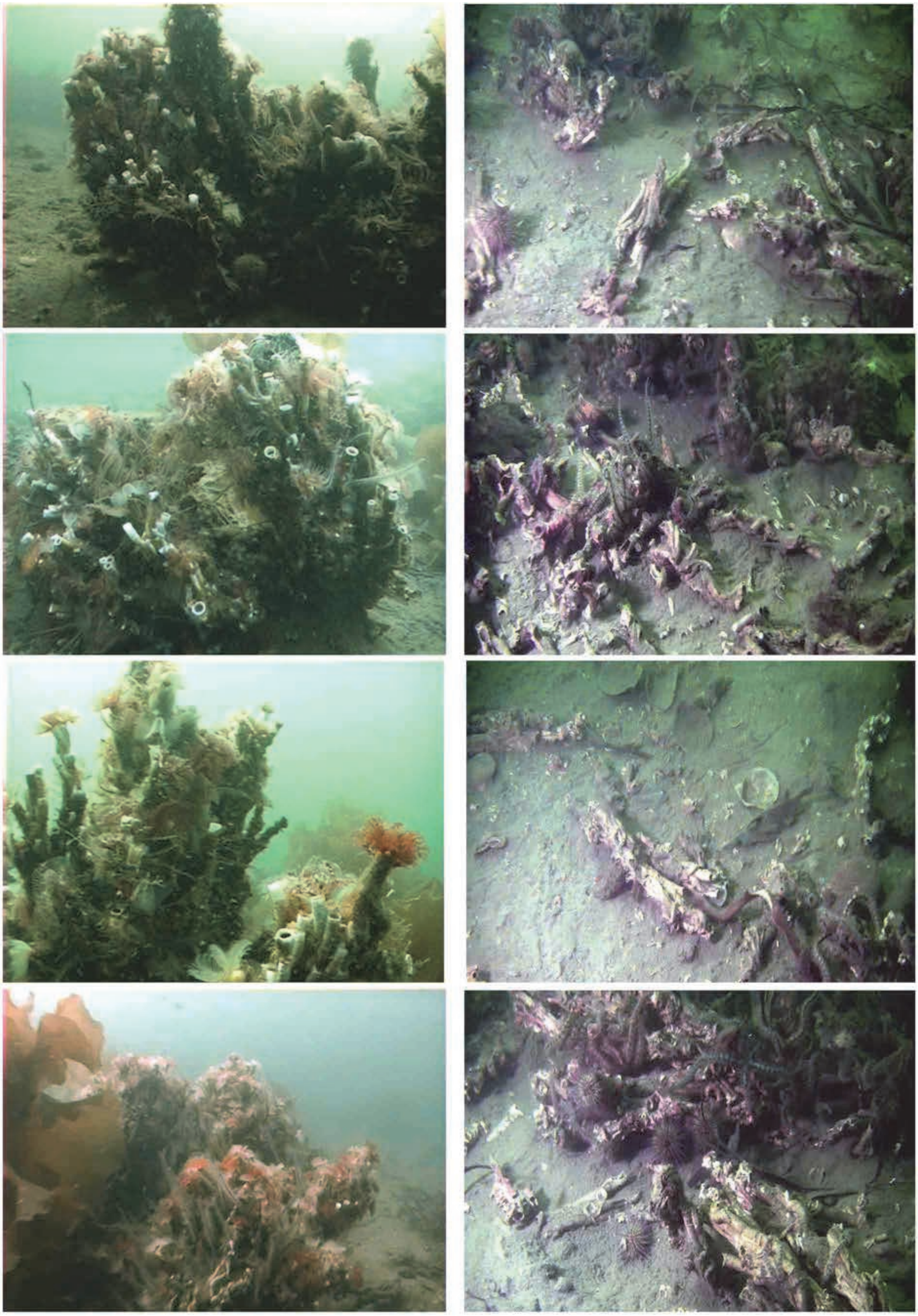

Figure 13. Representative screen grabs from video taken along MNCR phase 2 transect SV04 in South Creagan Bay in 2005 (left) and 2014 (right).

3.1.2.2 Condition transects

Reef condition parameters recorded during the current survey along the 40 transects (15 paired transect sites and 10 *Didemnum vexillum* relocatable sites) are provided in Table 1.3 (Annex 1) and summarised in Table 9. The data can be simplified by allotting each transect a condition score (CS). The derivation of the score is presented in Table 8. Because of the observational nature of most of the parameters, allocation of scores to sites should only be considered accurate to within the given score +/- 1.

Table 8. Condition score system for the serpulid reef habitat in Loch Creran.

Score	Canopy height (cm)	Broken reef (%)	Tube occupancy (%)	Pristine reefs present
1	>30	<50	>50	YES
2	10 - 30	<50	>50	YES
3	10 - 30	50 - 90	>50	YES/NO
4	10 - 30	50 - 90	10 - 50	YES/NO
5	10 - 30	50 - 90	1 - 10	YES/NO
6	10 - 30	90 - 99	1 - 10	NO
7	<10	>90	1 - 10	NO
8	<10	>90	<1	NO

Note that in the Figures of this section, a full legend is provided in Figure 14 but thereafter legends are minimal to avoid obscuring detail within the Figure or excessive Figure size. However, to minimise reference to Figure 14, in addition to the colour-coding of transects according to their condition score (see Figure 14), the score is also given in all figures in brackets following the transect code. Finer detail on the mosaicked sidescan imagery can be discerned by increasing the magnification of the viewing software. Where reef heights on sonargrams have been noted, these have been derived from a knowledge of towfish altitude, lateral target distance and shadow length by trigonometry using the unmosaicked imagery.

Table 9. Serpulid reef condition parameters recorded for paired transect sites (prefixed S) and relocatable sites (prefixed DR).

Transect	% cover	% broken	% occupied	Canopy height (cm)	Maximum height (cm)	% >30 cm height	Pristine reefs	Condition score
S1.1	1-5	100	0-1	<10	9	0	NO	8
S1.2	<1	100	0-1	<10	13	0	NO	8
S2.1	10-20	100	0-1	<10	10	0	NO	8
S2.2	<1	90-99	0-1	<10	16	0	NO	8
S3.1	20-40	90-99	1-10	<10	37		NO	7
S3.2	20-40	90-99	1-10	<10	26	0	NO	7
S4.1	1-5	50-90	10-50	10-30	35	1-10	YES	4
S4.2	1-5	<50	>50	10-30	42	10-50	YES	2
S5.1	10-20	90-99	1-10	10-30	20	0	NO	6
S5.2	10-20	90-99	1-10	10-30	28	0	NO	6
S6.1	10-20	90-99	1-10	<10	25	0	NO	7
S6.2	5-10	90-99	1-10	<10	27	0	NO	7
S7.1	20-40	50-90	1-10	10-30	28	0	NO	5
S7.2	20-40	50-90	1-10	10-30	38	<1	YES	5
S8.1	5-10	100	0-1	<10	14	0	NO	8
S8.2	10-20	100	0-1	<10	14	0	NO	8
S9.1	5-10	100	0-1	<10	14	0	NO	8
S9.2	5-10	100	0-1	<10	21	0	NO	8
S10.1	20-40	90-99	1-10	<10	15	0	NO	7
S10.2	10-20	90-99	0-1	<10	21	0	NO	8
S11.1	<1	90-99	1-10	<10	27	0	NO	7
S11.2	<1	100	0-1	<10	10	0	NO	8
S12.1	20-40	50-90	>50	10-30	33	1-5	YES	3
S12.2	20-40	50-90	>50	10-30	42	1-5	YES	3
S13.1	5-10	<50	>50	10-30	50	10-50	YES	2
S13.2	1-5	<50	>50	10-30	40	10-50	YES	2
S14.1	10-20	<50	>50	>30	65	80	YES	1
S14.2	5-10	<50	>50	>30	62	75	YES	1
S15.1	5-10	90-99	1-10	<10	25	0	NO	7
S15.2	10-20	90-99	1-10	<10	30	0-1	NO	7
DR01	1-5	100	0-1	<10	6	0	NO	8
DR02	10-20	90-99	1-10	<10	36	<1	NO	7
DR03	5-10	50-90	>50	10-30	28	0	NO	3
DR04	20-40	90-99	0-1	<10	22	0	NO	8
DR05	5-10	50-90	10-50	10-30	30	<1	NO	4
DR06	5-10	50-90	10-50	10-30	20	0	NO	4
DR07	1-5	100	0-1	<10	11	0	NO	8
DR08	20-40	50-90	10-50	10-30	35	1-10	YES	4
DR09	10-20	<50	>50	10-30	64	10-50	YES	2
DR10	1-5	90-99	0-1	<10	28	0	NO	8

Rubha Riabhach Bay

No sidescan imagery is available for this embayment prior to the 2015 survey by Geosurv Ltd. (Geosurv, 2015). Published surveys of the bay include observations of serpulid reef presence along transects perpendicular to the shore in 1994 Moore *et al*., 1998) and 2005 Moore *et al*., 2006) (Figure 14).

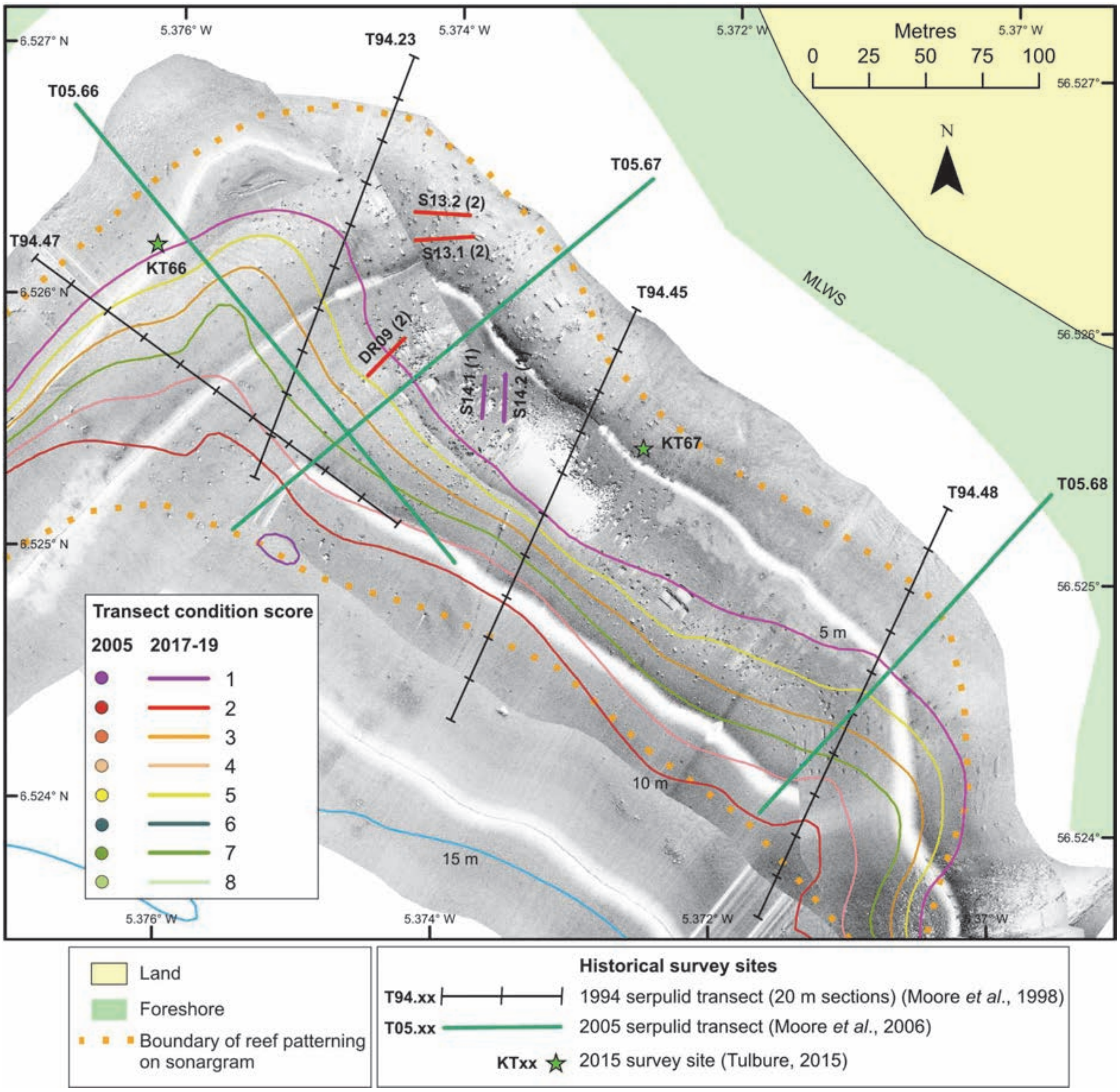

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Figure 14. 2015 sidescan sonar mosaic with distribution of historical and current survey sites in Rubha Riabhach Bay (box A in Figure 2).

Four 200 m long transects passed through the area of currently well-developed reefs in the north of the bay in 1994 with records of reef size and estimates of reef cover obtained within 20 m long sections of an approximately 3 m wide band. Reef size was assessed by placing reefs within three size categories based on their plan area with the aid of a template: small (<50 cm^2), medium (50 - 500 cm^2) and large (>500 cm^2). Area was not employed for the 2017-19 condition transect survey but equivalence between areal size categories and reef height can be found in section 3.1.1 (Table 6). No large reefs were recorded within any of the four 1994 transect bands, although a single large reef was observed just outside one of the bands. Medium reefs were also very sparse, being recorded in just one 20 m sector along one of the four transects. Reef density was low, with no reefs observed along one transect and <1% cover along the other transects.

No reef density measures are available from the 2005 survey. Small, medium and large reefs were observed within the transect band (approximately 4 m either side of the transect line) along all three transects with medium and/or large reefs present over a wide depth range (3.4 - 11.2 m, 0.9 - 9.6 m and 7.1 - 11.2 m along transects T05.66, T05.67 and T05.68 respectively (Figure 14).

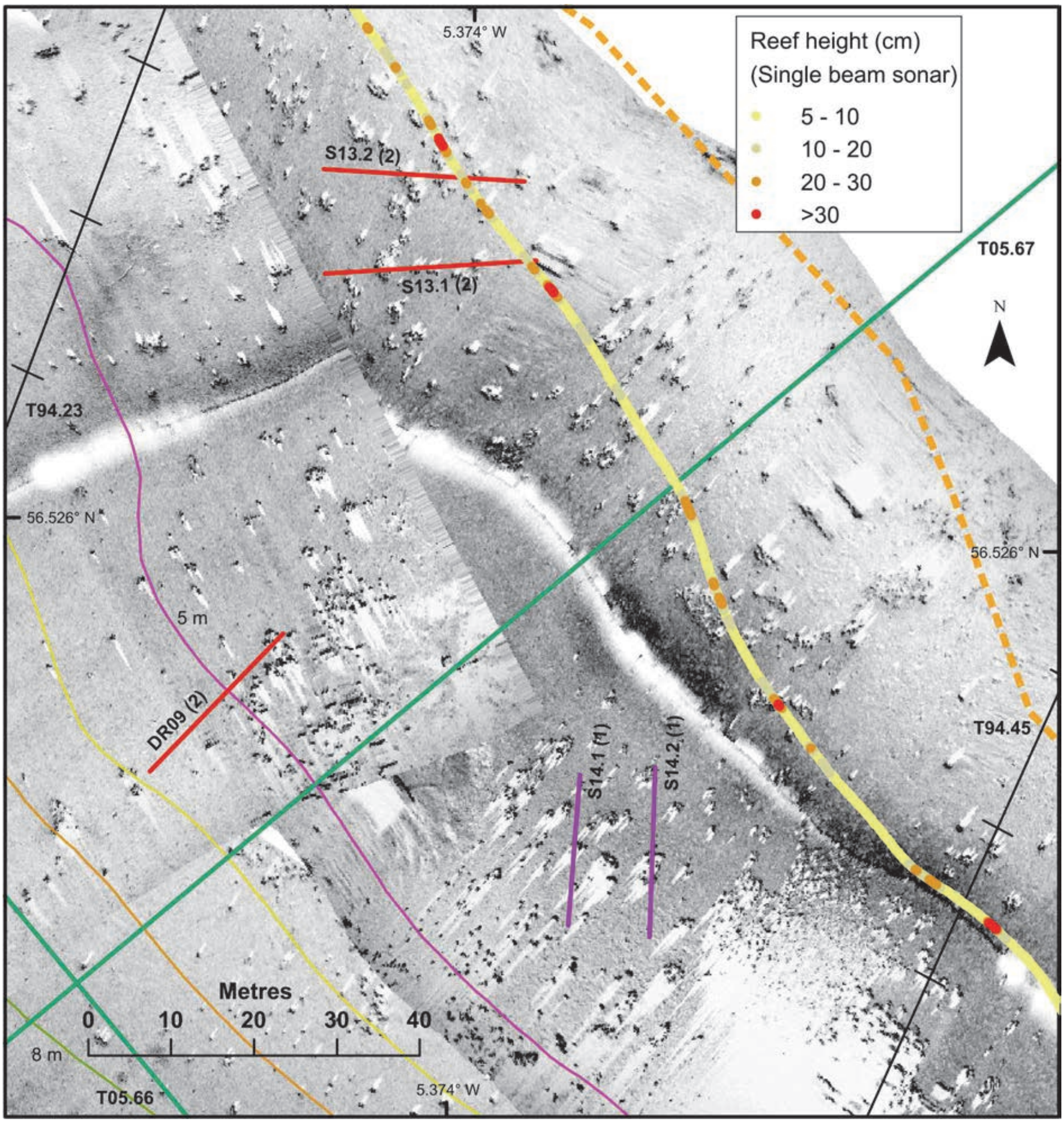

Figure 15. 2015 sidescan sonar mosaic with distribution of historical and current survey sites in Rubha Riabhach Bay. Figure shows the central region of Figure 14 in finer detail including reef heights from trial run of single beam sonar. Orange pecked line highlights margin of putative serpulid reef material.

In 2017/18 two pairs of condition transects (S13, S14) and one relocatable transect (DR09) were located in the north of Rubha Riabhach Bay (Figure 14, with finer detail in Figure 15). Some collapsed reef material was observed, but most of the reefs were largely unbroken with very little scattered reef rubble or comminuted tube material. Most reefs exceeded 20 cm in height with the overall canopy height exceeding 30 cm along the S14 transects. Pristine reefs (unbroken, densely populated, >30 cm height) were recorded along all transects, with a maximum height record of 65 cm. Although caution should be exercised when considering reef cover estimates in view of the subjective element, values are greater along all transects in 2017/18 than in 1994, considerably so in most cases (Table 9). Reef condition scores are the highest (1 - 2) for any region of Loch Creran in 2017/18. Similar levels of condition of the reefs were found in 2015 by Tulbure (2015) at two sites in the same region (KT66 and KT67). The overall visual impression from this locality is that it resembles the reef habitat occupying large areas off Rubha Mór and South Shian and in Sea Life Centre and South Creagan Bays in 2005, although the reefs were generally more scattered in Rubha Riabhach Bay. The large size and good condition of the Rubha Riabhach reefs are illustrated in Figure 16.

Figure 15 also shows partial results from the single beam sonar trial in the form of seabed target heights along one of the survey lines through the Rubha Riabhach reef bed. There are scattered records of 20 - 30 cm and >30 cm targets on an otherwise low relief seabed, which will undoubtedly correspond to individual or reef patches. There appears to be a degree of correspondence between the single beam and sidescan sonar patterns, although it should be borne in mind that the accuracy of georegistration of the mosaicked sidescan imagery is unknown.

Figure 16. Typical serpulid reefs from Rubha Riabhach Bay. Upper video screen grab shows reef along transect S14.1 (14/06/2017)). Lower photo from same vicinity (28/08/2018).

South Shian

Two *Didemnum vexillum* transects and four pairs of condition transects were located off South Shian in 2017/18. The most northerly transect DR08 was situated north of the fish farm pontoon in the vicinity of a pair of small vessel moorings, but beyond their radius of impact (see Moore *et al*., 2006). Sonargrams of the area are shown for 2015 (Figure 17) and 2004 (Figure 18). DR08 had a mid-range condition score (4). Most of the reef material was broken, unoccupied and displayed a low canopy height. Pristine reefs were present, although there were few such reefs (<10% >30 cm in height, Table 9). In the same region (site KT36) Tulbure (2015) recorded 88% collapsed reef material in 2015. The 2015 sonargram indicates the likely presence of a small patch of well-formed reefs to the west of the transect (around 20 x 20 m), several of which display shadow lengths indicative of heights of c.30 - 50 cm. However, the patterning over most of the region is suggestive of amorphous material, probably representing degraded reefs, although some of the texture is almost certainly artefactual. The quality of the 2004 image (Figure 18) also lacks clarity but the reef material is more clearly discernible, particularly towards the south end of the transect where ring reef-shaped structures are visible. Medium and large reefs were recorded between the depth range of 5.5 - 12.8 m along a 2005 transect (T05.36) which passed within 10 m of DR08. Some reef damage was also noted, possibly resulting from the moorings in the vicinity. These are clearly discernible on the sonargrams.

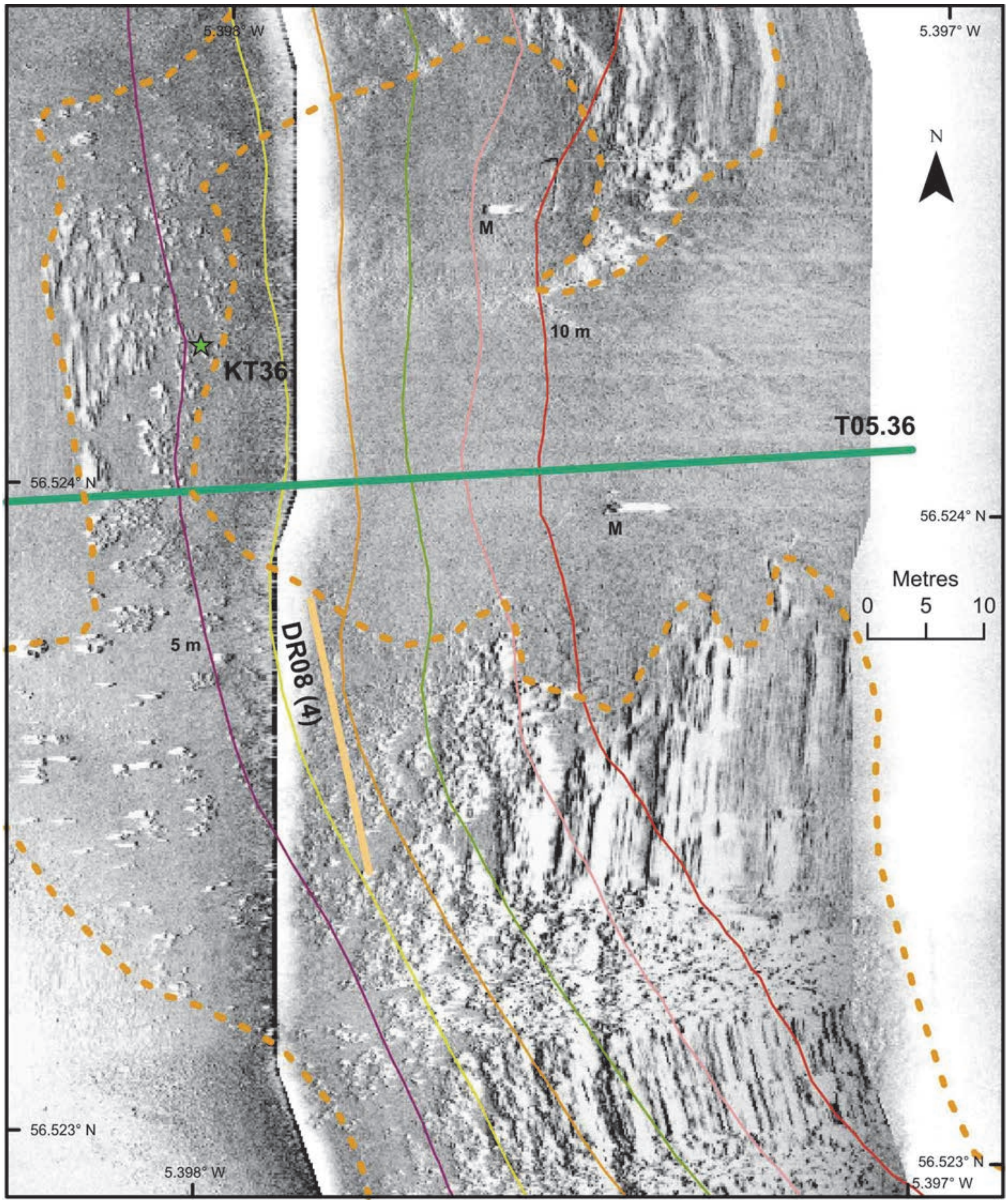

Figure 17. 2015 side scan sonar mosaic of area off South Shian (box B in Figure 2) showing location of transect DR08 and historical survey sites. Orange pecked line highlights margin of putative serpulid reef material. M denotes mooring block.

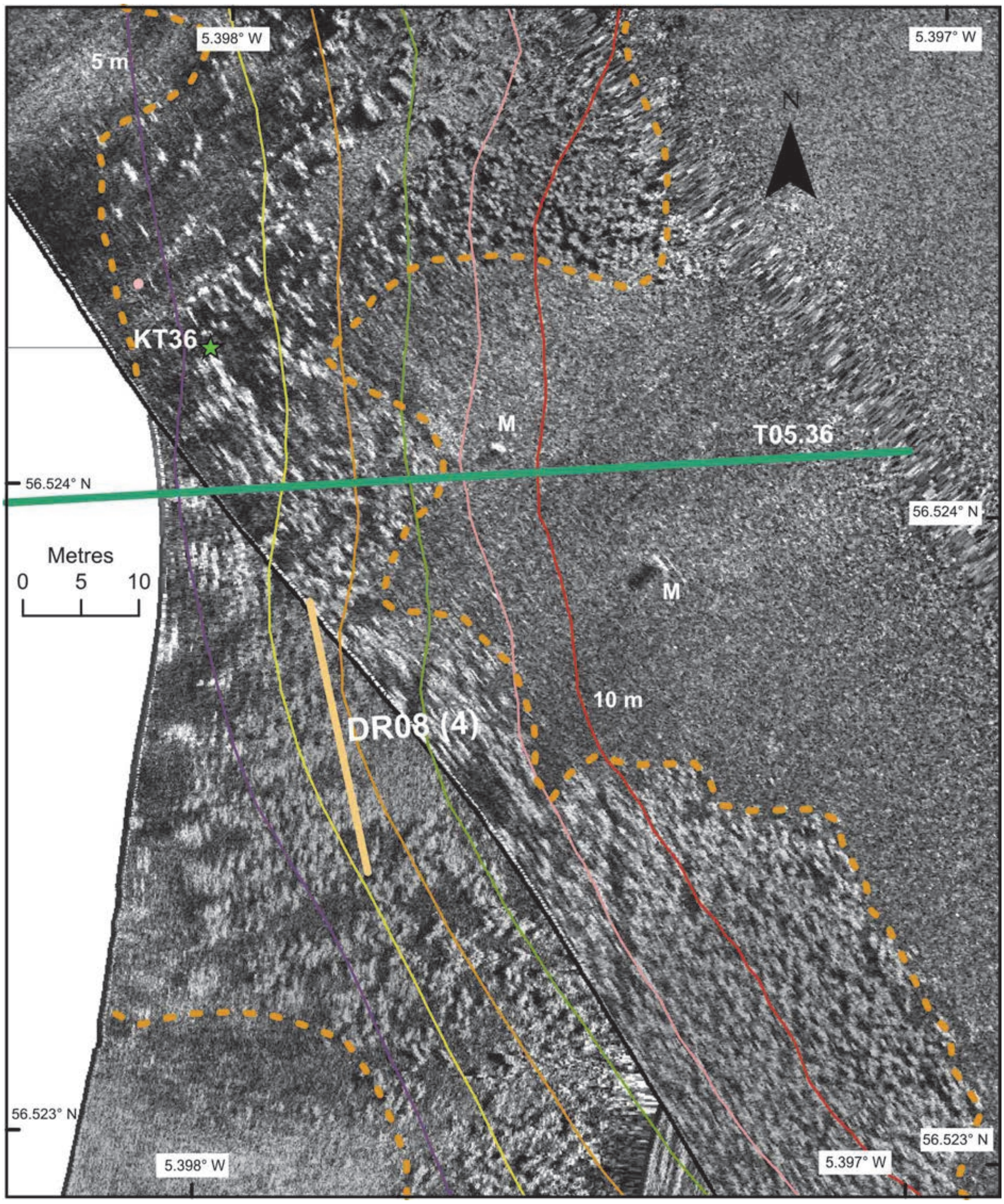

Figure 18. 2004 side scan sonar mosaic of area off South Shian (box B in Figure 2) showing location of transect DR08 and historical survey sites. Orange pecked line highlights margin of putative serpulid reef material. M denotes mooring block.

The paired condition transects S12 were located around 90 m south of the fish farm pontoon. The southern mooring lines of the pontoon are clearly visible in Figure 19 and illustrate the level of geographic distortion that can occur in the mosaicked sonargrams. The mooring line configuration shown in the 2004 image is likely to be more representative (Figure 20). The area has been a base for the aquaculture industry for many years and associated ground tackle such as mooring blocks and lines are scattered over the area Figures 19, 20). The principal band of serpulid reef material can be identified on the 2015 image (Figure 19) and is clearly curtailed in the region of the pontoon. Reef condition along the S12 transects was assessed as moderate (CS3). It was largely broken with a low canopy height but most tubes were occupied and pristine reefs were present (Table 9). The pattern of reef material over the area depicted by Figure 19 is generally fine-grained and amorphous indicating a lack of larger, well-formed reefs, although some examples do appear to be present, particularly in the vicinity of the transects, although the image unfortunately suffers from distortion in this area.

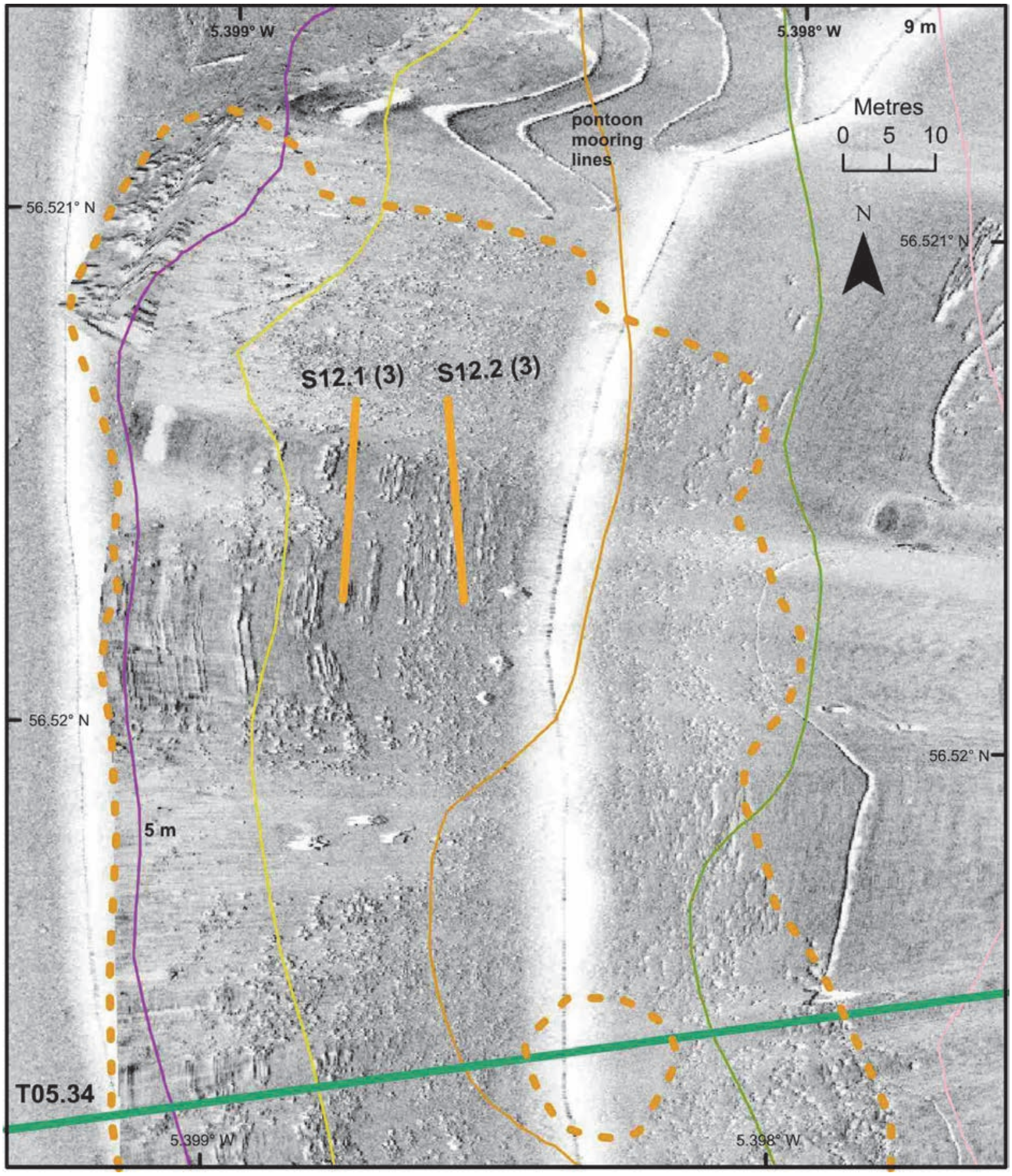

Figure 19. 2015 side scan sonar mosaic of area off South Shian (box C in Figure 2) showing location of transect DR08 and historical survey sites. Pecked line highlights margin of putative serpulid reef material.

The 2004 image also lacks clarity (Figure 20). Truncation of the reef band in the vicinity of the pontoon was clearly apparent at that time and in fact predates the construction of the pontoon (Moore, 2000). The 2005 transect T05.34 passed within 50 m of the 2017 condition transects, revealing the presence of medium/large reefs over a broad depth range of 4.2 to 10.9 m. The presence of smashed reefs was also noted, possibly associated with mooring damage. An example of a circular, reef-impoverished patch is shown at the bottom of Figures 19 and 20.

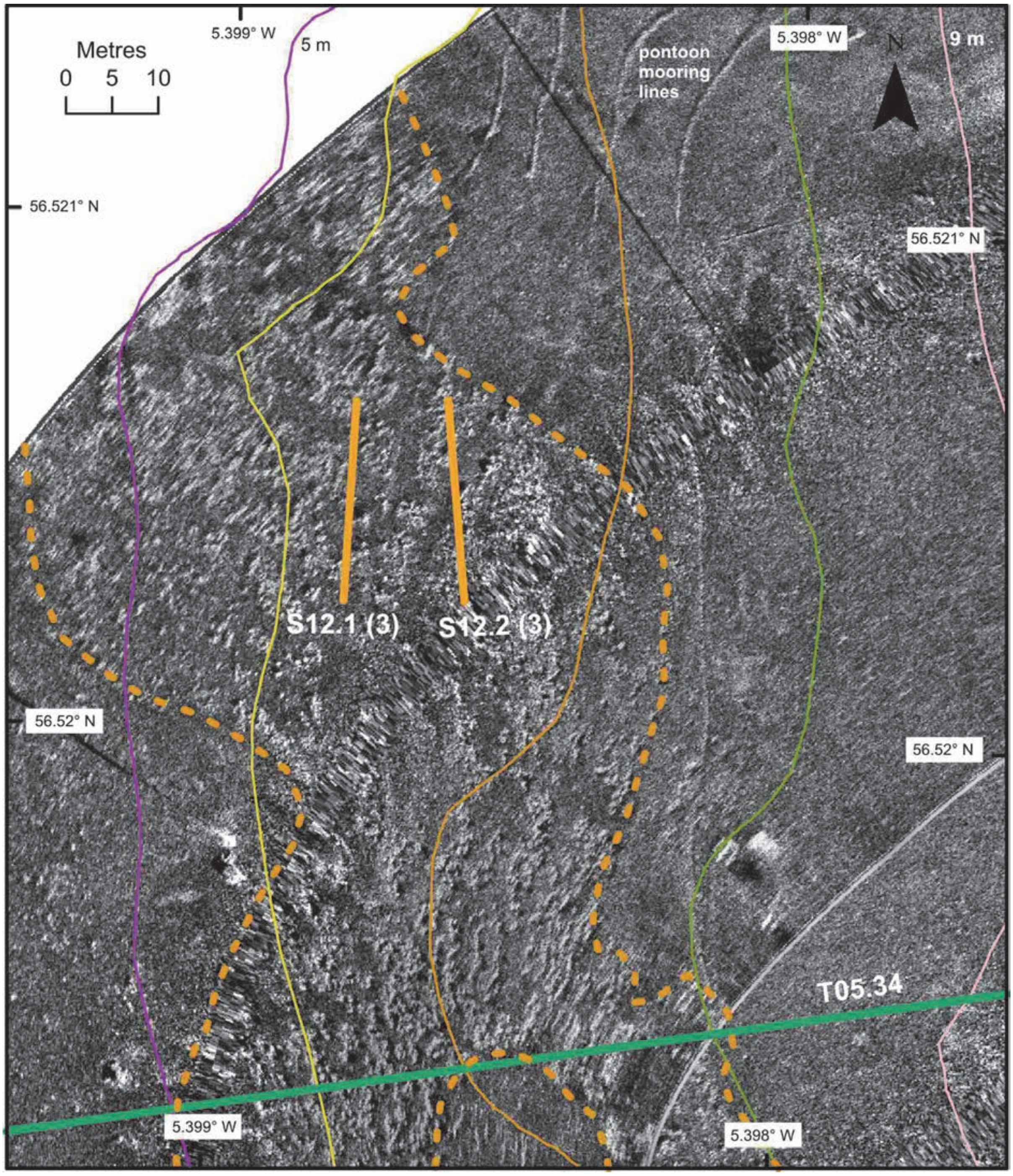

Figure 20. 2004 sidescan sonar mosaic of area off South Shian (box C in Figure 2) showing location of transect DR08 and historical survey sites. Pecked line highlights margin of putative serpulid reef material.

Seven of the 2017/18 transects were located in the southern half of the bay off South Shian, two of which (S10.1, S10.2) straddled the MNCR transect SV02 (Figure 21). All transects exhibited highly degraded reef material (CS7 - 8) consisting very largely of broken, unoccupied fragments (90 - 100%). No pristine reefs were recorded. Average canopy height was <10 cm and the tallest reef encountered was 27 cm. Reef condition was similar to that recorded for the MNCR transect SV02 in 2014. The side-scan imagery suggests that the transect findings are indicative of most of the embayment. The sonargrams largely display a fine-grain patterning or virtually no texture within the reef band. The larger targets evident on Figure 21 will be mooring weights, although small patches of putative reefs are possibly present with heights of around 30 - 50 cm, such as in the south-west corner of the surveyed area (black pecked line in Figure 21). Tulbure (2015) examined this area in 2015 (site KT33) recording maximum reef heights of 30 - 40 cm in four replicate plots, although 63% of reef material was collapsed.

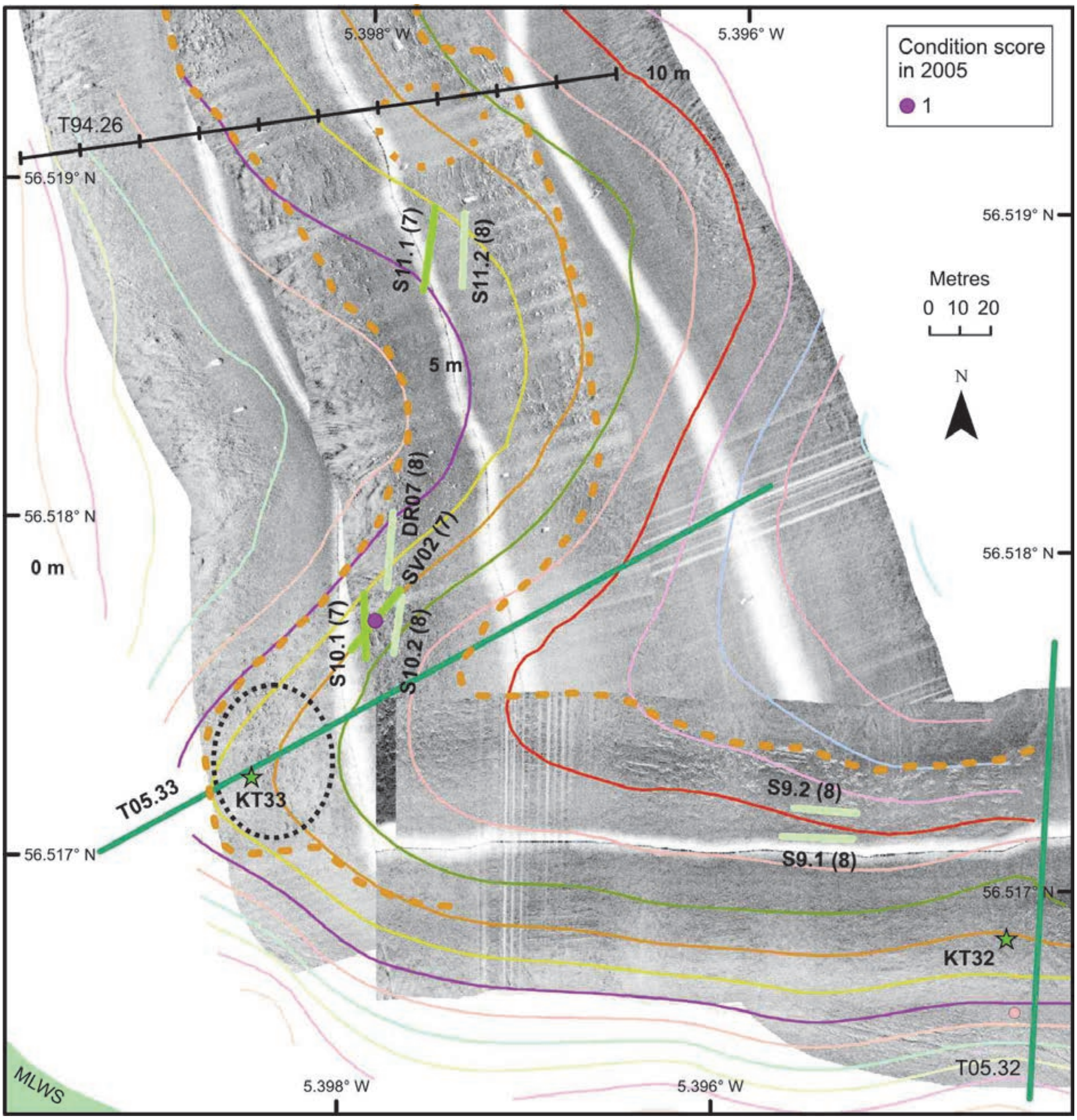

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Figure 21. 2015 sidescan sonar mosaic of southern half of bay off South Shian (box D in Figure 2) showing location of current and historical survey sites. Pecked line highlights margin of putative serpulid reef material. Black pecked line denotes possible patch of large reefs.

The reef patterning is coarser and far more distinct on the 2004 and 2005 sonar images (Figure 22), particularly on unmosaicked sonargrams, suggesting the widespread presence of large and often dense reef material. This is supported by the maximum condition score (1) ascribed to the MNCR transect SV02 in 2005 (section 3.1.2.1). Three historical transects were located in this region of the loch (Figures 21, 22). Reefs were recorded from 40 - 200 m along the 1994 transect T94.26 with large reefs present in every 20 m section from 100 - 200 m, although many reefs were flattened in one section (140 - 160 m). Large reefs were also recorded along the two 2005 transects, with the surveyor noting the presence of very dense reefs in good condition over an extensive area along T05.33 (Figures 21, 22).

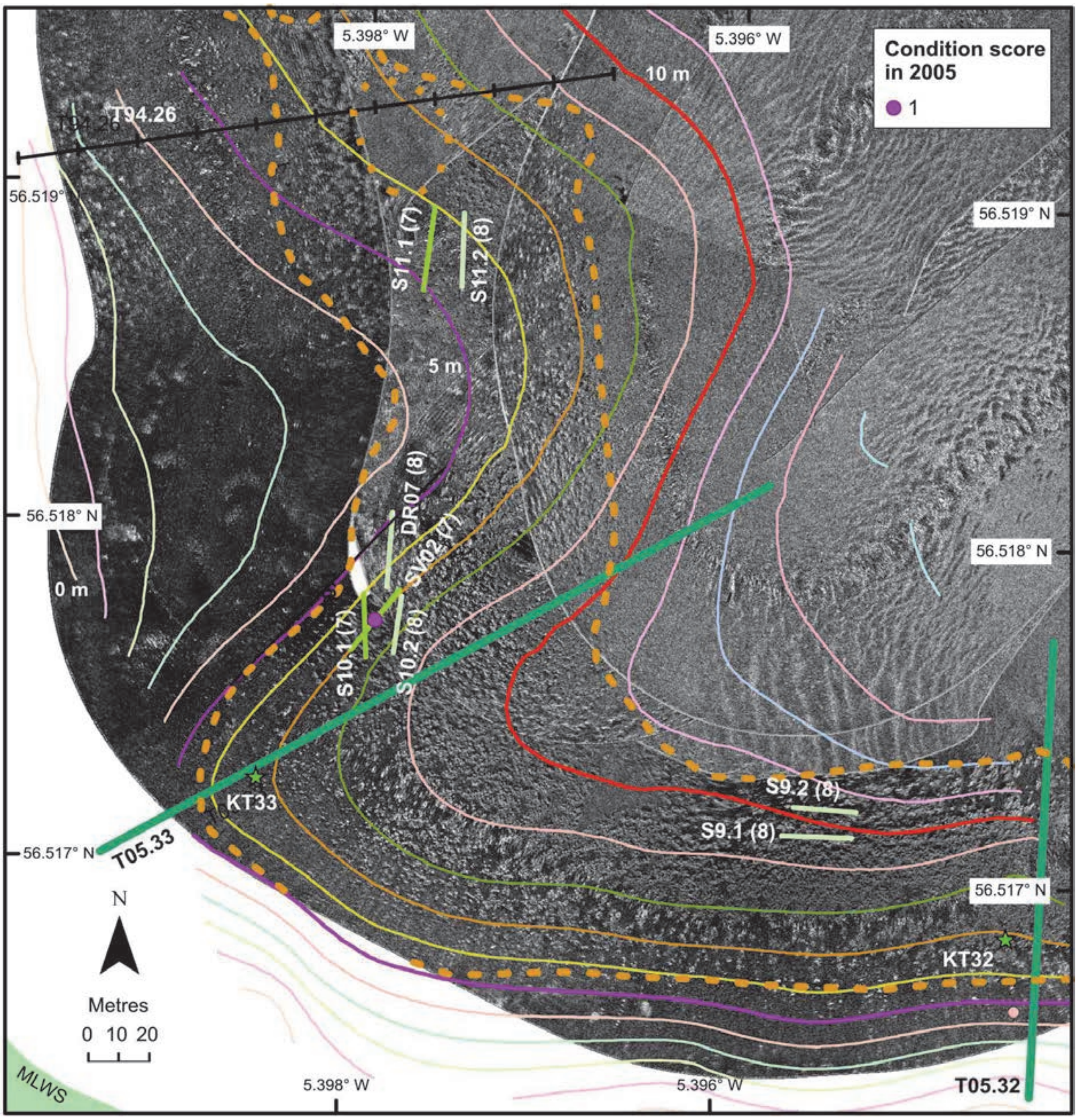

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Figure 22. 2004 sidescan sonar mosaic of southern half of bay off South Shian (box D in Figure 2) showing location of current and historical survey sites. Pecked line highlights margin of putative serpulid reef material.

Rubha Mór

Three *Didemnum vexillum* transects and three pairs of condition transects were located in the embayment east of Rubha Mor. One pair of transects straddled the MNCR survey site SV02 (Figures 23, 24). One transect (DR04) was positioned around 400 m east of the main group of sites and is shown in Figure 25.

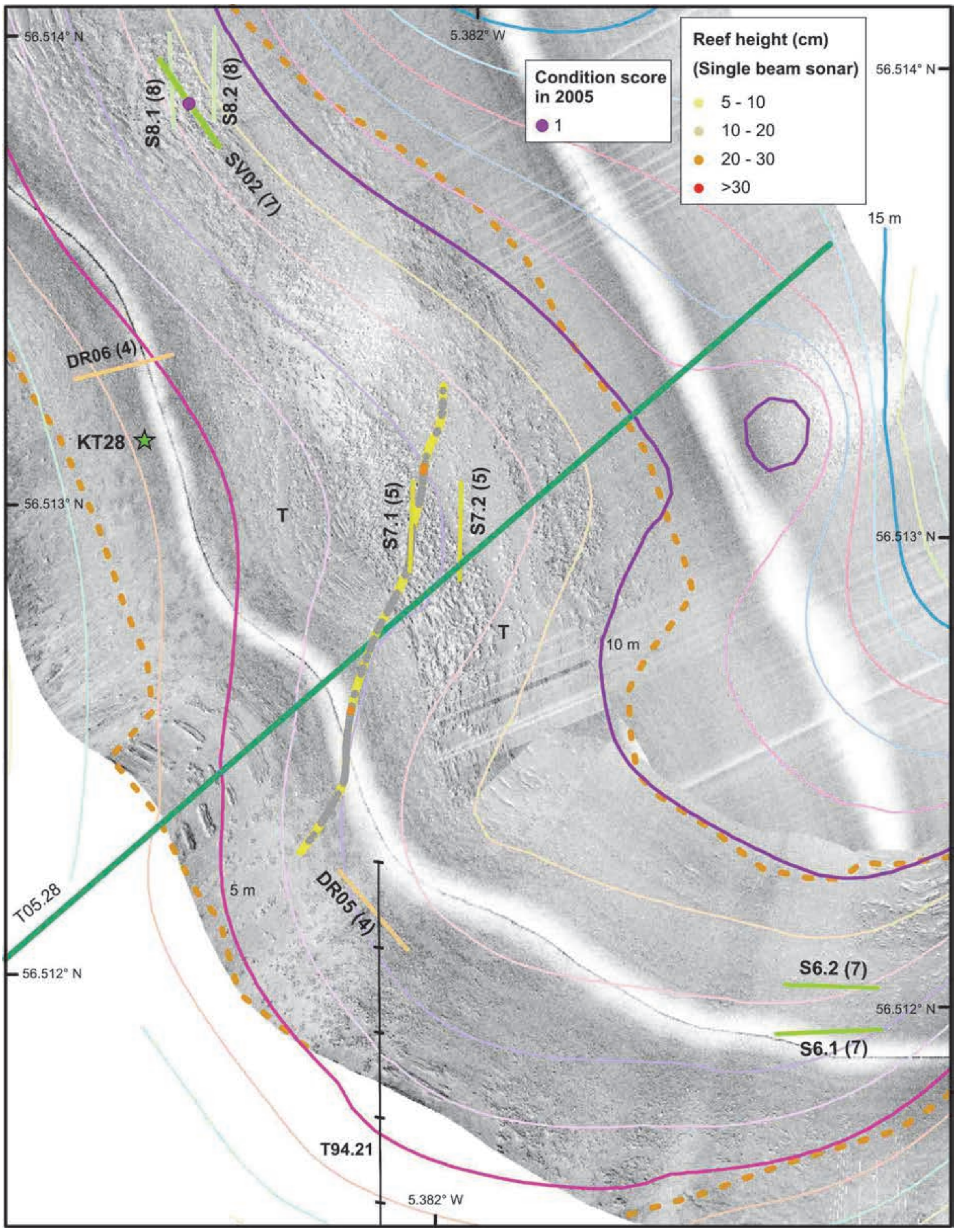

Figure 23. 2015 sidescan sonar mosaic of area east of Rubha Mór (box E in Figure 2) showing location of current and historical survey sites. Also shown are reef heights from trial run of single beam sonar. Pecked line highlights margin of putative serpulid reef material. 'T' denotes track of demersal gear.

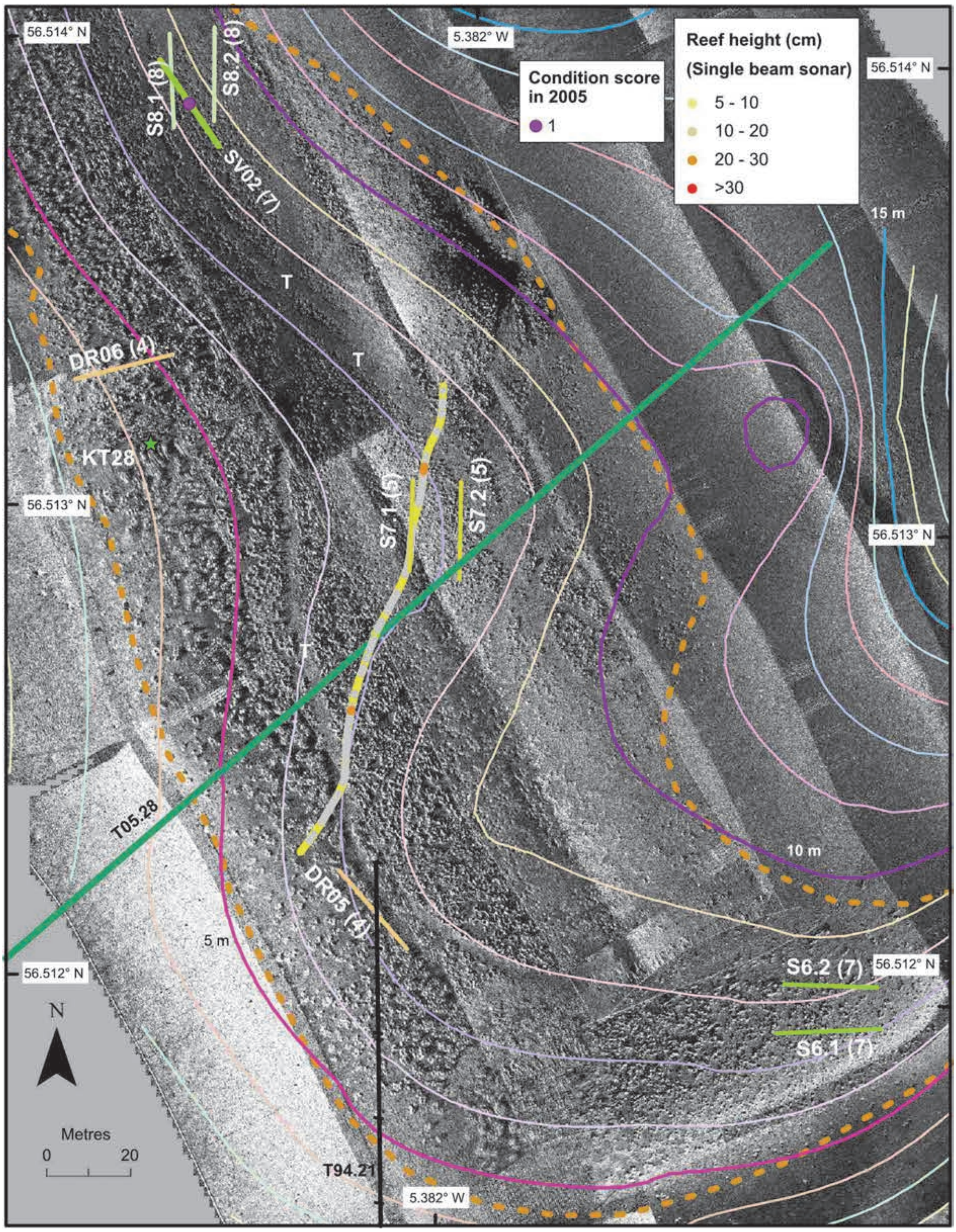

Figure 24. 2005 sidescan sonar mosaic of area east of Rubha Mór (box E in Figure 2) showing location of current and historical survey sites. Also shown are reef heights from trial run of single beam sonar. Pecked line highlights margin of putative serpulid reef material. 'T' denotes track of demersal gear.

All transects showed significant reef degradation with five of them exhibiting severe damage (CS 7 - 8). At these sites the reef material was dense in places but consisted very largely of low-lying (<10 cm), broken (>90%), unoccupied tubes (Table 9). At the other four Rubha

Mór sites the reef canopy was higher (10 - 30 cm), being less fragmented (50 - 90% broken), and at two of them supported a higher proportion of living worms (10 - 50%) (CS 4 - 5). One of the single beam sonar trial runs passed through the centre of this area providing greater detail on canopy height (Figure 23). This revealed heights varying between 10 - 20 cm and 0 - 10 cm, with very sparse material >20 cm.

The 2015 sonargram mosaic (Figure 23) suggests that the degraded habitat recorded along the transects is representative of most of the embayment. A scattering of larger reefs (>30 cm) is discernible in the vicinity of the S7 transects but the sonargram patterning is mostly fine-grained, and that which is more textured appears to have arisen largely through image distortion. Tulbure (2015) examined two sites at this locality in the same year recording 98 - 99% broken reef material and maximum reef heights of 10 - 20 cm in four replicate plots at KT28 in the vicinity of DR06 and 60 - 80% collapsed reef material and maximum reef heights of 22 - 51 cm in plots at KT26 near DR04.

The sonar mosaic shown in Figure 24 illustrates the reef condition in 2005. The widespread and coarse patterning is distinct, revealing dense, large, individual reefs, which contrast with the cleared reef tracks intersecting the region, possibly resulting from dredging (Moore *et al*., 2006). The change is illustrated by the MNCR site SV02 which underwent a change from CS1 in 2005 to CS7 in 2014.

Two historical transects passed through the centre of the embayment (Figure 24). Large reefs were recorded along the last 40 m of the 1994 transect T94.21 (6.2 - 7.6 m depth), whilst in 2005 the surveyor recorded the presence of very dense reefs along transect T05.28, with large reefs extending over a depth range of 4.6 - 10.5 m. Dredge damage was also noted. One 2005 transect (T05.26) passed through DR04 (Figure 25). The quality of the only available sidescan imagery for this region (2004) is poor, although at least part of the serpulid band can be discerned. In contrast to the severe degradation recorded at DR04 in 2018 (CS8), medium and/or large reefs were recorded over a wide depth range (1.5 - 12.2 m) along T05.26, with the surveyor noting the presence of dense reefs and 'very good large reefs'.

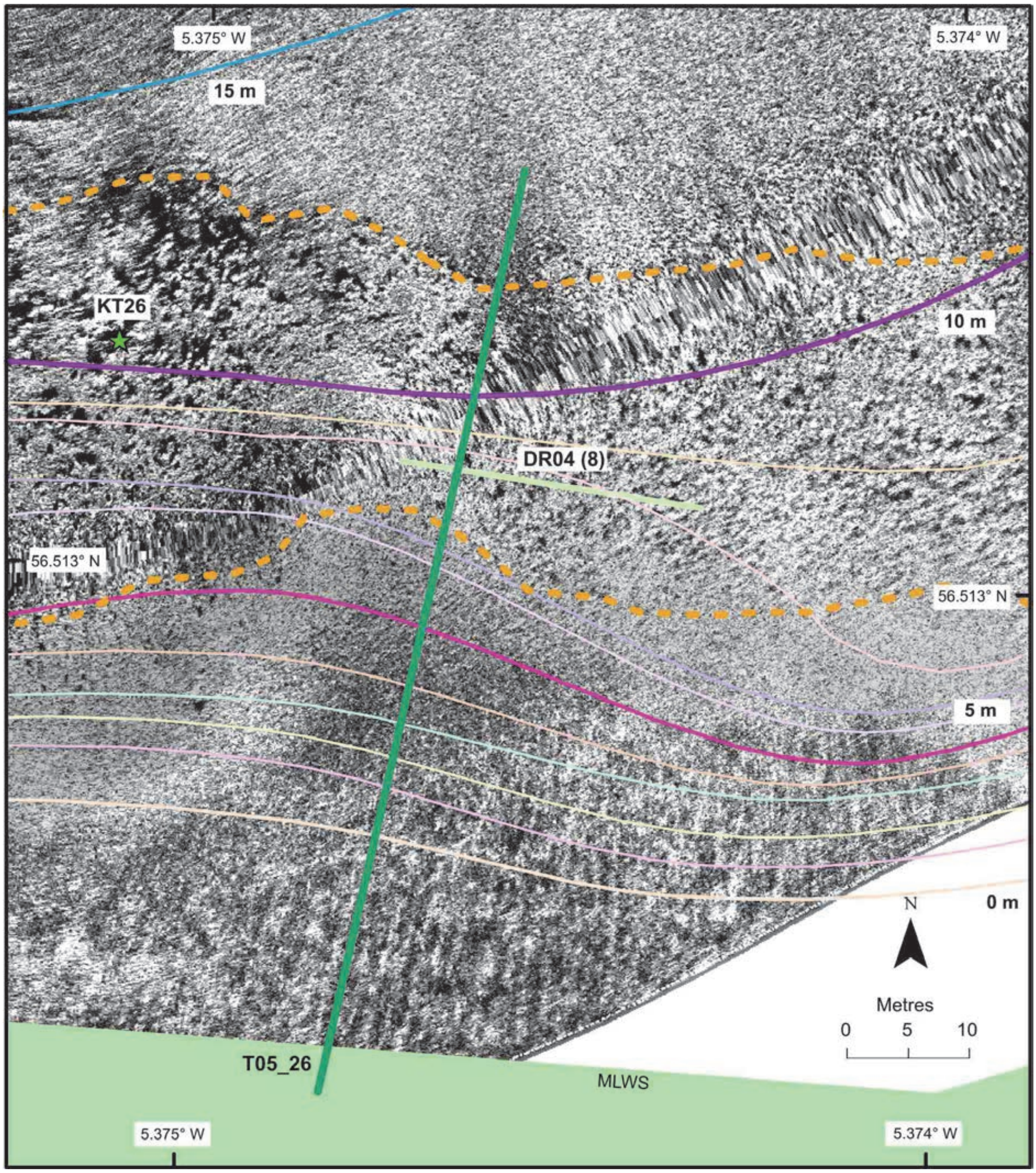

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Figure 25. 2004 sidescan sonar mosaic of area 900 m east of Rubha Mór (box F in Figure 2) showing location of current and historical survey sites. Pecked line highlights margin of putative serpulid reef material.

Dalrannoch

Transect DR03 was located north of Dalrannoch around 400 m west of Sea Life Centre Bay. It was one of the few locations where the 2015 sidescan imagery indicates the presence of dense, large reef structures (Figure 26). Sonar target shadows indicate the presence of many reefs with heights around 30 - 40 cm in the vicinity of DR03. No earlier sidescan sonar imagery is available for this site, although two diver transects traversed the area. In 1994 (transect T94.03) only small and medium reefs were found above a depth of 6.1 m and were very sparse (<1% cover) above 3 m. Large reefs were only recorded from 6.1 to 9.2 m, where medium reefs dominated. In 2005 large reefs were recorded from 2.3 - 8.0 m along transect T05.20, with the presence of some 'smashed reefs' noted. In 2015 Tulbure (2015) examined the condition of reefs at a site around 30 m from DR03 (KT20) in four replicate 3 x 3 m plots over a depth range of 6.4 - 7.3 m, where the percentage of collapsed reef material varied from 5 - 60%. However, reefs attaining heights of 30 - 40 cm were present in all plots and the surveyors noted the presence of numerous intact reefs over a depth range of around 1 - 9 m.

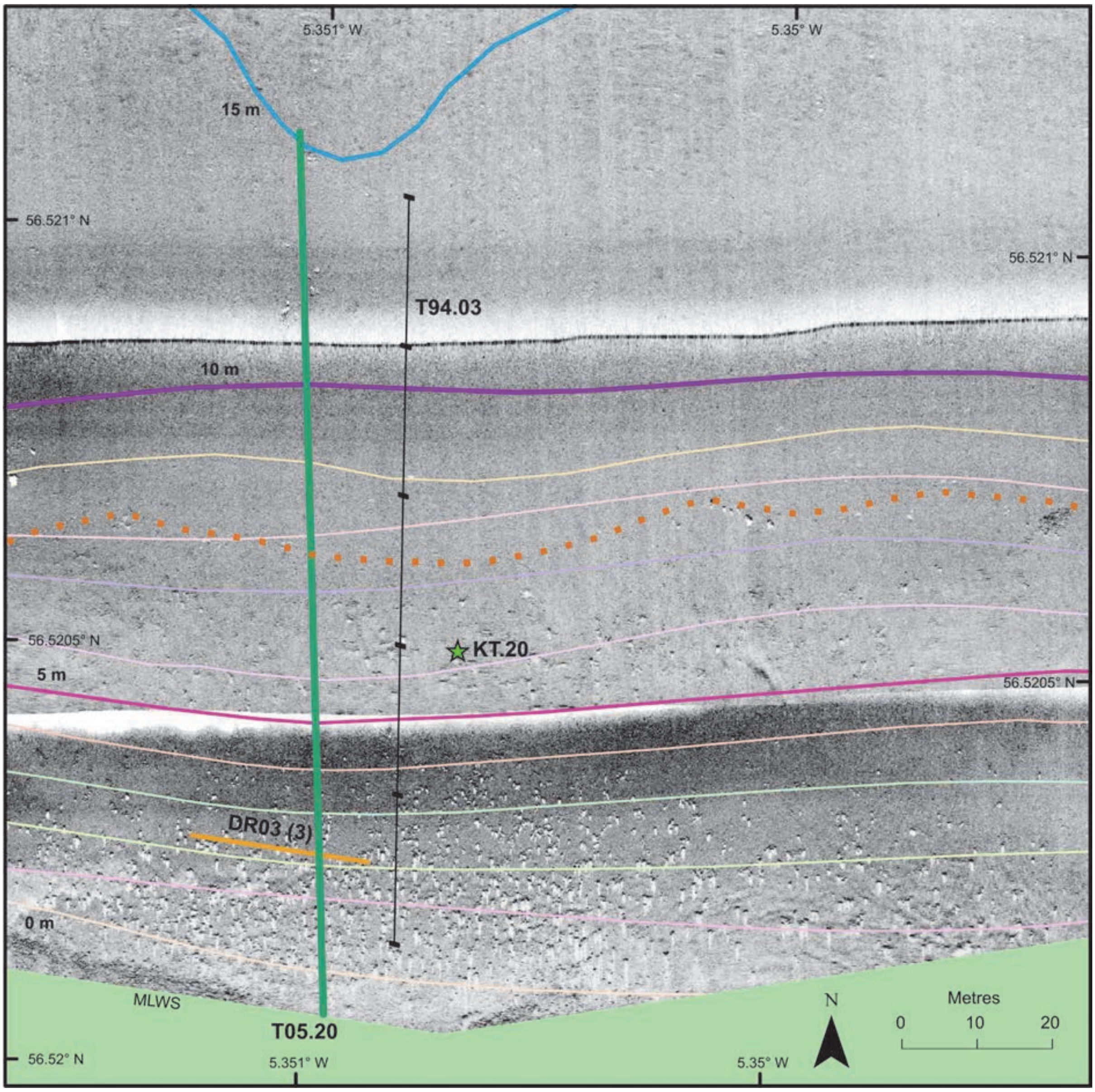

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Figure 26. 2015 sidescan sonar mosaic of area off Dalrannoch (box G in Figure 2) showing location of current and historical survey sites. Pecked line highlights margin of putative serpulid reef material.

Along the 2018 transect DR03 at a depth of 2.5 - 2.7 m, density was greater (5 - 10% cover) than that recorded at this depth in 1994. Canopy height was moderate (10 - 30 cm) with a maximum reef height of 28 cm. Previously taller reefs had collapsed or fallen over (50 - 90% broken) whilst maintaining a high level of occupancy (>50%). This contrasts with the impression of reef condition suggested by the 2015 sonargram, although the diver data from the same year (Tulbure, 2015) indicates that much of the reef patterning on the sonar image may be derived from collapsed material. It appears that a process of reef development followed by relatively minor decline has occurred over the years 1994 to 2018 at this site resulting in a current condition score of 3.

Sea Life Centre Bay

The 2017 paired condition transects S5.1 and S5.2 lay in the western half of Sea Life Centre Bay at a depth of 5.8 - 7.3 m passing through an area of largely broken reef material (>90%), containing few live worms (1 - 10% occupied) (Figure 27). Canopy height was 10 - 30 cm with no pristine reefs observed, the tallest reef structures measuring 28 cm. The 2015 sidescan imagery indicates that the low S5 condition score (6) was probably typical of the region at that time, with extensive, low-relief patterning evident on the sonargram. The 2015 diver reef condition survey (Tulbure, 2015) in the same area (site KT17) recorded 60 - 100% collapsed reef material with maximum heights of 15 - 30 cm in the four plots examined at depths of 2.8 - 4.8 m. Pre 2015 sidescan coverage of this area is poor, but the 2005 diver transect T05.17 showed large reefs to be present from 2.5 - 10.0 m with no record of damaged reefs. The 2015 sidescan imagery clearly reveals the presence of the major reef band inshore of the 7 - 8 m contours, but also shows diffuse material below the 9 m contour, possibly of serpulid origin.

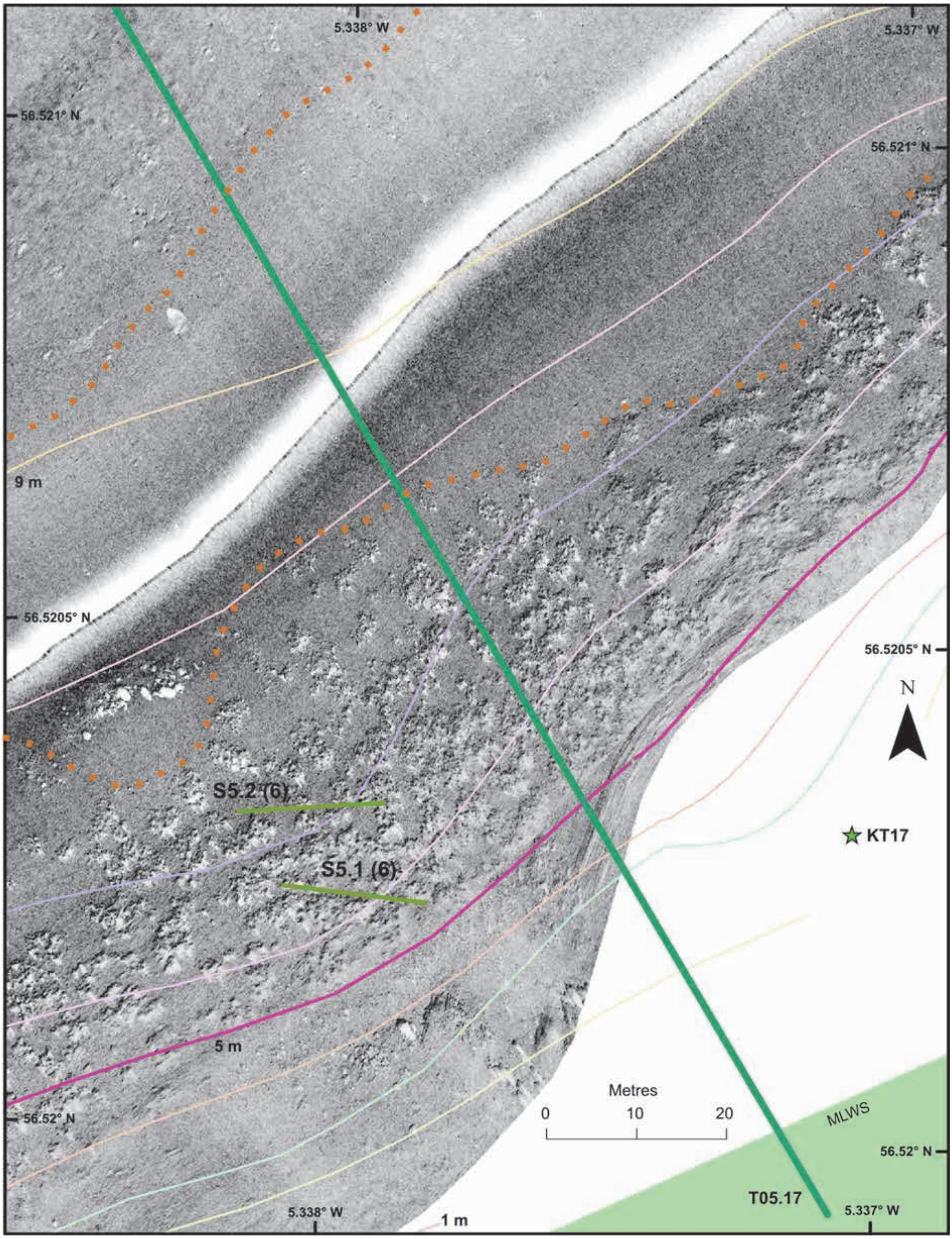

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Figure 27. 2015 sidescan sonar mosaic of area in western half of Sea Life Centre Bay (box H in Figure 2) showing location of current and historical survey sites. Pecked line highlights margin of putative serpulid reef material.

The seven condition transects and MNCR transect located in the principal serpulid reef area in the eastern half of Sea Life Centre Bay are shown in relation to the 2015 sidescan imagery in Figure 28.

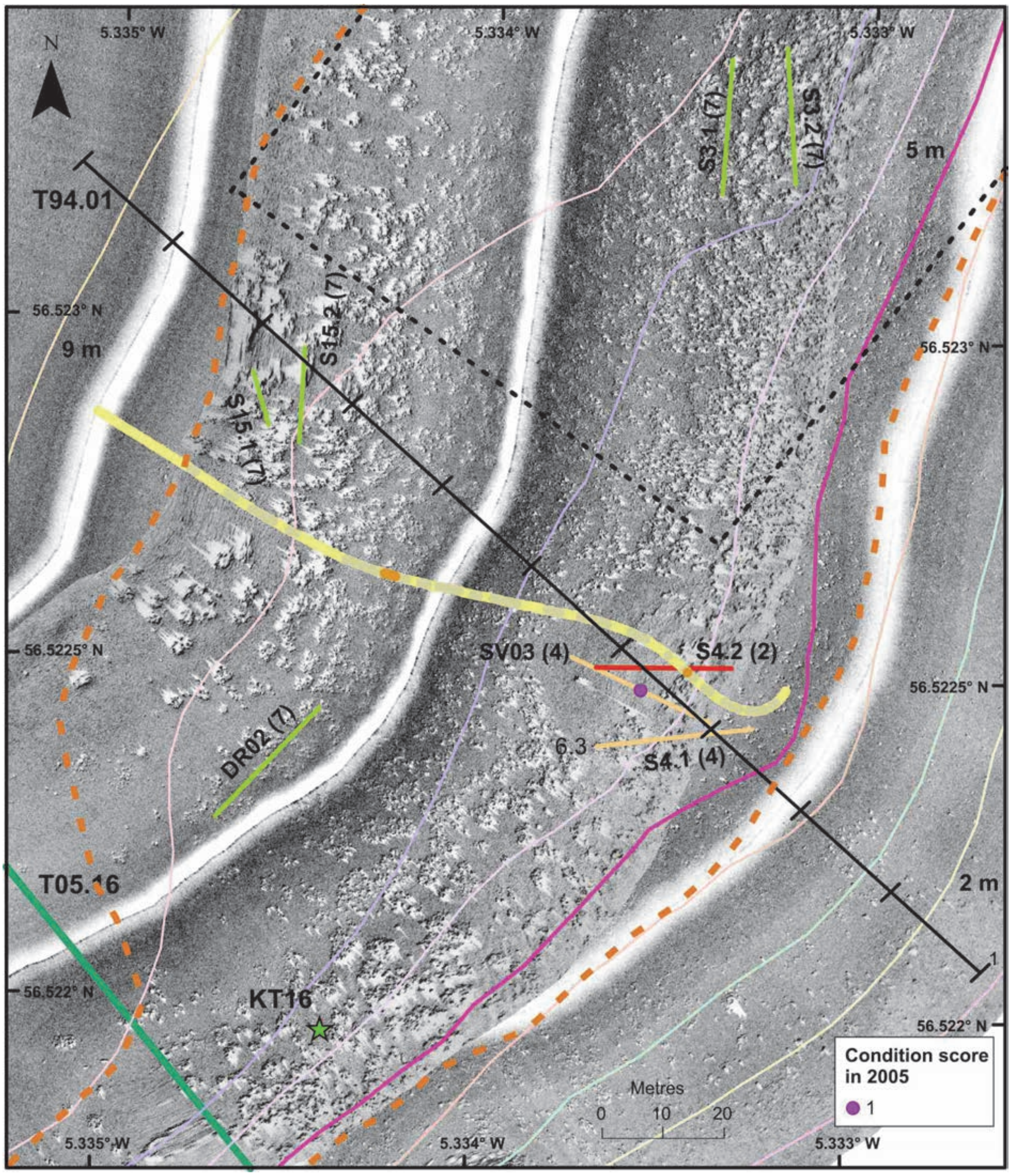

Figure 28. 2015 sidescan sonar mosaic of area in eastern half of Sea Life Centre Bay (box I in Figure 2) showing location of current and historical survey sites and reef heights from trial run of single beam sonar. Pecked orange line highlights margin of putative serpulid reef material. Pecked black line indicates area overlain with 2009 sidescan image in Figure 30.

Least damage was recorded in the vicinity of the MNCR site (CS 2 - 4), where canopy height was moderate (10 - 30 cm) through the presence of broken reefs but tube occupancy was locally high (>50% along S4.2) and pristine reefs were present. Some habitat degradation has occurred since the 2005 MNCR survey (CS1). All the other transects in the region were markedly degraded (CS7), with low-relief, broken reef material supporting sparse living worms. This is supported by the single beam sonar run that passed through the area, which indicated target heights rarely exceeding 20 cm (Figure 28). The 2015 sidescan results suggest the widespread presence of low-profile seabed material but with larger reef structures to the south of DR02 and north of DR02 to just north of S15. The S15 paired condition transects were undertaken in January 2019 with this in mind, but at this time the reefs were largely broken (>90%) with very few of them reaching 30 cm height (<1%). Transect DR02 passes through an area for which there is limited 2009 sidescan imagery (Figure 29). This shows the presence of large reefs commonly attaining heights of 40 - 50 cm, contrasting with the strongly degraded habitat in 2018.

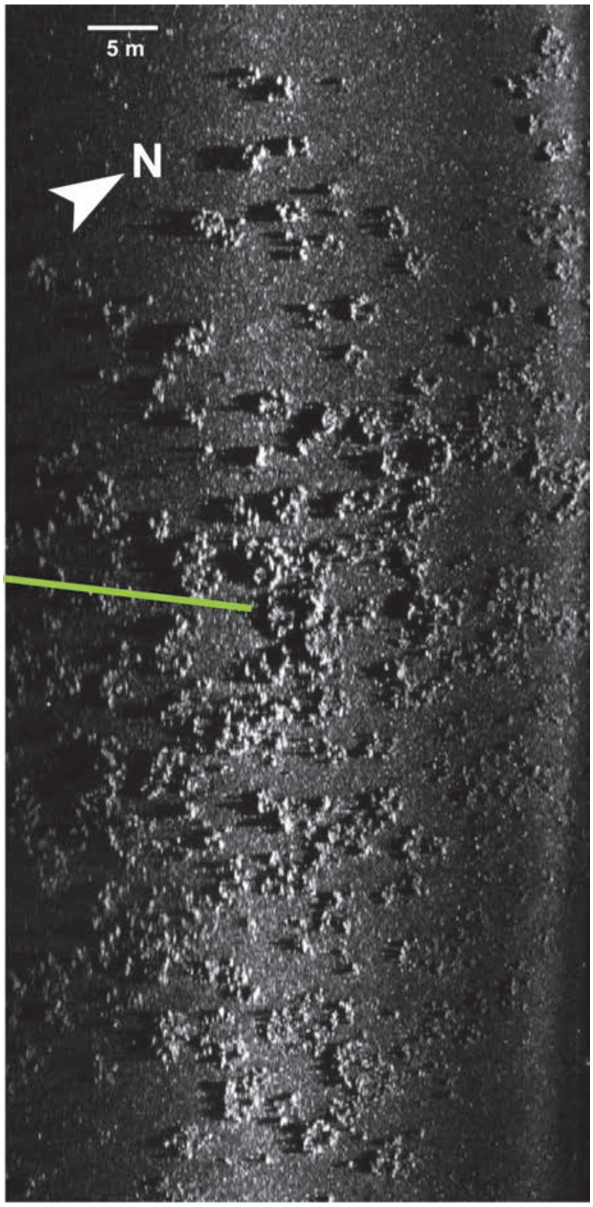

Figure 29. 2009 sidescan sonargram passing through the northern part of transect DR02. Centre of image 56.52270°N 5.334183°W.

In 2015 Tulbure examined a site (KT16) 40 m to the south of DR02 and found dense reef cover, of which 50 - 60% had collapsed but maximum reef heights ranged from 40 - 45 cm, corresponding to the long shadows on the 2015 sonargram. It should be noted that much of the MNCR transect SV03 as well as transect S4.2 appear in Figure 28 to lie within a patch of seabed devoid of reefs according to the 2015 sidescan survey. As suggested by the low correspondence between the patterning on the sonar images from the two adjacent sidescan runs here, it is likely that the georegistration of the mosaicking at this location lacks accuracy. This is also suggested by the lack of agreement with the highly precise single beam sonar results.

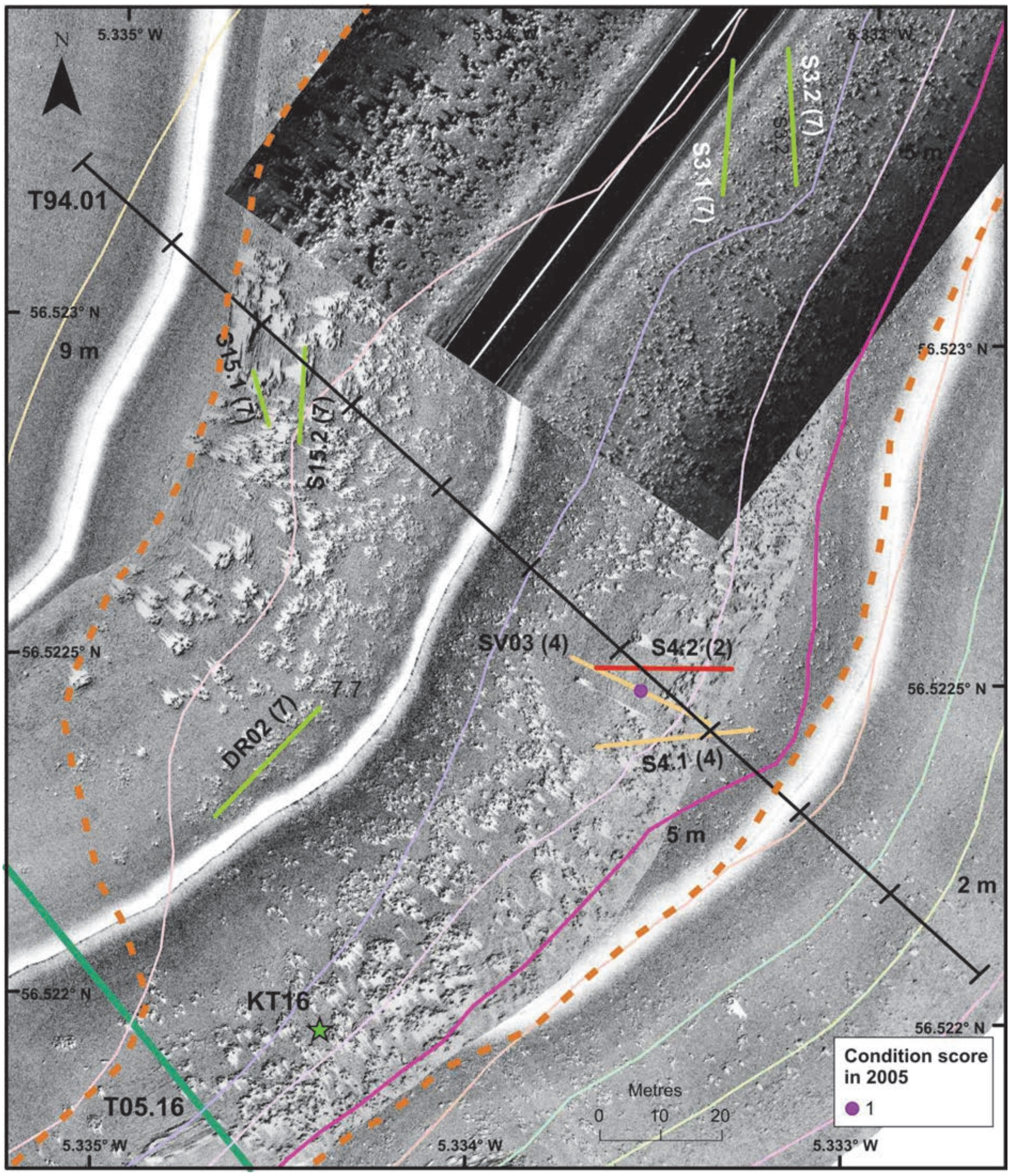

Figure 30. 2015 sidescan sonar mosaic of area in eastern half of Sea Life Centre Bay (box I in Figure 2) overlain with 2009 image (top right) showing location of current and historical survey sites. Pecked orange line highlights margin of putative serpulid reef material.

The 2005 sidescan coverage of the eastern region of Sea Life Centre Bay lacks clarity but detail of the reef material can be clearly discerned on sections of some of the 2009 sonar runs. Part of one such section is overlain on the 2015 imagery in Figure 30. Comparison with Figure 28 reveals that the larger reef targets visible around the S15 transects in 2015 are also evident in 2009, although they are better defined with well-formed ring-reef structures at the time of the earlier survey. Of particular note is the similarity in both years of the seabed texture around the S3 transects. A large area extending to at least 0.5 ha has a sonar signature indicative of dense reef fragments, consistent with the habitat recorded along the S3 transects in 2017. It appears that while some reef fragmentation has taken place since 2015, the process was already probably underway in 2009. No record of reef damage was made along dive transects traversing this region during the 1994 and 2005 surveys. In 1994 large reefs were recorded within every 20 m section of transect T94.01 from 40 - 180 m, spanning a depth range of 4.1 - 8.8 m. In 2005 large reefs were present from 3.8 - 10.5 m depth along transect T05.16 (Figure 30).

South Creagan

The 2017/18 diver transect survey revealed South Creagan Bay to have suffered the greatest degree of habitat degradation. All five transects passed through areas of predominantly broken reef rubble (<10 cm in canopy height, all fragments <16 cm) which supported very sparse living worms (CS8) (Table 9). Similar conditions were recorded along the MNCR transect SV04 in 2014 (section 3.1.2.1) and by Tulbure (2015) in 2015 (site KT2) over a depth range of 4.8 - 5.1 m, where 90 - 98% of the reef material was collapsed and attained maximum heights at the four replicate stations of 4 - 9 cm. The 2015 sidescan imagery (Figure 31) indicates that this level of degradation is characteristic of the embayment as a whole, the mosaic showing a lack of serpulid reef patterning, although ensonification of the area is patchy.

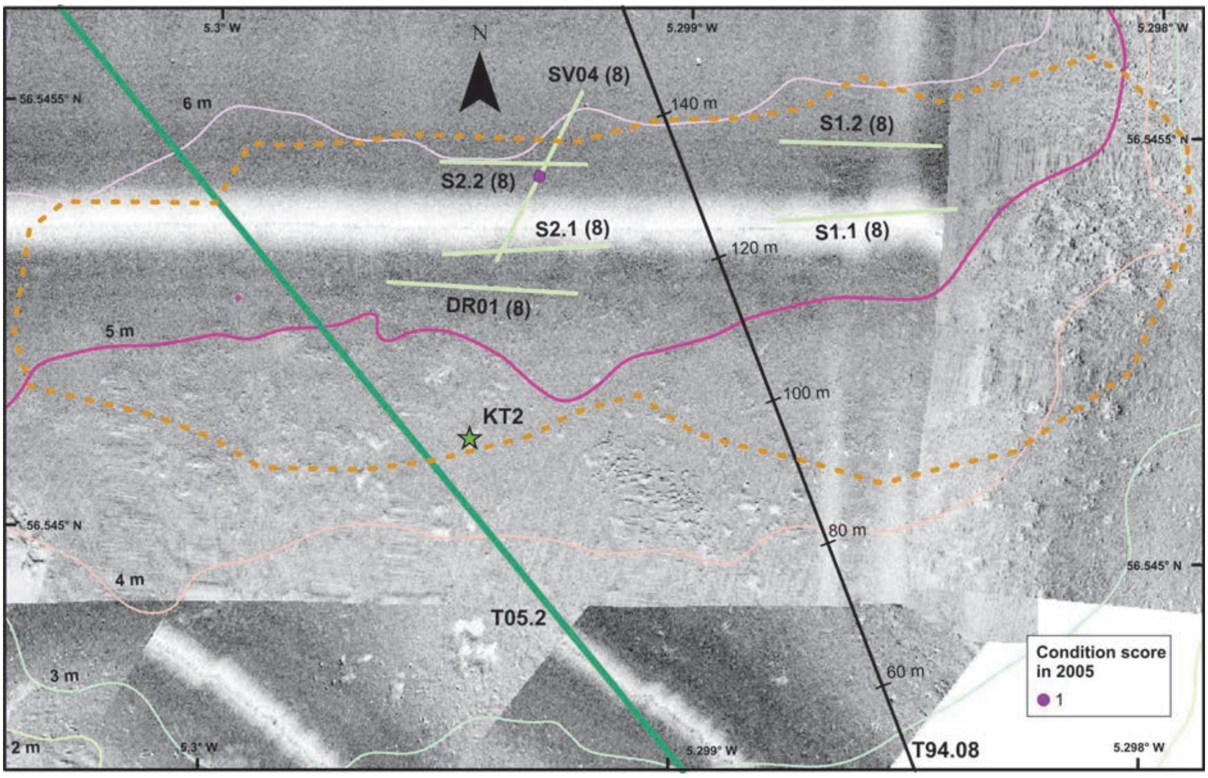

Figure 31. 2015 sidescan sonar mosaic of South Creagan Bay (box J in Figure 2) showing location of current and historical survey sites. No clear serpulid reef patterning, so pecked orange line highlights margin of putative serpulid reef material visible on 2005 sidescan image.

The 2015 - 2018 findings contrast strongly with those from 1994 - 2005. The 2005 sidescan survey (Figure 32) shows a band of distinct reef material, including large reefs, between depths of around 4 - 6 m, consistent with the high condition score (CS1) recorded along the MNCR transect SV04 in the same year (section 3.1.2.1). In 2005 medium and/or large reefs were observed along diver transect T05.2 over a depth range of 3 - 6 m, while in 1994 large reefs were recorded from around 80 m to 140 m along transect T94.08 over a depth range of approximately 4 - 6 m. Damaged reefs were not recorded along either of these transects.

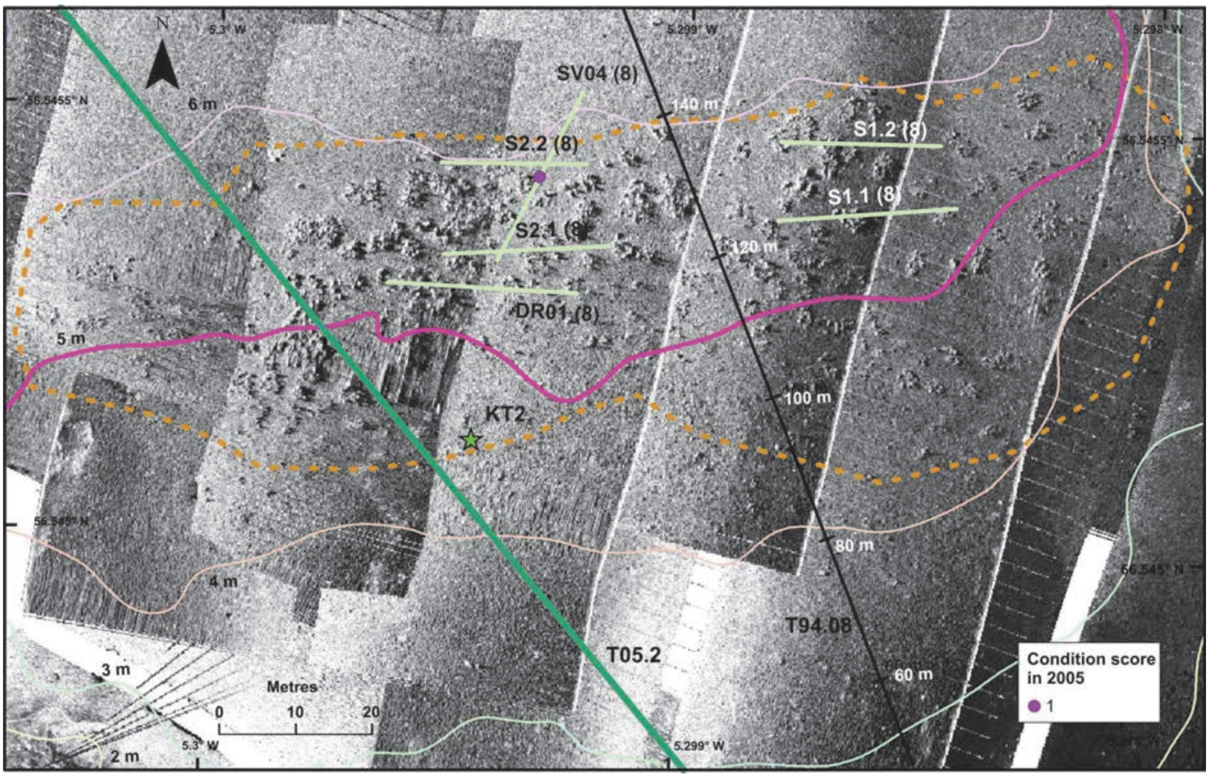

Figure 32. 2005 sidescan sonar mosaic of South Creagan Bay (box J in Figure 2) showing location of current and historical survey sites. Pecked orange line highlights margin of putative serpulid reef material.

Ardnaclach

The *Didemnum vexillum* relocatable transect DR10 was situated at Ardnaclach off the northern shoreline of the lower basin (Figure 33). In 2018 the serpulid reef material here at a depth of 6.5 m consisted very largely of broken fragments (>90%) of low height (<10 cm) occupied by sparse worms (<1%) (CS8). In the same vicinity Tulbure (2015) recorded 95 - 100% collapsed reef material at a depth of around 5 m, also noting the presence of much 'collapsed and broken up reef' extending from a depth of 4.6 m to 7.6 m (site KT77). The only available sidescan data for this area is from 2015 and this shows an indistinct patterning in the same area over a similar depth range (Figure 33), indicative of broad habitat degradation in this region of the loch. The 2005 dive transect T05.77 was located around 60 m east of DR10, where the presence of medium/large reefs was recorded over a depth range of 2.7 - 8.4 m, although only attaining 'moderate density' at a depth of around 6.4 m. No damaged reefs were noted.

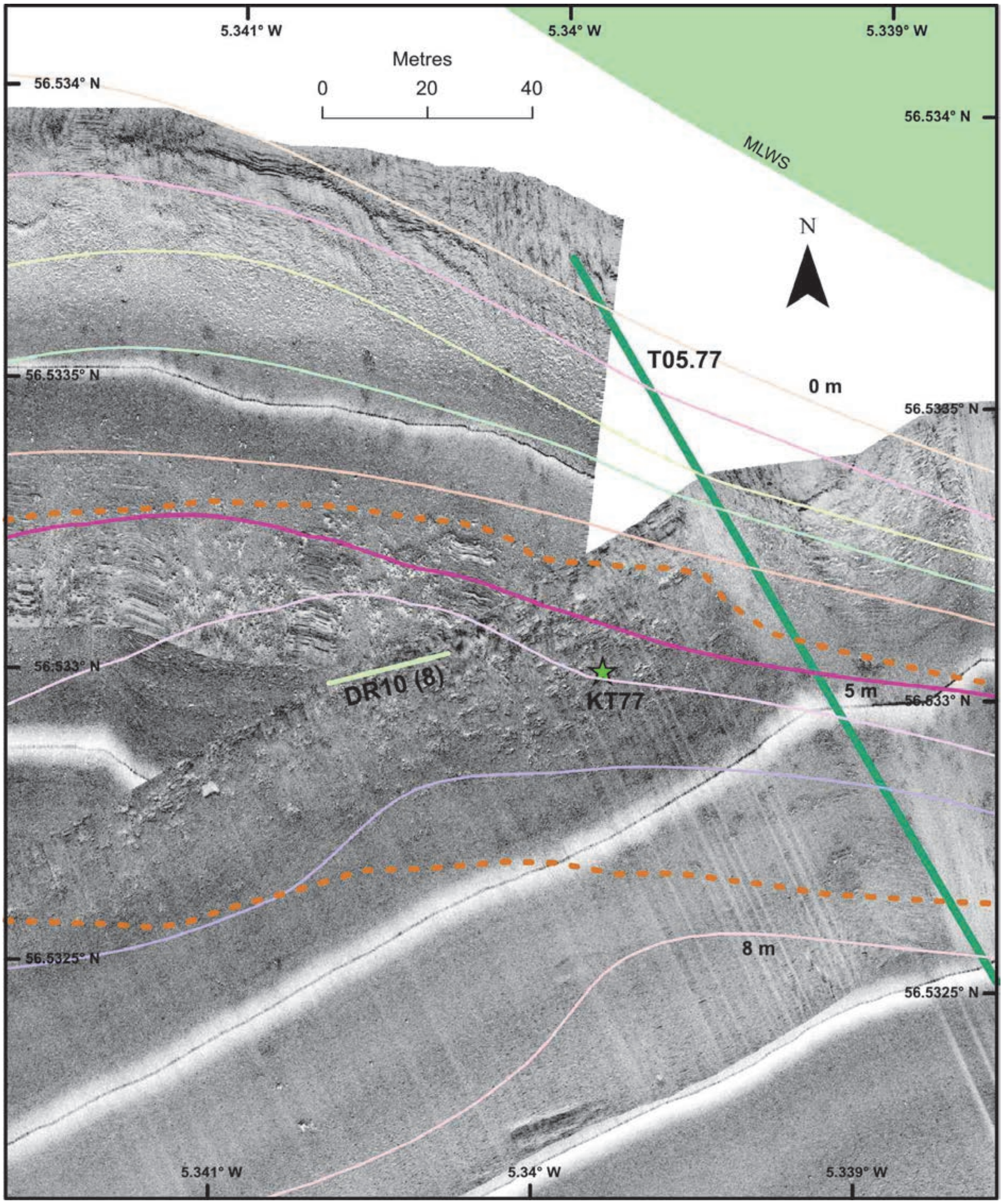

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Figure 33. 2015 sidescan sonar mosaic of area off Ardnaclach, northern coastline (box K in Figure 2) showing location of current and historical survey sites. Pecked orange line highlights margin of putative serpulid reef material.

Upper basin

The results for the reef condition zigzag dive transect sites in the upper basin of Loch Creran are presented in detail in Table 1.5 (Annex 5) and summarised in Table 10. Analysis of these data to derive reliable indications of reef condition is limited by the paucity of reef material observed throughout the upper basin (<1% cover). The 1994 survey of the upper basin (Moore, 1996) recorded similar levels of coverage, with only one of the eight transects and one of the total of 53 transect sections (each of 20 m length) exceeding a coverage of 1% (viz. 1 - 5%). This does not imply that coverage has not changed as the 2018 survey recorded maximum coverage within an area of approximately 5 x 5 m in an attempt to confine recording to the region of the serpulid belt, as this is narrow in the upper basin, due probably in part to the steep inshore seabed profile compared to that in the rich serpulid reef regions of the lower basin. The 1994 survey 20 m transect sections (over which the coverage values were assessed) traversed a much greater depth range than the 2018 measurement plots and so are likely to underestimate maximum coverage.

Table 10. Serpulid reef condition parameters recorded for the 2018 zigzag transect dives in the upper basin of Loch Creran.

Site	**% cover**	**% broken**	**% occupied**	**Canopy height (cm)**	**Maximum height (cm)**	**Individual tubes**	**Small reefs**	**Medium reefs**	**Large reefs**
S94	<1	50-90	>50	<10	12	YES	YES	NO	NO
S97	<1	<50	>50	<10	13	YES	YES	NO	NO
S99	<1	<50	>50	<10	10	YES	YES	NO	NO
S106	<1	50-90	>50	<10	20	YES	YES	YES	NO
S107	<1	<50	>50	<10	6	YES	YES	NO	NO
S109	<1	100	0-1	<10	3	YES	NO	NO	NO

The 2018 figures for the proportion of broken reef material and occupied tubes (Table 10) suggest a generally higher level of reef condition than for much of the lower basin, but caution should be exercised in view of the very small amount of serpulid material encountered. It is probably more instructive to consider the size of reefs recorded. In 1994 medium reefs were recorded along 3 of the 8 upper basin transects, a similar proportion to that observed in 2005 (6 of 18 transects). In 2018 medium reefs were only present at one of the 6 sites where they were recorded in 2005. Large reefs were unrecorded in the upper basin in 1994 but were present along 3 of the 18 2005 transects but at none of these 3 sites in 2018. The zigzag nature of the 2018 survey maximises the likelihood of encountering reef material compared to previous surveys. It seems likely that there has been a temporal reduction in reef size in the upper basin, at least between 2005 and 2018. While sparsely scattered, small, dead reef fragments were observed at some upper basin sites, there was no evidence in 2018 of the collapsed remains of large reefs, so characteristic of much of the lower basin.

3.1.3 Serpulid reef colonisation substrates

The experimental serpulid colonisation substrates established in Loch Creran by Cook (2016) in March 2012 were examined in June 2017. At Cook's main study site in Sea Life Centre Bay successful colonisation and subsequent survival of *Serpula vermicularis* occurred over this period on four of the five treatments (Table 11). Clumps of up to 30 tubes were recorded (Table 1.7, Annex 1) reaching heights of up to 17 cm and covering up to 20% of the substrate (Table 11, Figure 34). In view of non-normality of the data, analyses were carried out on ranked data. Analysis of variance and subsequent multiple comparisons based on the ranked data (for justification of this approach see Conover & Iman, 1981) revealed significantly greater reef height and coverage on cobbles and scallops in large mesh bags ($p<0.05$, Table 11).

Analysis of the results of colonisation of the scallops in large bags treatment deployed at a total of five sites throughout Loch Creran showed significant geographical variation in both reef height and cover (Table 12). The Sea Life Centre Bay and Rubha Mór sites had the highest reef heights and coverage, although the mean ranked height at Rubha Mór was not significantly greater than either the Upper Basin or Kelco sites and the coverage at the Sea Life Centre and Rubha Mór sites was only significantly greater than the Mussel farm site. There was little development of tube clumps at the mussel farm site (maximum height 4 cm, maximum cover 5%) and greatest development at the Sea Life Centre site (maximum height 17 cm, maximum cover 20%). When the above statistical testing was repeated on the median values of height and cover using the non-parametric Kruskal-Wallis and Dunn's paired comparisons tests the outcomes were unchanged.

Table 11. Serpulid reef maximum clump height and percentage cover of five experimental colonisation substrates (treatments) at the main study site in Sea Life Centre Bay, Loch Creran. Data includes means and range of six replicates of each treatment. Mean ranked values of treatments sharing the same statistical group code are not significantly different.

Treatment	**Max. clump height (cm)**			**% reef cover**		
	Mean	**Range**	**Statistical group**	**Mean**	**Range**	**Statistical group**
Boulder	0.8	0 - 2.5	b	0.3	0 - 2	b
Cobbles large bag	11.5	9 - 13	a	15.3	10 - 20	a
Pile of scallop shell	0.0	0 - 0	b	0.0	0 - 0	b
Scallops small bag	4.4	0 - 9	b	1.8	0 - 5	b
Scallop shell large bag	12.0	7 - 17	a	10.7	2 - 20	a

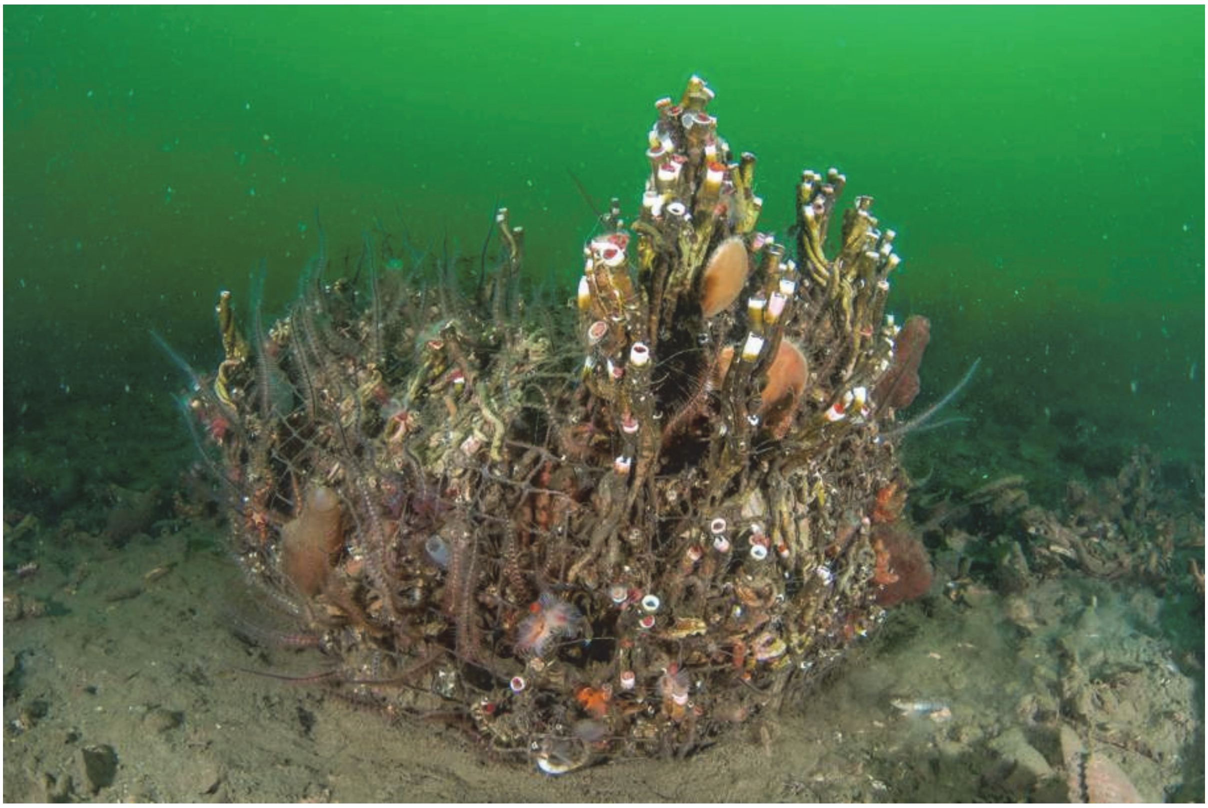

Figure 34. Reef development on experimental colonisation substrate (scallop shell large bag) in Sea Life Centre Bay, May 2017.

Table 12. Serpulid reef maximum clump height and percentage cover of colonisation substrate of scallops in large bag at five sites in Loch Creran. Data includes means and range of five - six replicates of each treatment. Mean ranked values for sites sharing the same statistical group code are not significantly different.

Site	**Max. clump height (cm)**			**% reef cover**		
	Mean	**Range**	**Statistical group**	**Mean**	**Range**	**Statistical group**
Main site (Sea Life Centre Bay)	12.0	7 - 17	a	10.7	2 - 20	a
Rubha Mór	7.8	6 - 9	ab	10.8	5 - 20	a
Kelco	4.7	0 - 8	bc	3.3	<1 - 10	ab
Mussel farm	1.3	0 - 4	c	0.8	0 - 5	b
Upper Basin	3.4	0 - 14	bc	4.0	0 - 15	ab

3.2 Horse mussel beds

3.2.1 Density

Comparisons of the density of *Modiolus* along transects examined in both the current study and in 2005 (Moore *et al*., 2006) are complicated by differences in methodology. Detailed, quantitative surveying involving counts of *Modiolus* and counts of cross-string intersection hits of *Modiolus* within quadrats was only carried out along two transects in 2018. A rapid measure of *Modiolus* density (SACFOR abundance) replaced this approach along the other transects in 2018. In 2005 only cross-string quadrat hits were recorded along all transects.

The use of cross-strung quadrats was designed to derive a measure of percentage cover of the seabed by *Modiolus*; the number of hits will underestimate the abundance. To facilitate temporal comparisons the relationship between density measures derived from cross strung quadrats and from complete counts of *Modiolus* individuals within quadrats was examined using the data derived from the 100 quadrats employed at a total of 10 sites along transects MM01 and MM05 in 2018.

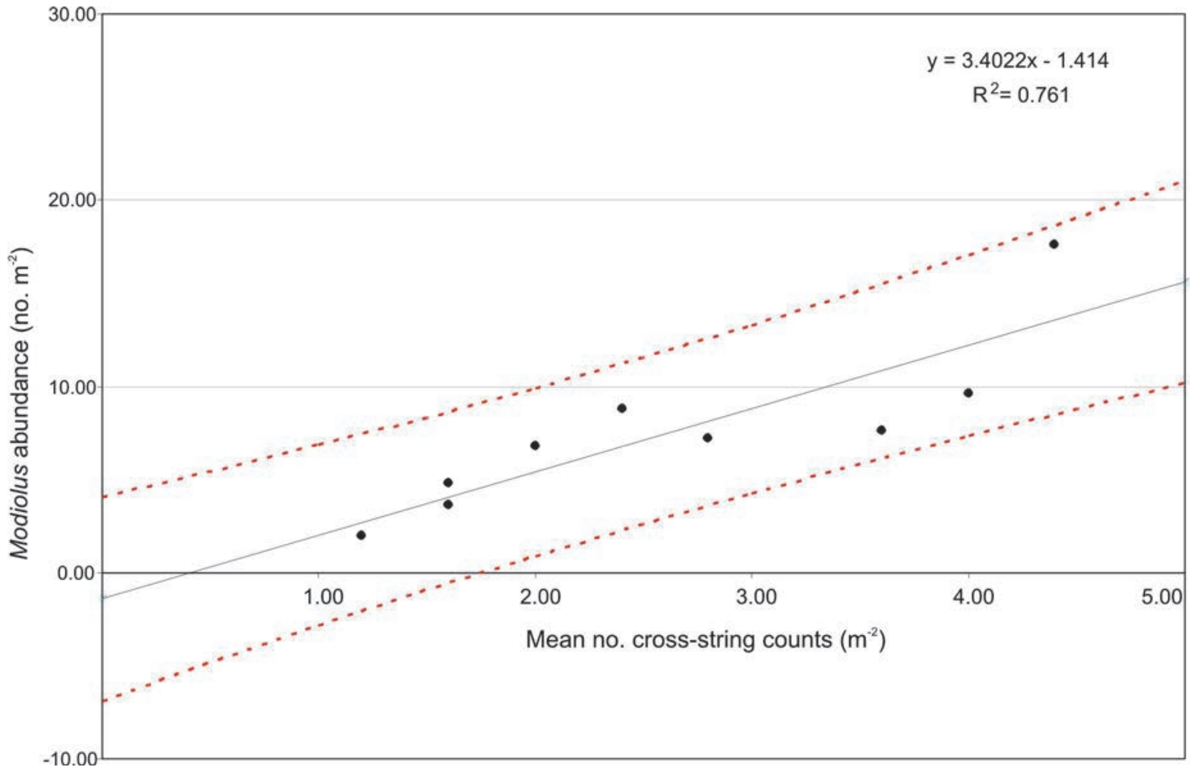

Figure 35. Relationship between the density of Modiolus modiolus and mean number of cross-string hits of Modiolus individuals per m² within ten replicate strung quadrats at ten sites. Linear regression line shown with 90% confidence band for predicted y vales (red dashed lines).

Figure 35 shows for each site the mean number of cross-string hits per m^2 and *Modiolus* abundance per m^2, with the fitted linear regression line. There is a strong relationship between the two variables ($r = 0.8724$; ANOVA, $p = 0.001$). Also shown in the Figure is the 90% confidence band within which one can be certain that 90% of y values (*Modiolus* abundance) predicted from the equation will lie. From the graph it can be seen that for a mean cross-string count of 2 m^{-2} the range of predicted *Modiolus* abundances will be approximately 1 - 10 m^{-2} and for a cross-string count of 5 the range of predicted values will be approximately 10 - 20 m^{-2} (at the 90% confidence level). This permits a translation of cross-string counts into SACFOR abundance values. Cross-string counts <2 m^{-2} span an abundance range of 0 - 10 m^{-2} (SACFOR N - C), counts from 2 - 5 span a range of 1 - 20 m^{-2} (SACFOR C - A) and counts >5 predict abundances >10 m^{-2} (SACFOR A).

Modiolus SACFOR abundances recorded along all eight transects worked in 2018 are given in Table 2.1 (Annex 2) and illustrated for upper basin transects in Figure 36.

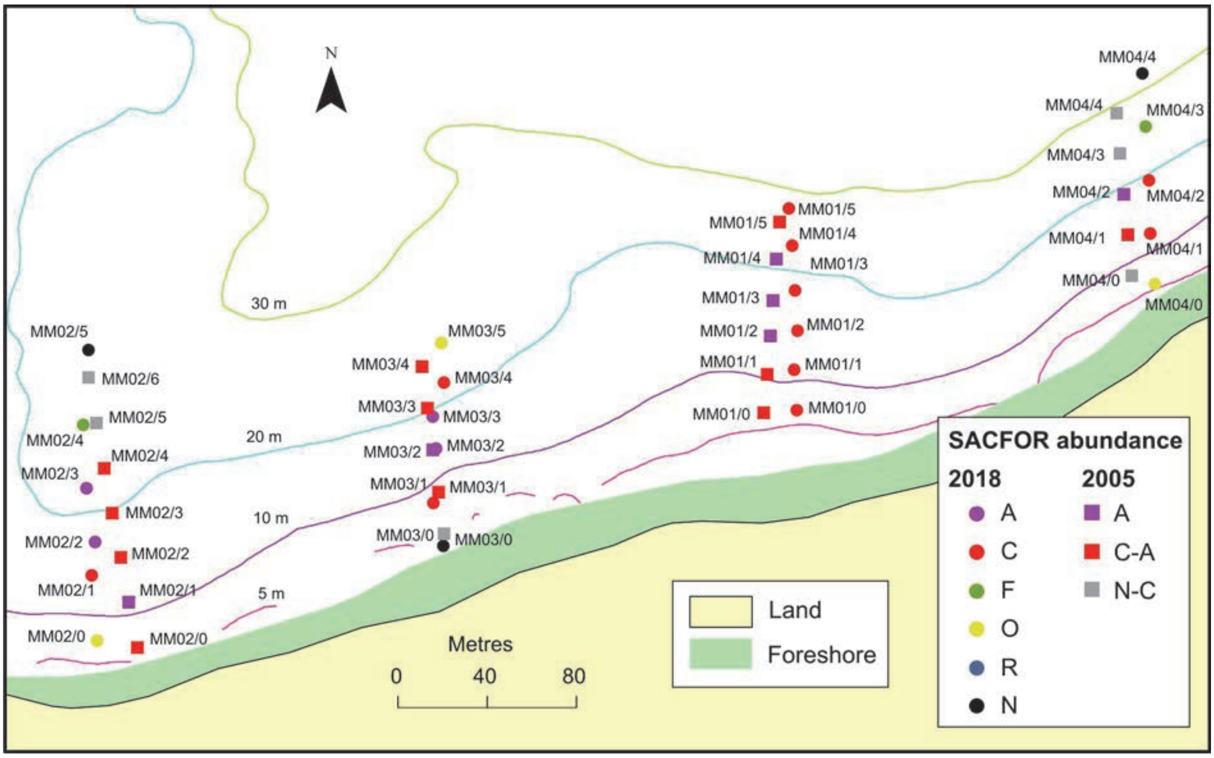

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Figure 36. Modiolus SACFOR values along four transects in the upper basin of Loch Creran in 2018 and 2005 (Moore et al., 2006). 2005 values derived from cross-string quadrat counts (see text).

Although there are slight differences in the location of the 2005 and 2018 transects some indications of temporal abundance changes are evident. Along transect MM01 *Modiolus* is at least common at all stations in both years; however, it was abundant at three stations in 2005 but at no stations in 2018. More detailed analysis of this transect is given later in this section. Along transect MM02 *Modiolus* abundances are similar for most neighbouring stations in both years, apart from the shallowest MM02/0 where it was common - abundant in 2005 but occasional in 2018. These stations were at a similar depth (5.7 - 6.5 m). Along transects MM03 and MM04 there is no clear evidence of temporal change. There is an apparent decline from abundant to common at the MM04/2 stations but these were located at different depths (15.4 and 18.5 m).

Modiolus was common or abundant at all four stations along transect MM05 in both years (Figure 37). However, reductions from abundant to common were recorded at the two deeper stations (8.5 - 10.5 m depth) in 2018. More detailed analysis of temporal change along this transect is provided below.

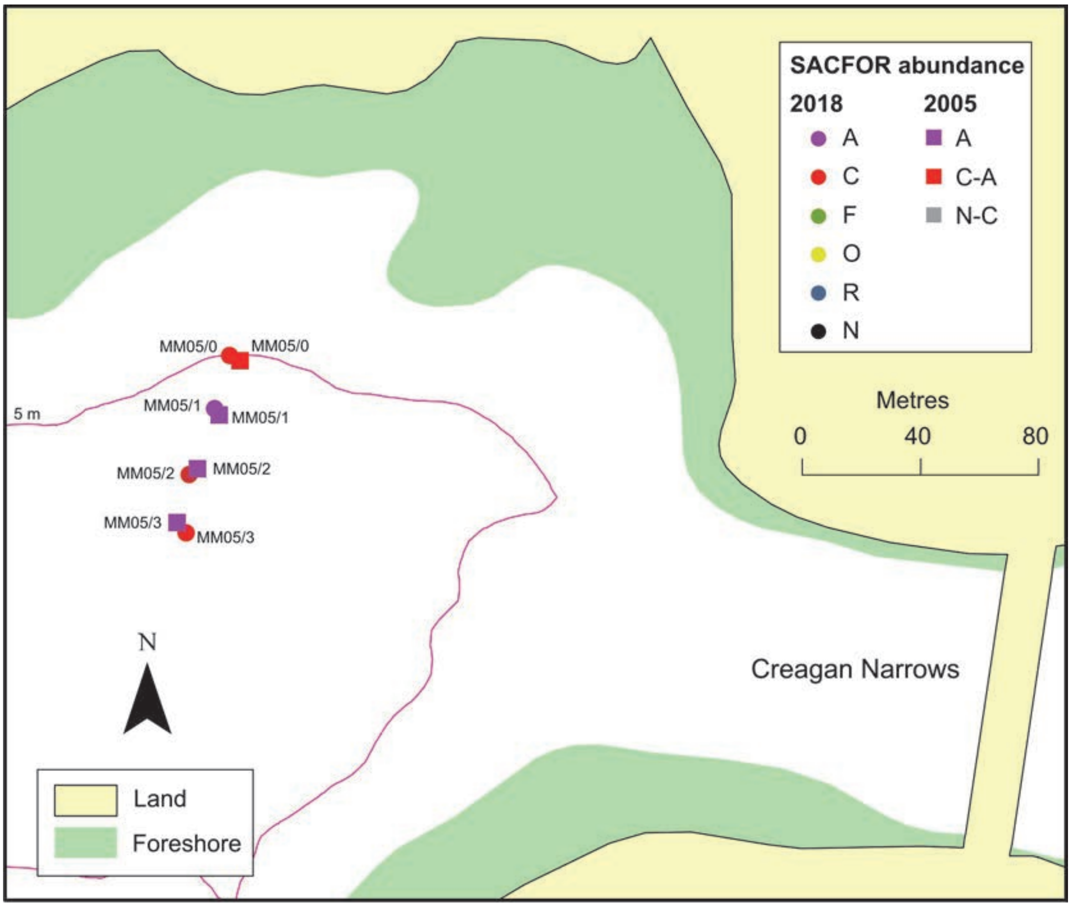

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Figure 37. Modiolus SACFOR values along transect MM05 off Creagan in 2018 and 2005 (Moore et al., 2006). 2005 values derived from cross-string quadrat counts (see text).

In 2018 *Modiolus* was absent at all stations along transect MM06 off Druim Cairine at the mouth of the loch, except at station MM06/4 where it was rare (Figure 38). It was recorded at five of the six stations in 2005, with two records of common and one of abundant. In view of the record of superabundant *Modiolus* along the 2005 serpulid survey transect T05.52 in the same locality (Moore *et al*., 2006), an additional *Modiolus* transect (MM08) was worked in 2018 along the line of T05.52 (Figure 38). *Modiolus* was absent at all stations in 2018, apart from one where it was common. In 2005, in addition to the maximum SACFOR record of superabundant, the surveyor noted 'extensive *Modiolus* to 14 m and beyond'. There has been a considerable reduction in abundance and spatial extent of the *Modiolus* population at this locality.

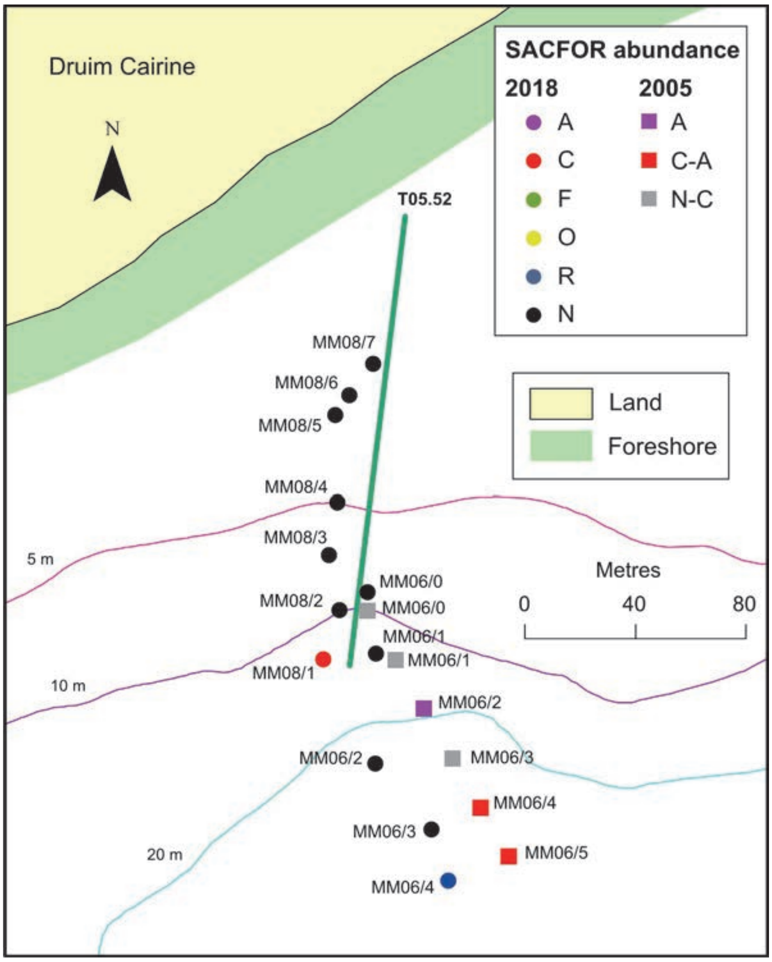

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Figure 38. Modiolus SACFOR values along transect MM06 at the mouth of Loch Creran in 2018 and 2005 (Moore et al., 2006). 2005 values derived from cross-string quadrat counts (see text). Also shown are SACFOR values along transect MM08 in 2018 and the location of the 2005 serpulid reef survey transect T05.52.

Modiolus was present at five of the eight stations along transect MM07 off North Shian in 2018, being common - abundant at three of them from 12 - 14 m depth (Figure 39). *Modiolus* was also recorded at five of the eight stations worked in 2005, with SACFOR values of common - abundant at stations close to those in 2018 where the same abundance category was recorded. There is no indication of a temporal change in abundance at this location.

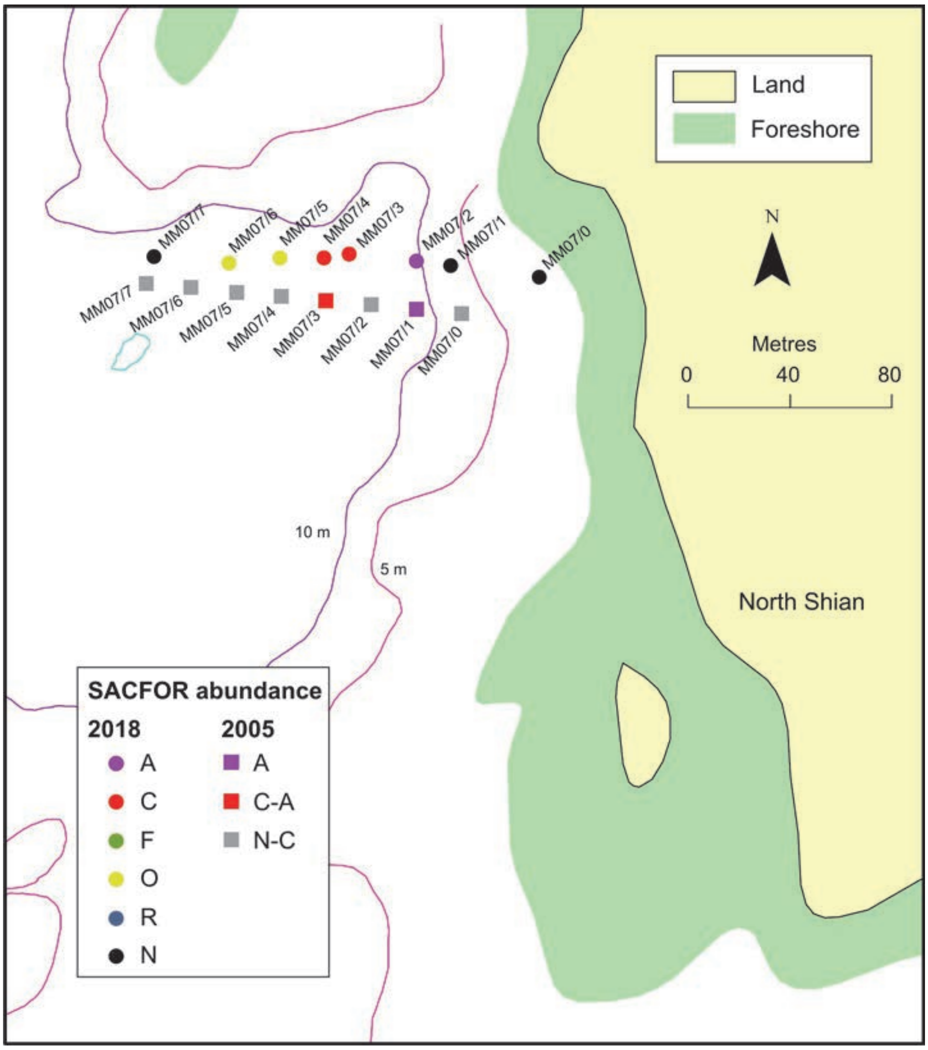

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Figure 39. Modiolus SACFOR values along transect MM07 off North Shian near the mouth of Loch Creran in 2018 and 2005 (Moore et al., 2006). 2005 values derived from cross-string quadrat counts (see text).

In 2018 more detailed *Modiolus* density data were collected along transect MM01 (which showed the highest densities amongst the upper basin transects in 2005) and transect MM05 (which showed the highest densities recorded along all transects in 2005). Raw data collected along the two transects, in terms of the number of cross-string *Modiolus* hits and total number of *Modiolus* in ten quadrats at each station, are given in Tables 2.2 and 2.3 (Annex 2). From these two parameters two density measures can be derived, respectively percentage cover by *Modiolus* and abundance as no. *Modiolus* m^{-2}. Mean values for these measures are summarised in Table 13.

Depths at corresponding stations between the two years were very close (≤0.3 m - Table 13). *Modiolus* abundance was only measured in 2018, so no temporal comparisons are possible. All abundances lie within the SACFOR range of common, with the exception of an abundant record along transect MM05 (see Figures 36, 37).

Table 13. Density measures for Modiolus modiolus in 10 replicate quadrats at stations along transects MM01 and MM05 in 2018 and 2005 (Moore et al., 2006). No. hits are the total number of cross-string intersections (out of 160) overlying live Modiolus within ten quadrats, from which % cover is derived. Mean abundance of live Modiolus within replicates (only available for 2018) and station depth also shown.

Station	**Depth (m)**		**No. hits**		**Mean % cover**		**Mean abundance (no. m^{-2})**
	2018	**2005**	**2018**	**2005**	**2018**	**2005**	**2018**
MM01/0	5.5	5.5	3	3	1.88	1.88	2
MM01/1	8.4	8.4	4	6	2.50	3.75	3.6
MM01/2	11.5	11.5	4	17	2.50	10.63	4.8
MM01/3	15.5	15.5	7	22	4.38	13.75	7.2
MM01/4	20.9	20.9	9	18	5.63	11.25	7.6
MM01/5	26.8	26.8	4	5	2.50	3.13	3.6
MM05/0	5.2	5.2	6	5	3.75	3.13	8.8
MM05/1	7.1	7.0	11	54	6.88	33.75	17.6
MM05/2	8.5	8.6	10	49	6.25	30.63	9.6
MM05/3	10.2	10.5	5	43	3.13	26.88	6.8

The statisticians Thomas and New (2006) discussed and applied various approaches to the statistical analysis of cross-string quadrat data in their examination of temporal change in percentage cover (percentage presence *sensu* Thomas & New (2006)) of *Modiolus* in Loch Alsh, recommending the adoption of a one sample t-test for the comparison of two surveys. This involves determination of the mean cross-string hit count for each station and derivation of the temporal difference in mean counts for each station. The t-test compares these actual differences with a null hypothesis of zero difference. Although the cross-string counts, which are constrained between 0 and 16, could not be assumed to approximate a normal distribution, due to the central limit theorem there should not be a problem in treating the differences between mean counts as having a normal distribution, and this was borne out by their analyses (Thomas & New, 2006). The mean percentage cover for transect MM01 as a whole is 7.40% in 2005 declining to 3.23% in 2018. Using the one sample t-test this reduction is at the margin of significance ($t = 2.5$, $p = 0.054$). Because of the low power of the one sample t-test used on *Modiolus* cross-string hit data, Thomas and New (2006) recommended employing a minimum of 20 stations. Only six stations were available along transect MM01.

An alternative approach to the t-test is the use of the Mack-Skillings test (a non-parametric, two-way ANOVA equivalent) (Hollander & Wolf, 1999). This was used to test for a temporal effect on cross-string counts blocked by station, and revealed a significant difference between years ($MS = 8.4$, $p = 0.004$). As the frequency distribution of counts is similar in terms of spread and shape in both years, it can be concluded that there has been a significant reduction in the median value for *Modiolus* percentage cover (from 6.25% to 0.00%) along transect MM01 between the years 2005 and 2018.

The raw cross-string hits data (Table 13) reveal a marked reduction in percentage cover at three of the four stations along transect MM05. This reduction is from a mean of 37.75% in 2005 to 8.00% in 2018 over the transect as a whole. Due to the small number of stations the one sample t-test only indicates borderline significance ($t = 2.9$, $p = 0.063$). The Mack-Skillings test reveals a strongly significant temporal change in the distribution of percentage cover values (MS = 27.6, p = <0.001), but as there are marked differences in the shape and spread of the frequency distribution of counts in the two years, we cannot infer temporal change in the median or mean. However, chi-squared tests confirm the reduction in percent cover at three of the four stations (χ^2>31, p < 0.001 in all cases).

3.2.2 Distribution

The results of the spot dive survey of *Modiolus* distribution in the upper basin of Loch Creran are provided in Tables 2.4 and 2.5 (Annex 2) and the results of the dropdown video survey in Tables 2.6 and 2.7 (Annex 2). The results have been collated with those of the *Modiolus* transect survey and *Modiolus* data from the *Limaria* drift dive survey to produce maps of the distribution of horse mussel beds in the loch.

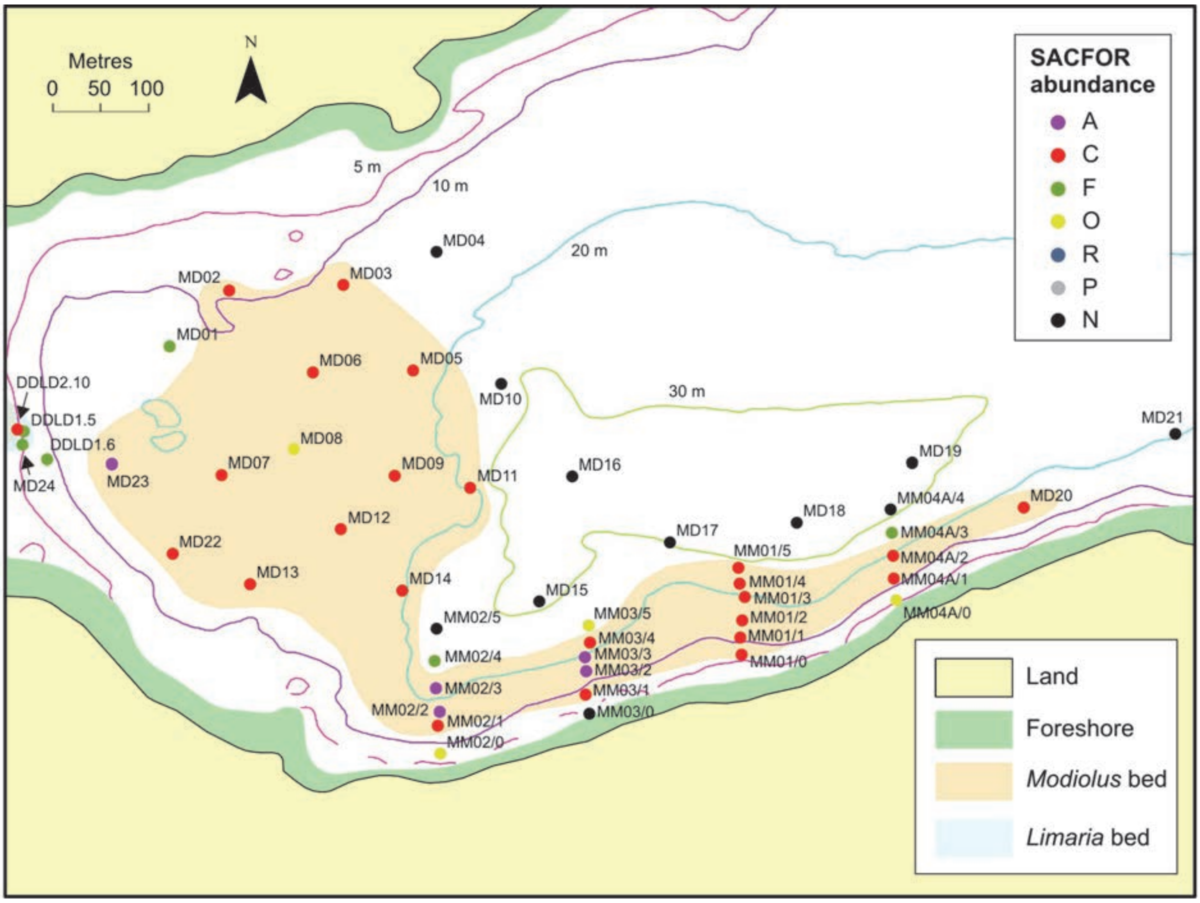

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Figure 40. Distribution of the upper basin Modiolus bed, showing Modiolus SACFOR abundance at all survey stations.

The largest bed is located in an area of weak tidal currents in the upper basin of the loch, extending over an area of 16.31 ha (Figure 40) on a substrate of mixed muddy sand with shells, gravel and pebbles over a depth range of 5 - 27 m. Population density is fairly low for a *Modiolus* bed with scattered individuals and small clumps attaining a SACFOR density of common over most of the area, with patches of abundant and sparse mussels locally. The habitat can be referred to the biotope **SS.SBR.Mus.Mod.HAs** and is described in more detail in section 3.2.3.

The East Creagan bed lies in the eastern region of Creagan Narrows and its approaches, where tidal currents run at up to 5 knots (Figure 41). The bed has been inadequately surveyed but the limited data available suggest it has a depth range of around 1 - 4 m and is of the order of 4.3 ha in extent. *Modiolus* was found to attain high densities within Creagan Narrows, embedded within a substrate of pebbles, gravel and shells, but declining with reducing current strength eastwards and becoming associated with the byssal turf of *Limaria hians*. No measurements of shells were taken, but the visual impression was of a population of relatively small, clean mussels (Figure 42), in contrast to those populating the Upper Basin bed (see section 3.2.4). The East Creagan bed is ascribable to the biotope **SS.SBR.Mus.ModT**.

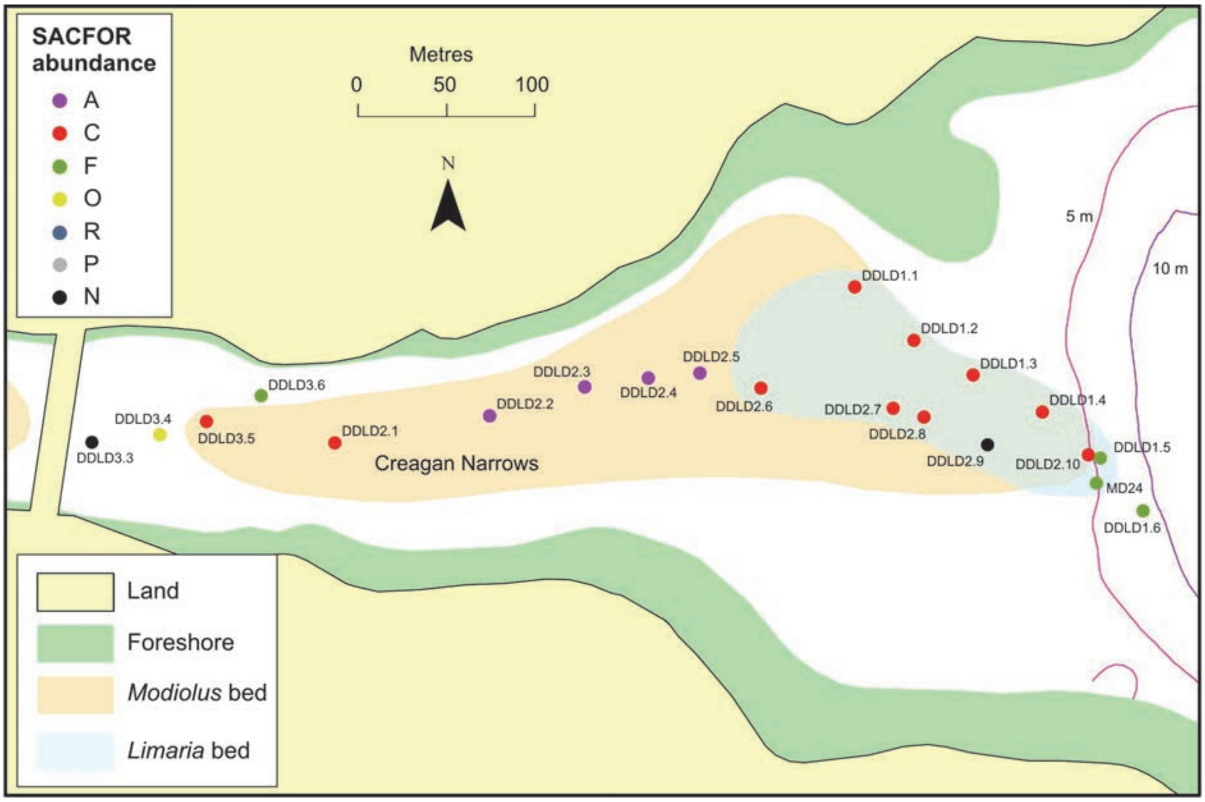

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Figure 41. Distribution of the East Creagan Modiolus and Limaria beds, showing Modiolus SACFOR abundance at all survey stations.

Figure 42. Video screen grab of Modiolus bed in the vicinity of station DDLD2.3, Creagan Narrows.

The West Creagan bed was located west of the Creagan bridge, largely in the western approaches to Creagan Narrows on a substrate of coarse sand with gravel, pebbles and shell material over a depth range of 2 - 11 m (Figure 43). Most of the bed supported a cover of superabundant *Ophiothrix fragilis* (Figure 49) and, in much of the less tide-swept region, nest material of *Limaria hians*. Apart from on its eastern side, the boundary of the bed cannot be accurately delineated, as surveying focussed on the *Limaria* bed here. The polygon in Figure 43, showing the distribution of the biotope **SS.SBR.Mus.ModT**, is very largely based on the current survey but takes account of sparse bed records from 2012 (Moore *et al*., 2013). This provides an extent estimate of 3.50 ha, although the bed may extend significantly farther south than depicted.

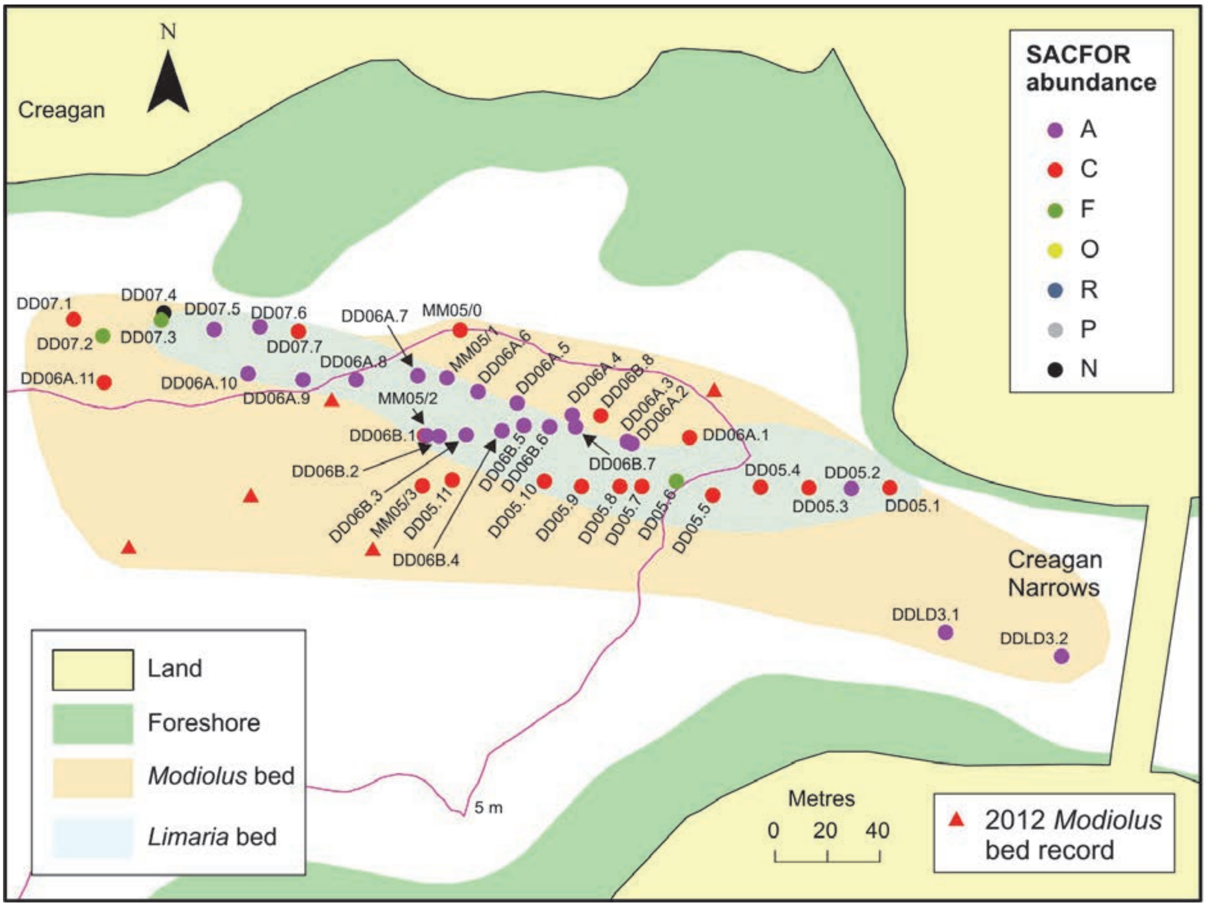

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Figure 43. Distribution of the West Creagan Modiolus and Limaria beds, showing Modiolus SACFOR abundance at all survey stations. Modiolus bed records from 2012 (Moore et al., 2013) also shown.

Modiolus bed patches were scattered in the tide-swept channel between North and South Shian near the entrance to the loch (Figure 44) occupying a total area of around 5.89 ha over a depth range of 6 - 26 m. The substrate was predominantly shelly sand or gravel with pebbles and cobbles. *Modiolus* was scattered over the *Limaria* bed here in low numbers but formed bed patches along the periphery of the *Limaria* bed, both in areas of stronger currents in the north and weaker currents in the south. All pockets can be referred to the biotope **SS.SBR.Mus.ModT**, of which they are fairly poor examples with low *Modiolus* densities. It is possible that density may have been underestimated in places, with mussels being obscured by byssal turf, but it is believed that Figure 44 provides a reasonable interpretation of the overall pattern of the spatial relationship between *Modiolus* and *Limaria* beds at this location. However, the survey programme here was aimed primarily at examining *Limaria* distribution and so the spatial extent of *Modiolus* beds in the area is probably underestimated, particularly in the north.

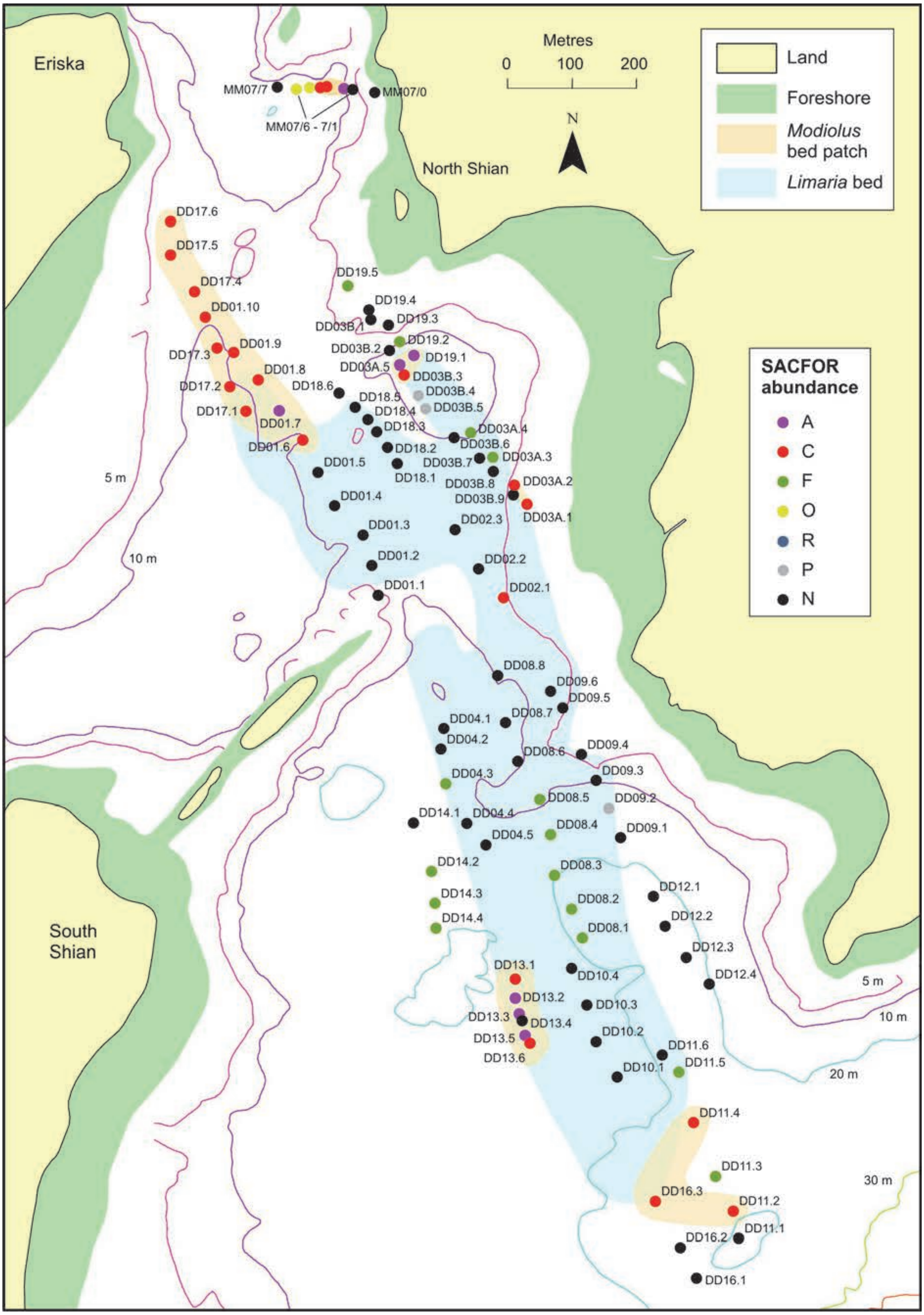

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Figure 44. Distribution of the Shian Modiolus and Limaria beds, showing Modiolus SACFOR abundance at all survey stations.

3.2.3 MNCR phase 2 survey (MM01/3A)

The site was located midway along transect MM01 in the upper basin of the loch at a depth of 12 - 15 m (Figure 4). The substrate consisted of poorly mixed, shelly, muddy sand (20%) with gravel and small pebbles (40%) and dead *Modiolus* shells (40%). Live *Modiolus* was scattered over the area as individuals and in the form of small clumps (common overall but abundant in patches). Representative images of the habitat at this site are shown in Figure 45. The shell material supported a sessile epibiota dominated by *Balanus balanus*, *Pododesmus patelliformis* and ascidians such as *Dendrodoa grossularia*, whilst the vagile fauna of the area was dominated by *Munida rugosa*, *Liocarcinus depurator*, *Asterias rubens*, *Ophiothrix fragilis*, *Aequipecten opercularis* and *Antedon bifida* (Table 2.8, Annex 2). In all 61 taxa were recorded, very similar to the total recorded at the same site in 1999 (62 - Mair *et al*., 2000) and 2005 (58 - Moore *et al*., 2006). Species composition and abundance were also similar for these surveys, although *Modiolus modiolus* was recorded at a higher density level in 1999 and 2005 (abundant) than in 2017 (common). The site is referable to the biotope **SS.SBR.Mod.HAs**., although it has affinities with **SS.SBR.ModCvar**.

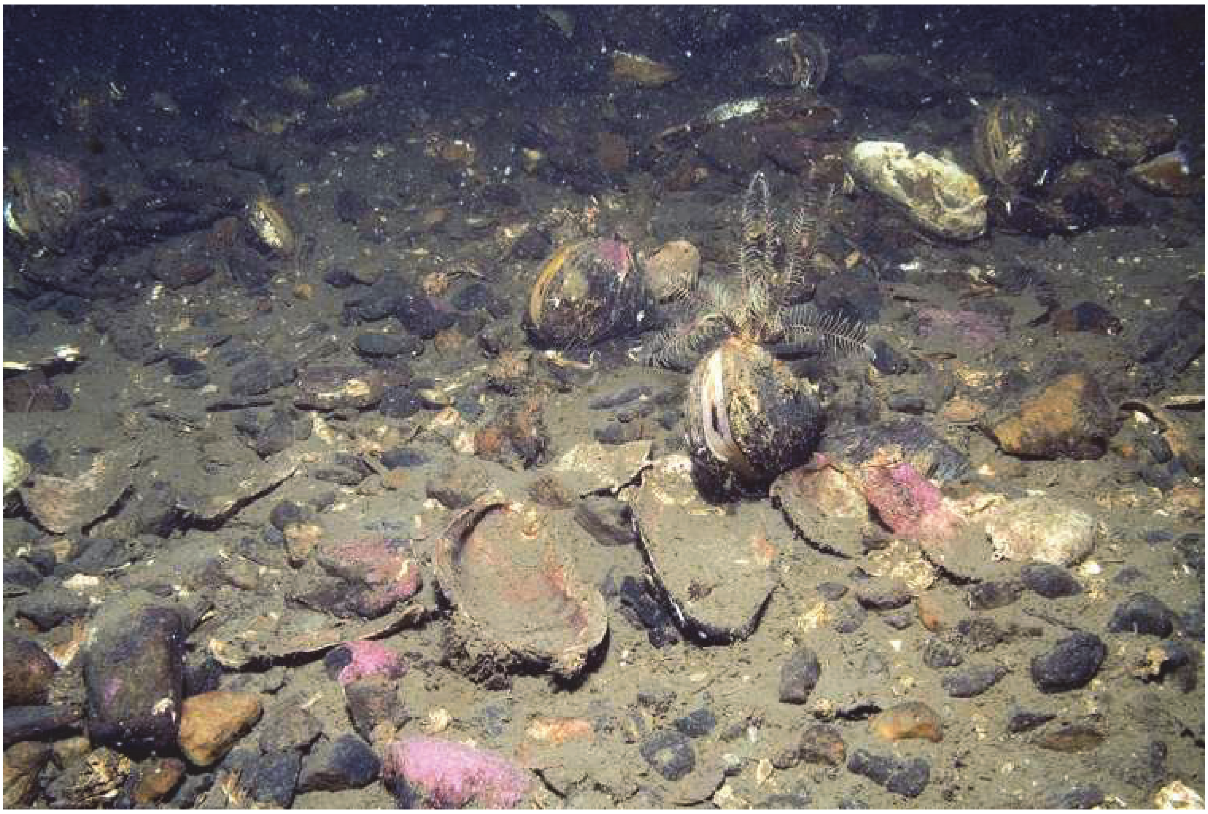

Figure 45. Representative images of the Modiolus bed habitat at MNCR phase 2 site MM01/3A.

Table 14. The abundance (N) and diversity of fauna in four clumps of <u>Modiolus modiolus</u> at site MM01/3A in the current study (2017) and in 2005 (Moore et al., 2006). Diversity values include no. taxa (S^1 - S^4), Pielou evenness index (J') and Shannon-Wiener function using log_2 (H'_2) and log_e (H'_e). p value given for t test of means from both years.

	2005					**2017**					
	Replicate					**Replicate**					
	1	**2**	**3**	**4**	**Mean**	**1**	**2**	**3**	**4**	**Mean**	***p***
S^1 (raw data)	91	99	107	104	100.25	105	83	109	112	102.25	0.797
S^2 (excluding non-overlapping taxa)	88	95	103	98	96.00	99	78	104	103	96.00	1.000
S^4 (excluding above , aggregate and binary taxa)	71	76	83	75	76.25	78	66	86	87	79.25	0.602
N	369	449	467	491	444.00	318	276	372	403	342.25	0.039
J'	0.815	0.789	0.828	0.836	0.817	0.878	0.881	0.865	0.858	0.870	0.004
H'_e	3.476	3.418	3.660	3.610	3.541	3.825	3.690	3.851	3.830	3.799	
H'_2	5.014	4.931	5.281	5.208	5.109	5.518	5.324	5.556	5.525	5.481	0.009

The biota associated with four samples of *Modiolus* clumps taken from nearby station MM01/C is detailed in Table 2.9 (Annex 2) and taxon diversity shown in Table 14. Clump samples included 191 taxa with a mean of 102 taxa per clump, similar to the equivalent figures for 2005 (total 174, mean 100) (Table 14).

Taxon counts based on the raw data can inflate taxon richness values due to the presence of possibly overlapping taxa (e.g. *Golfingia vulgaris* and *Golfingia* spp. juv.), so values based on both raw (S^1) and non-overlapping taxa (S^2) are also given in Table 14. Table 14 also shows values for the calculated diversity measures, the Shannon-Wiener function (H') and Pielou evenness (J'). In order to increase the validity of temporal comparisons, these figures are based on the reduced species complement (S^2), further reduced by excluding aggregate taxa (e.g. Ostracoda spp.) and taxa recorded in binary form (e.g. algae and colonial animals). Comparisons of the mean number of taxa per clump using t tests show no temporal change in taxon richness whether raw data is used (S^1) or reduced data sets excluding overlapping taxa (S^2) or overlapping, aggregate and binary recorded taxa (S^4) ($p > 0.6$ in all cases) (Table 14). Shannon-Wiener and Pielou evenness indices both show a slight but significant increase in mean value between the years ($p<0.01$). This will be discussed further below. Moore *et al*. (2006) found a slight but significant increase in taxon richness and Shannon-Wiener diversity between 1999 and 2005 at this site.

The numerically dominant taxa in the years 2017 and 2005 are listed in Table 15. Seventeen of the top 25 taxa recorded in 2005 were amongst the top 25 in 2017 and of the remaining nine, only two were not recorded in 2017. One of these, *Perrierella audouiniana* (a lysianassid amphipod), may correspond to the Lysianassidae juveniles taxon recorded in 2017. The ascidian *Pyura microcosmus* was not present in the 2017 clump samples, although it was present in the area, being recorded during the diver epibiota survey (Table 2.8, Annex 2). The much smaller *Pyura tessellata* was found in the clump material but not during the diver survey, where its *in situ* recognition would be impossible (<1 cm in length).

Table 15. The 25 most abundant taxa in Modiolus clump samples at site MM01/C in the current study (2017) and in 2005 (Moore et al., 2006). Abundance as mean count in four replicate clump samples. Green type denotes 2005 taxa also in 2017 top 25, blue type also recorded in 2017, and red type not found in 2017.

2017		2005	
Taxon	**Mean count/clump**	***Taxon***	**Mean count/clump**
Ostracoda spp	20.75	*Verruca stroemia*	42.75
Spirobranchus triqueter	17.75	*Spirobranchus triqueter*	40.50
Dendrodoa grossularia	17.75	*Nereimyra punctata*	25.50
Pisidia longicornis	15.50	*Pododesmus patelliformis*	25.00
Balanus balanus	15.00	*Dendrodoa grossularia*	25.00
Verruca stroemia	13.00	*Balanus balanus*	18.00
Mediomastus fragilis	12.50	*Lepidonotus squamatus*	13.50
Pholoe inornata	11.75	*Mediomastus fragilis*	13.50
Harmothoe spp juv/indet	9.00	*Phtisica marina*	13.25
Balanus spp. spat	8.25	*Pyura microcosmus*	10.00
Leptochiton asellus	7.75	*Pisidia longicornis*	9.50
Dipolydora coeca	7.50	*Modiolus modiolus*	9.50
Phoronis ovalis	6.75	*Crassicorophium bonellii*	8.75
Kurtiella bidentata	6.50	*Harmothoe* spp. juv./indet.	8.50
Oxydromus pallidus	6.00	*Polycirrus* spp.	8.25
Lumbrineris aniara	5.25	*Ophiothrix fragilis*	8.25
Hiatella arctica	4.75	*Dipolydora coeca*	6.75
Mytilus edulis juvs	4.50	*Oxydromus pallidus*	6.50
Dipolydora flava	4.25	*Pholoe inornata*	6.00
Crassicorophium bonellii	4.25	*Pseudoprotella phasma*	5.50
Lepidonotus squamatus	4.00	*Mytilus edulis*	5.50
Mya truncata	4.00	*Myrianida* spp	4.50
Polycirrus norvegicus	3.75	*Flabelligera affinis*	4.50
Modiolus modiolus	3.75	*Hiatella arctica*	4.50
Pholoe baltica	3.50	*Pholoe baltica*	4.25
Paradoneis lyra	3.50	*Perrierella audouiniana*	4.00

The temporal reduction in density of *Modiolus* along transect MM01 was reflected in the numbers of live shells in the clump material (mean of 9.50 in 2005 and 3.75 in 2017 (Table 15). This may have influenced the abundance of several sessile taxa that were found predominantly on live shells in the clump material, such as *Verruca stroemia*, *Spirobranchus triqueter*, *Pododesmus patelliformis*, *Dendrodoa grossularia* and *Balanus balanus*. These species were amongst the top six dominant taxa in 2005. If they are excluded from the species abundance data sets for both years, there is no longer a significant difference in any of the diversity measures between the years (t test, p >0.10).

3.2.4 Population structure

Figure 46 illustrates the size structure of *Modiolus* from site MM03/C in the close vicinity of the MNCR site MM01/3A in the upper basin of Loch Creran. The raw data are provided in Table 2.10 (Annex 2). The population is strongly dominated by large mussels in the size range 70 - 130 mm, equivalent to an age range of around 7 - 20 years, based on the von Bertalanffy growth curve for the upper basin population in Mair *et al.* (2000). Little recruitment seems to have taken place over the last six years. Population size structure is little different from that recorded at the same location in 1999 (Mair *et al*., 2000) and in 2005 (Moore *et al*., 2006) (Figure 46).

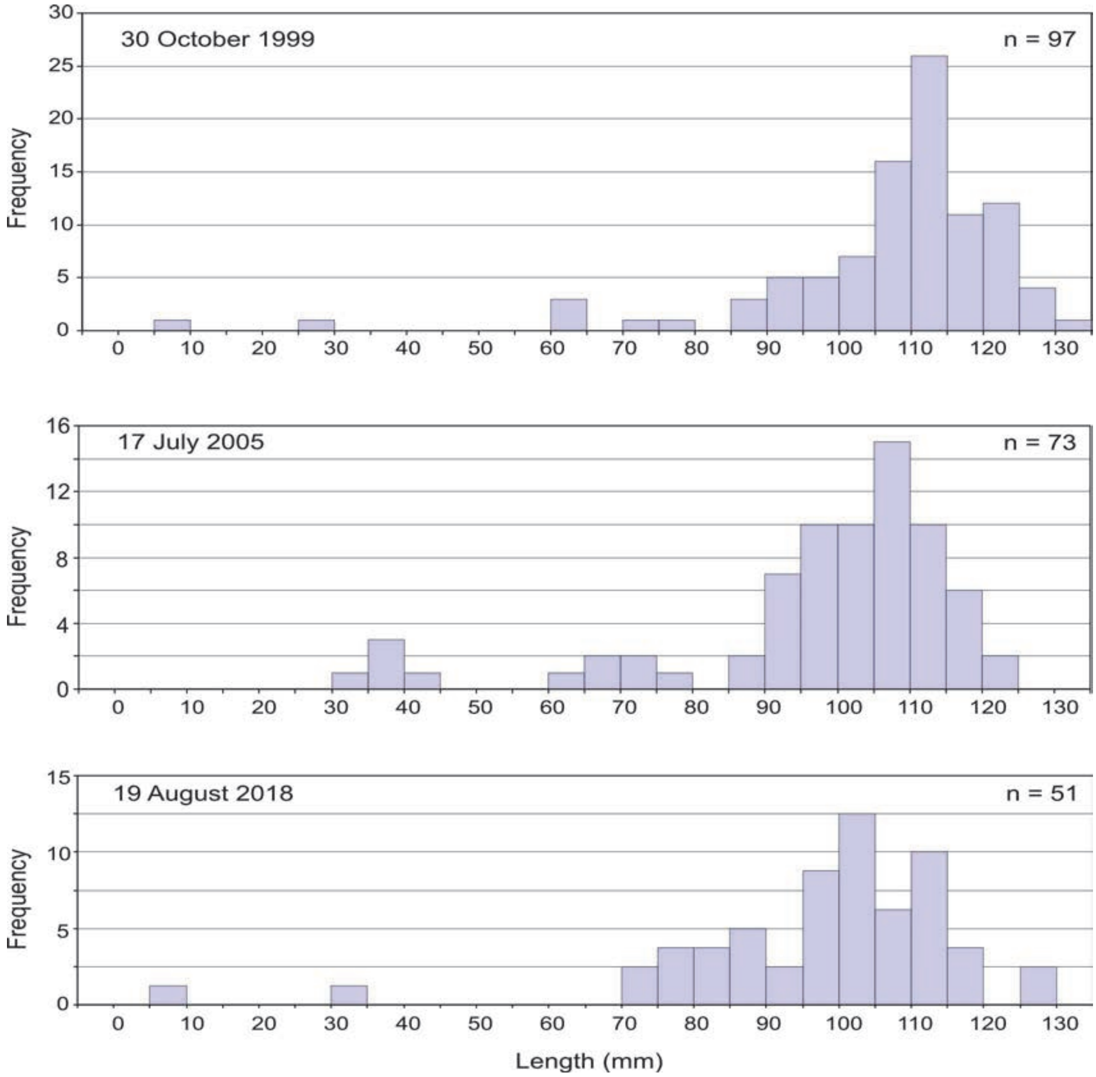

Figure 46. Length frequency distribution of Modiolus modiolus collected from the upper basin of Loch Creran in 1999 (Mair et al., 2000), 2005 (Moore et al., 2006) and in 2018 (current study).

3.3 Flame shell beds

3.3.1 Distribution

Detailed results from the diver drift survey of *Limaria hians* distribution are presented in Tables 3.1 and 3.2 (Annex 3), and from the three grab samples taken off South Shian in Table 3.3 (Annex 3).

Figure 47 shows the distribution of records of byssal turf cover off South Shian in 2017/18, as well as the SACFOR abundance of *Limaria hians* at the three grab stations near the southern margin of the bed in 2017. The polygon incorporates all records with a turf cover of ≥10%, which is considered to constitute the flame shell bed biotope **SS.SMx.IMx.Lim** (Moore *et al*., 2013). In fact the records indicate that turf coverage was high (>50%) over the great majority of the area delineated by the polygon, with only very localised, small patches of <20% cover. The aerial extent of the South Shian bed in 2017/18 was 32.62 ha compared to an estimate of 18 ha in 2012 (Moore *et al*., 2013). The difference is due to the wider distribution of recording sites in 2017/18, particularly in the south of the bed, where very few stations were located in 2012. This also accounts for the apparent extension in 2017/18 midway along the northern boundary of the bed. Apart from in these areas there were only small, localised differences between the polygons and these are explicable in terms of inadequate station coverage in one survey or the other, or the presence of small patches of non-flame shell habitat. There is no evidence for any substantial temporal change in the distribution or spatial extent of the flame shell bed. The mean turf coverage within the 2017/18 polygon was 67% which was similar to that in the 2012 polygon (76%). As survey stations were distributed differently in both surveys, and their positions were not randomly allocated throughout the bed, a close match in mean coverage vales would not be expected. The recorded depth range of the bed was greater in 2017/18 (5.2 - 23.2 m) than in 2012 (3.9 - 18.5 m) as a result of the increased sampling intensity in the deeper, southern region of the bed.

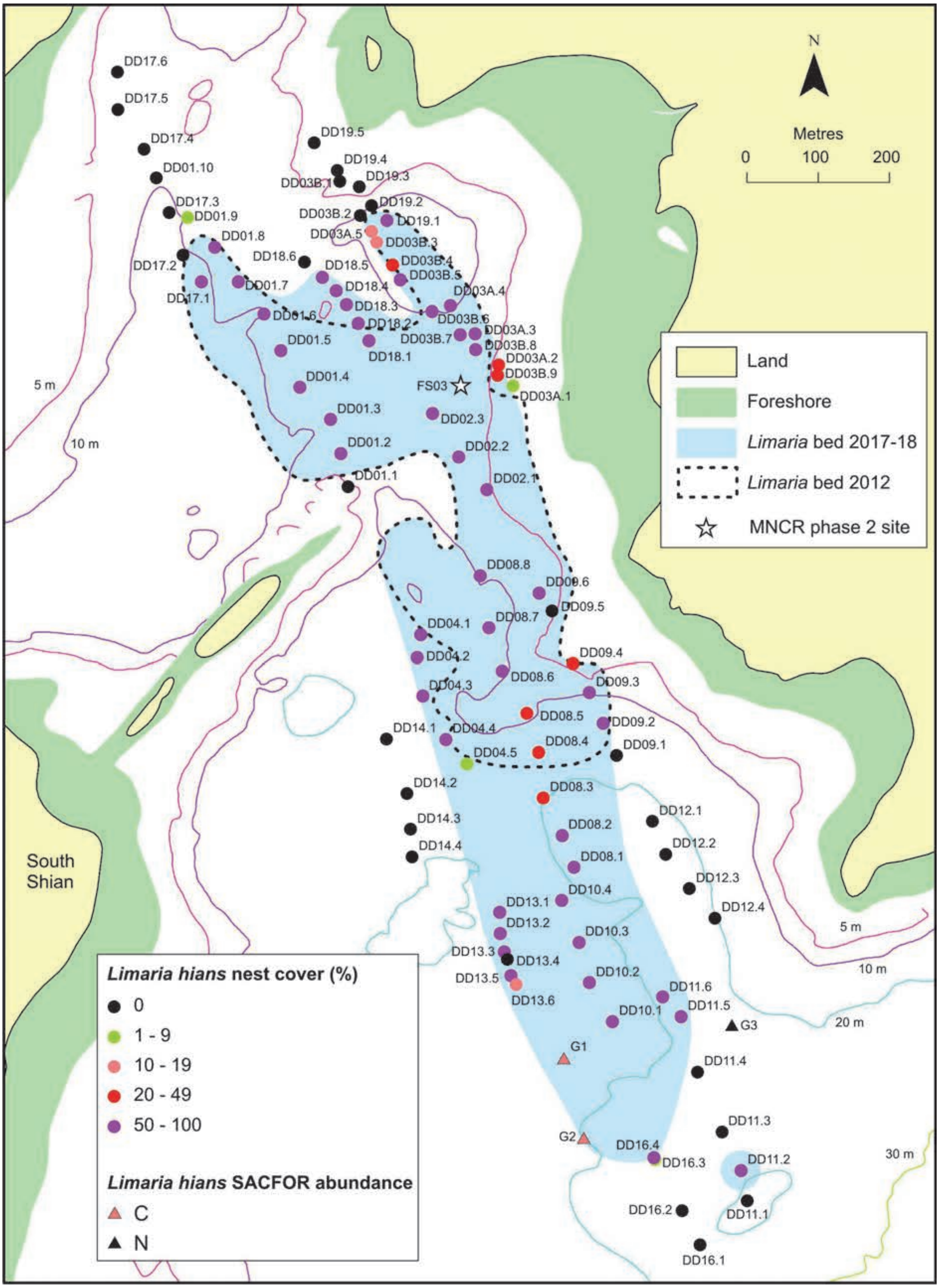

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Figure 47. Distribution of 2017/18 Limaria hians turf cover records (DD sites) and SACFOR abundance records (G sites) off South Shian, with polygon delineating the Limaria bed. 2012 bed extent (Moore et al., 2013) also shown.

The flame shell bed off Creagan lies in the western approaches to Creagan Narrows (Figure 48). In 2017 the bed was found to take the form of a narrow strip about 300 m in length and 30 m in width with high byssal turf coverage towards the ends (>50%) and low - medium coverage in the central region (mostly 10 - 50%). Mean cover over the bed as a whole in 2017 was 45%. Over much of the bed *Limaria* byssus forms a matrix with occupied and empty shells of *Modiolus modiolus*, which also support a bed of superabundant *Ophiothrix fragilis (Figure 49)*.

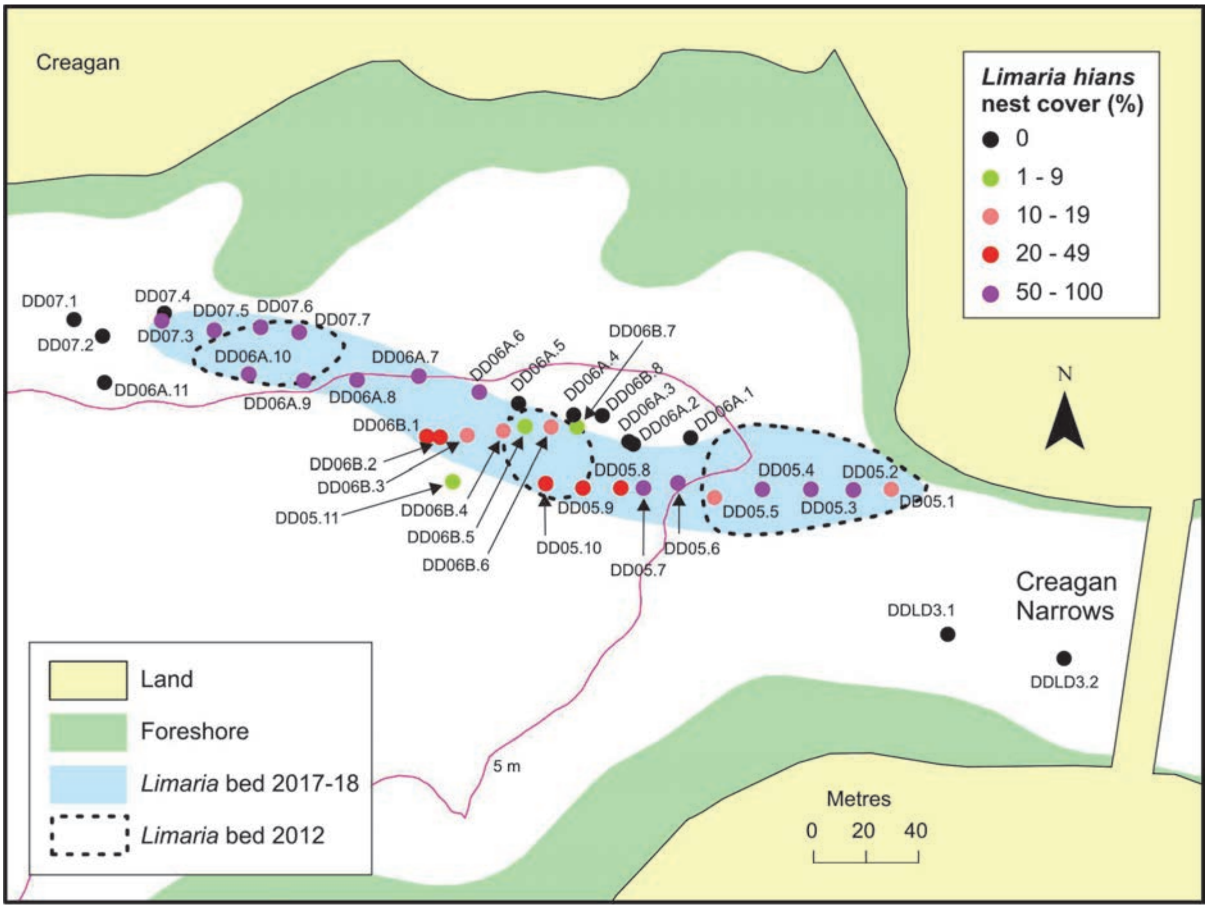

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Figure 48. Distribution of 2017 Limaria hians turf cover records off Creagan, with polygon delineating the Limaria bed. 2012 bed extent (Moore et al., 2013) also shown.

The spatial extent of the bed in 2017 was 0.86 ha. In 2012 the bed was found to cover 0.5 ha as three patches (Figure 48). There is, however, no reason to believe that there has been a change in the distribution of the bed, as in 2012 no survey sites were located in the gaps between the patches. The mean turf cover in 2017 (45%) was slightly lower than that recorded in 2012 (51%), although this will reflect the higher proportion of sites located in the central region of the bed in 2017 (where cover estimates are lower), as well as perhaps the difficulty in gauging *Limaria* byssal coverage amongst dense *Modiolus* and ophiuroids. The recorded depth range of the bed was slightly wider in 2017 (1.8 - 10.6 m) than in 2012 (4.4 - 10.5 m).

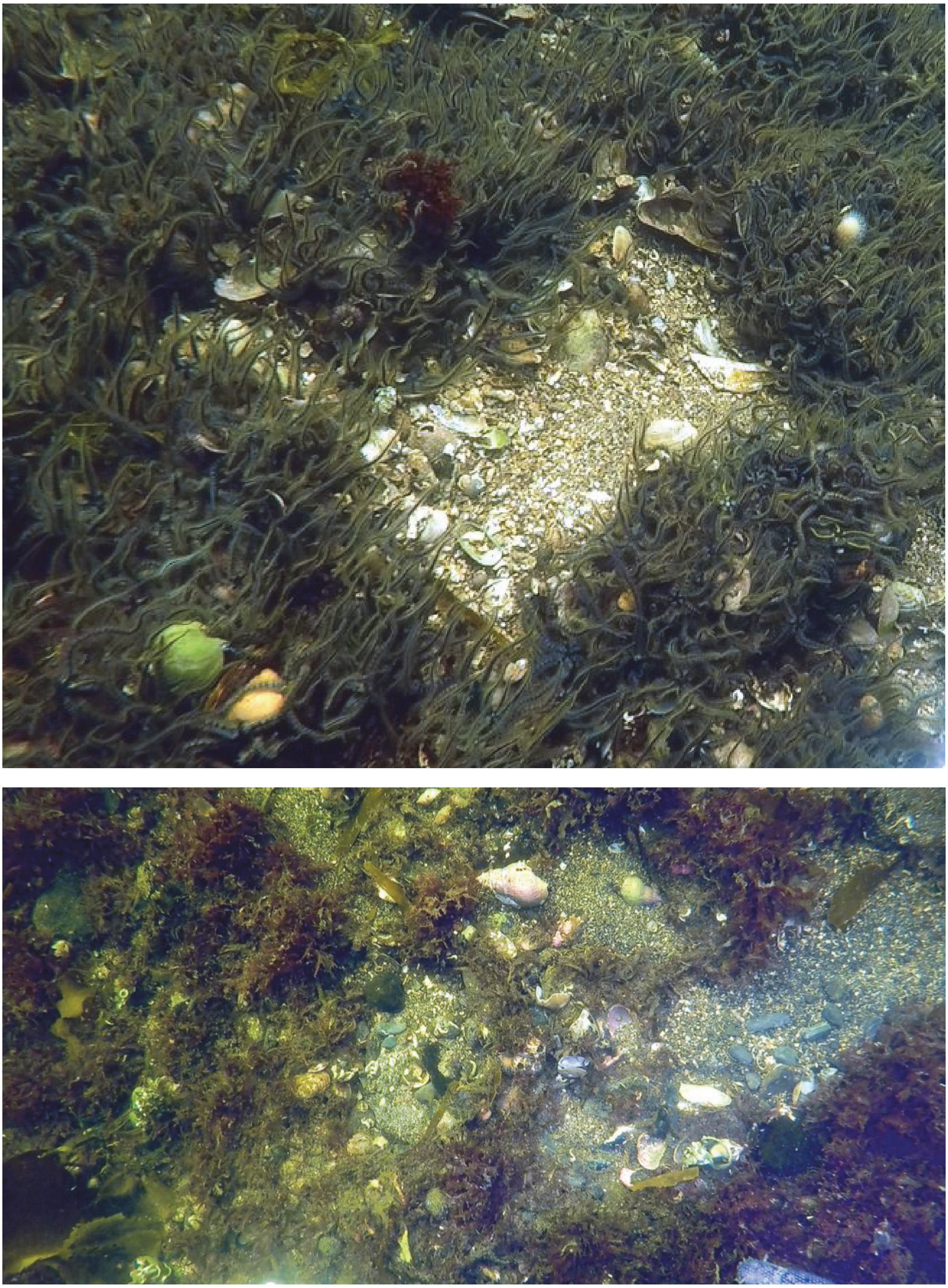

Figure 49. Representative video grabs of Limaria beds at Creagan (station DD05.3; upper photo) and in the upper basin of Loch Creran (station DDLD2.10; lower photo).

A third, previously unknown *Limaria* bed was found during an examination of *Modiolus* distribution in the eastern approaches to the Creagan Narrows in the upper basin of the loch (Figure 50). The geographical coverage of the bed is incompletely known but the few stations worked in the area suggest a spatial extent of the order of 1.40 ha. The bed was recorded over a depth range of 1.6 - 5.7 m in an area of coarse sand with dense shells and pebbles consolidated by *Limaria* byssus but not overtopped by it and supporting an algal turf (Figure 49). The matrix of byssus, shells and stones averaged 48% cover within the delimiting polygon. *Modiolus modiolus* was common at most of the survey stations within the bed.

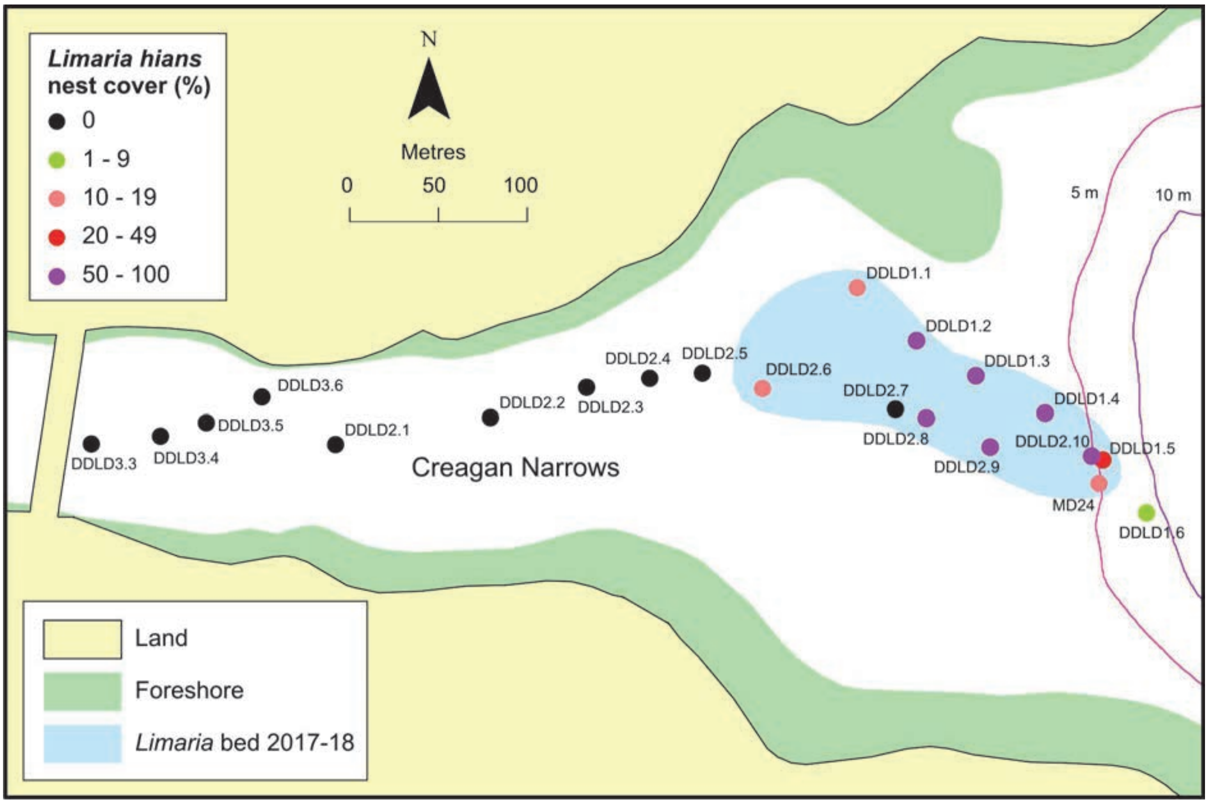

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Figure 50. Distribution of 2017 Limaria hians turf cover records in the upper basin in the eastern approaches to Creagan Narrows, with polygon delineating the Limaria bed.

3.3.2 *MNCR phase 2 survey (FS03)*

The transect was located on the Shian bed in an area of luxuriant *Limaria* turf (95% cover) on a substrate of silty sand and gravel at a depth of 7.5 - 7.8 m (Figure 6). The turf housed abundant *Limaria hians* and was perforated by dense, distinct gallery apertures and supported a rich red algal turf strongly dominated by *Plocamium cartilagineum* and a park of *Laminaria hyperborea* (Figure 51). The site is clearly referable to the biotope **SS.SMx.IMx.Lim**. Dominant faunal elements included *Antedon bifida* and *Crossaster papposus*. A total of 65 epibiotic taxa were recorded (Table 3.4, Annex 3), almost identical to that observed along the same transect in 2012 (66) (Moore *et al*., 2013). The only notable difference in the epibiota between the years was a temporal decrease in the invasive red alga *Dasysiphonia japonica* (from abundant to frequent).

Figure 51. Habitat photograph of the Limaria bed at South Shian (site FS03), showing Limaria hians gallery apertures and red algal turf dominated by Plocamium cartilagineum.

Core samples included 136 taxa with a mean of 84 taxa per core (80 per core excluding possible overlapping taxa), somewhat higher than equivalent figures for 2012 (total 111, mean 68) (Table 16). Inspection of the 2012 data reveals that certain major taxonomic groupings are not represented (e.g. algae, hydroids, bryozoans) suggesting that such elements of the epibiota were not analysed. When these groups are excluded from the taxon counts (S^3), there is no significant difference between mean values for the two years (t test, P = 0.08). There is some indication of a slight temporal increase in taxon richness when aggregate and binary recorded taxa are excluded (S^4), from a mean of 53 to 63, although it is not quite statistically significant (t test, p = 0.06). There are no temporal differences in the means of either H' or J' based on the reduced taxon complement (Table 16).

Table 16. The abundance (N) and diversity of fauna in four replicate cores (area 83 cm²) through Limaria bed at site FS03 in the current study (2017) and in 2012 (Moore et al., 2013). Diversity values include no. taxa (S^1 - S^4 - see text), Pielou evenness index (J') and Shannon-Wiener function using log_2 (H'_2) and log_e (H'_e). p value given for t test of means from both years.

	2012					2017					
	Replicate					Replicate					
	1	2	3	4	Mean	1	2	3	4	Mean	p
S^1 (raw data)	80	63	68	59	67.5	75	88	87	84	83.5	
S^2 (excluding overlapping taxa)	72	60	65	54	62.8	71	83	85	79	79.5	
S^3 (excluding overlapping taxa and taxa not examined in 2012)	72	60	65	54	62.8	68	72	74	71	71.25	0.08
S^4 (excluding above , aggregate and binary taxa)	63	48	54	46	52.8	58	61	66	65	62.5	0.06
N	625	278	521	269	423	435	427	398	420	420	
J'	0.85	0.85	0.85	0.81	0.84	0.85	0.83	0.86	0.85	0.85	0.55
H'_e	3.52	3.31	3.39	3.10	3.33	3.44	3.43	3.61	3.56	3.51	
H'_2	5.07	4.77	4.90	4.47	4.80	4.96	4.95	5.21	5.13	5.06	0.12

The species abundance data from the cores are provided in full in Table 3.5 (Annex 3). The top 25 taxa for both 2017 and 2012 are listed in Table 17, which shows that 13 of the taxa amongst the top 25 in 2012 were also represented in the top 25 in 2017. Ten of the others were also recorded in 2017, leaving only two taxon groupings of juveniles absent in 2017. Numbers of *Limaria hians* in the cores were similar in both years (mean of 5.0 in 2012, 4.0 in 2017), although the use of small cores is an imprecise approach to the assessment of *Limaria* density.

Table 17. The 25 most abundant taxa in cores through Limaria bed at site FS03 in the current study (2017) and in 2012 (Moore et al., 2013). Abundance as mean count in four replicate cores of area 83 cm². Green type denotes 2012 taxa also in 2017 top 25, blue type also recorded in 2017, and red type not found in 2017.

2017		**2012**	
Taxon	**Mean count/core**	**Taxon**	**Mean count/core**
Pholoe inornata	38.00	NEMATODA spp	50.25
OSTRACODA spp	27.00	*Aonides oxycephala*	38.75
Amphipholis squamata	21.25	*Golfingia vulgaris*	27.50
Onoba semicostata	19.25	*Mediomastus fragilis*	26.75
Flabelligera affinis	15.50	OSTRACODA sp	25.50
Aonides oxycephala	14.25	*Modiolus* sp juv	15.75
Mediomastus fragilis	11.75	*Polycirrus* sp	13.50
Psamathe fusca	11.50	*Nereimyra punctata*	13.25
Sphaerosyllis hystrix	11.50	OPHIUROIDEA spp juv	12.75
Munna spp	11.50	*Flabelligera affinis*	12.00
NEMATODA	10.25	*Pholoe inornata*	10.25
Hiatella arctica	9.50	*Capitella capitata* agg	8.75
Modiolula phaseolina	9.25	Polynoidae spp juv	8.00
Polycirrus norvegicus	8.75	*Sphaerosyllis taylori*	7.50
Kurtiella bidentata	8.75	*Cirratulus cirratus*	5.50
Lysianassa ceratina	8.25	*Asclerocheilus intermedius*	5.50
Pholoe baltica	7.25	*Metaphoxus fultoni*	5.50
Enchytraeidae sp	6.75	*Hiatella arctica*	5.25
Rissoa parva	6.75	*Eumida sanguinea*	5.00
Nereimyra punctata	5.75	*Glycera lapidum*	5.00
Mytilus edulis juvs	5.75	*Psamathe fusca*	5.00
COPEPODA spp	5.50	Enchytraeidae sp	5.00
Abra alba	5.25	*Limaria hians*	5.00
Prosphaerosyllis tetralix	4.00	Pectinidae spp juv	4.75
Limaria hians	4.00	*Kurtiella bidentata*	4.75

4. DISCUSSION

4.1 Serpulid reefs

The current condition of the serpulid reef habitat of the lower basin of Loch Creran is summarised in Figure 52, which shows the condition scores derived along the 40 transects worked between 2017 and 2019. The mean score during this period is 5.8 with 58% of transects providing the lowest scores of 7 - 8. Based on published data and a considerable amount of observations throughout the lower basin it can be stated that the mean condition score for the same areas would lie within the range 1 - 2 in 2005 with only small, localised patches falling below this. This reduction in condition has taken the form of reef fragmentation, with a concomitant lowering of canopy height, and reduction in tube occupancy. There is no clear evidence for a reduction in the coverage by reef material, although much of it is now sparsely inhabited by *Serpula vermicularis*. Severe degradation of the reefs has occurred over most of the area of reef coverage in all the principal regions of the habitat (Sea Life Centre Bay, Rubha Mór, South Shian, South Creagan Bay), apart from Rubha Riabhach Bay, where the habitat is largely undamaged and of similar condition to that pertaining in 2005 within the principal regions of the habitat. Due to the historical paucity of reefs in the upper basin, the temporal trend in reef condition here is uncertain. The consequences of the change in this keystone species to the associated community has not been formally addressed in this study.

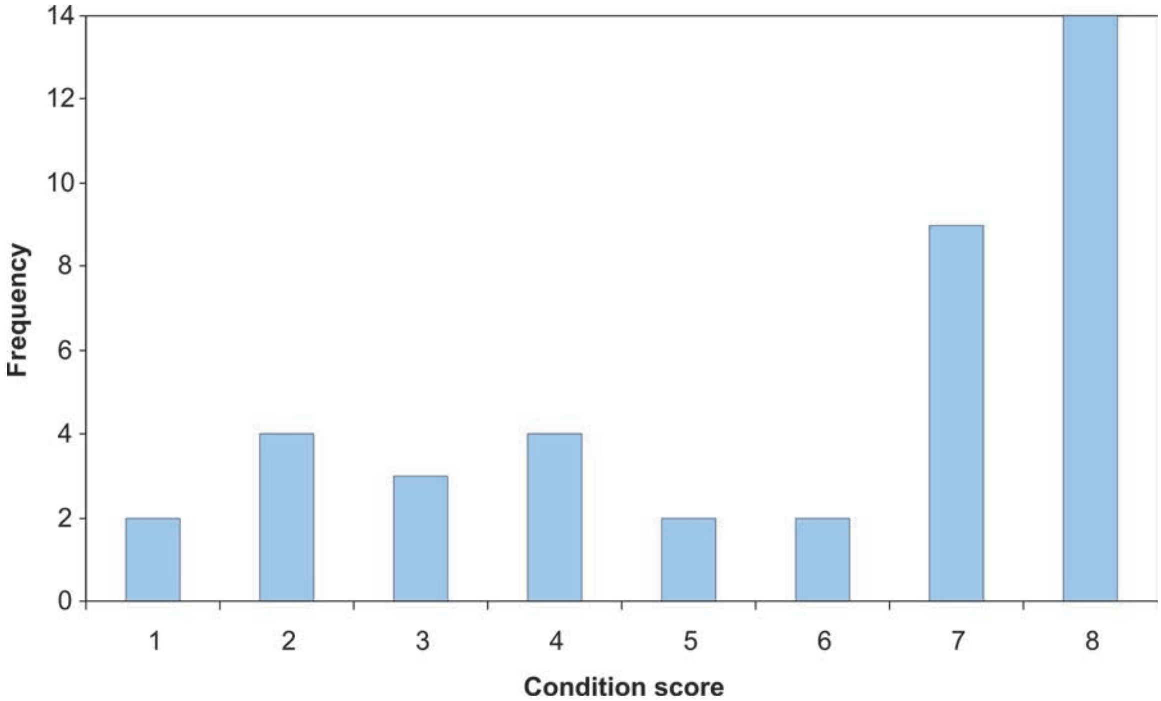

Figure 52. Frequency of survey transects examined in 2017 - 2019 allocated to serpulid reef condition scores (1 = largely undegraded, 8 = largely unpopulated reef rubble).

Although firm evidence for the widespread degradation of serpulid reefs was first revealed in 2013 during dive inspections by Heriot-Watt University of areas off South Shian and Rubha Mór and in Sea Life Centre Bay aimed at locating healthy reef material for filming by the BBC, analysis of previous video and sonar material suggests that the process had been probably underway for several years. An expanse of broken reef material including dead rubble (with a condition score of c.4) is visible on footage filmed by the cameraman John Aitcheson off Rubha Mór in 2011 for the BBC series Hebrides - Islands on the Edge. The site was recommended by the first author of this report as it was known to have previously supported a dense and well-developed example of the habitat. The 2009 sidescan imagery from Sea Life Centre Bay reveals an extensive area (at least 0.5 ha) giving the sonar signature of reef rubble. The 2007 sidescan coverage of the embayment south of Rubha Mór portrays a pattern of distinctly better defined reef structures than those indicated by diffuse texture of the 2015 sonar imagery. Although localised damage was recorded during the SCM survey of Loch Creran in 2005 (Moore *et al*., 2006) and in an earlier 1994 survey (Moore, 1996), the extensive areas of broken reef material visible today were not observed then. The evidence suggests that the damage identified in 2013 may be part of a long-term decay of reef material in the loch.

Attempts at relating reef damage to storm events have so far proved unsuccessful (e.g. Tulbure, 2015). The collation of wind data for the Oban area over the years 2007 - 2014 by Tulbure (2015) shows sustained wind strengths (>3 hours duration) not exceeding 44 kn. The prevailing winds are south-westerly and winds from the sector east to north are rare, with only a single record of speeds exceeding 29 kn in 2008 (maximum 39 kn). The previously dense reef beds off Rubha Mór and South Shian in the south-west of the loch will be protected from the prevailing winds.

According to Figurski *et al.* (2011), the maximum bottom orbital velocity (u_b) generated by wave surge is a good indicator of forces exerted on substrates and marine organisms and can be calculated for shallow water as follows:

$$u_b = \left(\frac{\pi H}{T}\right)\left(\frac{\cosh(ks)}{\sinh(kd)}\right)$$

where H is wave height, T is wave period, d is seabed depth, s is height of required measurement above seabed and k is wave number (2π /wavelength). Based on water wave theory and a knowledge of fetch and depth it is possible to derive estimates of wave height, length and period from which can be derived approximate values for maximum orbital velocity for a typical serpulid reef 30 cm high. For the Rubha Mór and South Shian region of the loch the model predicts that a hurricane force wind of 64 kn from the prevailing wind direction will generate a u_b of <0.01 kn at a depth of 5 m. For the maximum 39 kn north-easterly wind (Tulbure, 2015) u_b is 0.7 kn and 0.2 kn at respectively 5 m and 10 m depth. For Sea Life Centre Bay the maximum recorded wind speed (41 kn) over the longest fetch generates u_b estimates of 0.4 kn and <0.1 kn at respectively 5 m and 10 m depth. It appears unlikely that storms would make a significant contribution to reef damage, particularly in view of the fact that during the current survey there appeared to be no relationship at any location between the level of damage and depth.

The existence of serpulid reefs in Loch Creran was first recorded in 1882 by Smith (1887), who described the presence of bunches of occupied serpulid tubes up to 30 cm in height amongst a bed of *Zostera marina*. Over 100 years later in 1989 Connor (1990) recorded the presence of reefs at five of the eight dive sites examined in the loch (excluding two tide-swept sites at the mouth of the loch). These sites included the northern region of Sea Life Centre Bay where 'gardens of *Serpula vermicularis*' were observed over the shallower region of the survey covering 6 - 13 m depth and Rubha Garbh (south) where a 'dense *Serpula* bed' was noted below a depth of 5 m. Connor (1990) commented that at these two sites the serpulid aggregations 'formed unusually large mini-reefs, up to 20 cm across'. Such reefs can be classed as medium sized reefs in the classification employed by subsequent surveys (see section 3.1.1). In view of the widespread presence (and often dominance) of considerably larger reefs throughout much of the loch in later years, including at the Sea Life Centre and Rubha Garbh locations, the observation of only such small reefs by Connor (1990) is surprising.

Table 18 shows the number of transects examined during the 1994 (Moore, 1996) and 2005 (Moore *et al*., 2006) surveys where the presence of reefs of different size categories were recorded. Transects are excluded from consideration that were located near the mouth of the loch beyond the main distributional limits of reefs and in the vicinity of the Barcaldine Pier, where organic pollution from the old alginate factory caused the exclusion of reefs for a distance of around 1 km (Moore *et al*., 1998). Although lacking statistical rigour, the data suggest a temporal pattern of decreasing frequencies of small and medium reefs and an increasing frequency of large reefs. Also taking into consideration the absence of large reefs observed by Connor (1990), it would appear likely that there has been an overall trend of reef size increase over the years 1989 - 2005. This does not mean that large reefs were not present in the loch in 1989. Reefs of up to 75 cm in height and individual well-formed reefs of up to 1 m in width were observed during the 1994 survey (Moore, 1996).

Table 18. Number of transects within serpulid colonisation region of Loch Creran displaying presence of small, medium and large reefs during surveys in 1994 (Moore, 1996) and 2005 (Moore et al*., 2006).*

	1994 survey		**2005 survey**	
	# transects	**% of total**	**# transects**	**% of total**
Total	37		79	
Small reefs	34	92	64	81
Medium reefs	26	70	50	63
Large reefs	13	35	39	49

There is a distinct maturation sequence in the growth of Creran serpulid reefs whereby reefs grow in a bush-like form to a certain height (typically around 40 - 65 cm) before collapsing. The collapse frequently takes the form of a splitting of the reef from the centre producing a peripheral, ring-like concentration of populated tubes surrounding a relatively sparsely-populated central region. The cause of collapse is incompletely known, although Bosence (1979) has implicated weakening through biological erosion by boring sponges and algae and biting by fish and echinoids. According to Bosence (1979) in Ardbear Lough, Ireland, this fragmentation of reefs followed by subsequent colonisation is the principal way the reef habitat expands to replace large areas of previously soft substrate. In Loch Creran it would appear that although there is evidence of collapsed reefs supporting dense concentrations of living worms, much of this material has not attracted successful recruitment and survival and has undergone further erosion and fragmentation.

Although individual reefs pass through a sequence of growth and fragmentation, this does not explain the apparent synchrony in the fragmentation phase throughout much of the loch, such that a perceived, general decline in intact structures and the population size of *Serpula vermicularis* has occurred over the last ten years or so. Possible explanations include physical damage, pollution, food supply and predation.

Although there are clear examples of reef fragmentation due to anthropogenic activities such as mooring, the operation of demersal gear and aquaculture related activities (Moore *et al*., 1998, 2006), the nature of the broken reef material throughout much of the loch clearly indicates that the major process of degradation has been brought about by natural collapse of reef structures, rather than by physical contact. Evidence of these types of anthropogenic impact was already present in 1994 (Moore, 1996) and 2005 (Moore *et al*., 2006). Since then it is known that anchoring by yachts has taken place in South Creagan Bay (Moore. pers. obs.) and this may explain why this previously pristine reef site is now possibly the most degraded region of the loch, with the reefs now reduced to rubble. No other clear examples of anthropogenic damage since 2005 have been identified during the current study.

Tett *et al*. (2008) have recorded a substantial reduction in diatom numbers and total chlorophyll concentration in the plankton of the loch between the periods 1975 - 1981 and 2006 - 2007. Whilst this may lead to a reduction in serpulid population density through limitation of food supply, it does not account for the discrepancy in the level of degradation throughout the loch, particularly between Rubha Riabhach Bay and much of the rest of Loch Creran. For the same reason, pollution seems an unlikely contributor to reef decay.

It may be instructive to examine the level of synchrony in reef degradation within the loch. As described in section 3.1.2.2, no large reefs were recorded within any of the four transect bands passing through the northern region of Rubha Riabhach Bay in 1994 (Moore, 1996). Medium reefs were also very sparse, being recorded in just one 20 m sector along one of the four transects. Reef density was low, with no reefs observed along one transect and <1% cover along the other transects. Five transects passed through this region in 2017/18 revealing largely unbroken reef material with coverage values up to 10 - 20% and large pristine reefs up to 65 cm height recorded along all transects. The difference in reef condition between this site and much of the rest of the loch may be that it is lagging behind in the reef development sequence.

One possible explanation for the apparent synchrony in reef degradation over much of the loch may relate to the availability of suitable colonisation substrates. Following the finding of a correlation between reef abundance and the availability of colonisation surfaces within the preferred muddy sand areas of the loch, Moore *et al.* (1998) suggested that substrate availability may represent a limiting resource. This has been questioned by Perry *et al*. (2015) commenting that there are extensive areas of bedrock outcropping from the floor of the loch but these only support very limited reef development. However, it is unlikely that such outcrops represent suitable habitats for reef development. These outcrops consist predominantly of relatively bare, smooth rock densely populated by grazers, particularly *Psammechinus miliaris*, which reaches densities exceeding 100 m^{-2} on the main outcrop in the loch off south Rubha Riabhach (Moore *et al*., 2006) (Figure 54). Hughes (2006) has recorded mean densities of *P. miliaris* up to 144 m^{-2} at other locations in the loch. *Psammechinus miliaris* and *Echinus esculentus* have been observed feeding on serpulid tubes and their stomachs have been found to be full of tube debris (Bosence, 1979). Juvenile worms are likely to be particularly vulnerable to such grazing activity. Reefs are found at a few locations in the loch associated with cobble and boulder fields but here interstitial spaces provide some refuge from predation during early development of the worm. In Loch Creran the decline in new reef development may be associated with exhaustion of suitable colonisation surfaces. Ironically, limited availability of such substrates has been proposed as a cause of the development of reefs in the first place (Bosence, 1979; Ten Hove & Van den Hurk, 1993).

Limitation by the colonisation substrate resource could explain why introduction of a suitable opportunity in the form of the experimental units deployed in 2012 has attracted striking reef development in some cases, in contrast to the poor condition of the surrounding reef material. Reef development on the units is particularly marked on the larger units with a degree of predator exclusion from netting (Figure 34), unlike the boulder, where only relatively sparse individual tubes are present, most of which having developed within a refuge from predation at the base of the boulder (Figure 54).

The above discussion implies that broken reef material provides a poor colonisation substrate. Early evidence for this lies in the poor recovery of damaged reef areas in the loch. The 3 m wide tracks of reef rubble off Rubha Mór, possibly caused by dredging activity, were first observed in 1998 (Moore, pers. obs.) and were still clearly evident in the 2005 and 2007 sidescan imagery. They can still be discerned in the 2015 imagery, less clearly, but this may be because the adjacent reef material has deteriorated to a similar degree. Hughes *et al.* (2008) found a mean *Serpula vermicularis* tube extension rate in Loch Creran of 3.3 cm y^{-1} and Moore (unpublished) has estimated reef growth at c.3.0 cm y^{-1} based on measurement of reefs developing on substrates deployed at known times. This growth potential has clearly not been realised in the case of the Rubha Mór tracks.

Colonisation by *Serpula vermicularis* of dead reef material in Loch Creran is known to take place (e.g. Chapman *et al*. 2007, Hughes, 2011). Chapman *et al*. (2007) found no significant difference in recruitment levels to dead and live *S. vermicularis* tubes deployed over a period of 90 days, although recruitment to vertically-orientated scallop shells was significantly greater. Over a longer-term experiment Hughes *et al.* (2011) deployed 15 - 20 cm long tube clusters in the loch, half of which were enclosed in mesh to exclude urchins, over a period of five years. There was a marked difference in *S. vermicularis* recruitment between the two treatments after one year, with caged clusters supporting 11 - 40 worms and uncaged clusters 0 - 2 worms, although there was little survival in both treatments after five years. Low long-term survival of worms in the caged treatment may have been due at least in part to the vulnerability to predation of the small worm tubes emerging from the mesh.

The fragmentation of large, highly spatially complex, reef structures providing a high level of refuge to developing juvenile worms into less-rugose, smaller and potentially more mobile fragments is likely to increase the potential for predation both through the grazing activities of urchins and by other species such as *Asterias rubens* and *Buccinum undatum*, both of which are commonly found on reef material, the former being known to exert its stomach down the tubes of *S. vermicularis* (Bosence, 1979). The pool of *Psammechinus miliaris* available to exploit newly accessible surfaces through fragmentation is considerable. Figure 53 shows the abundance of *P. miliaris* recorded on 10 reefs of varying plan area within Loch Creran (data from study by Chapman *et al*., 2012). From the derived regression, the density of *P. miliaris* on reef material can be determined as 577 m^{--2}.

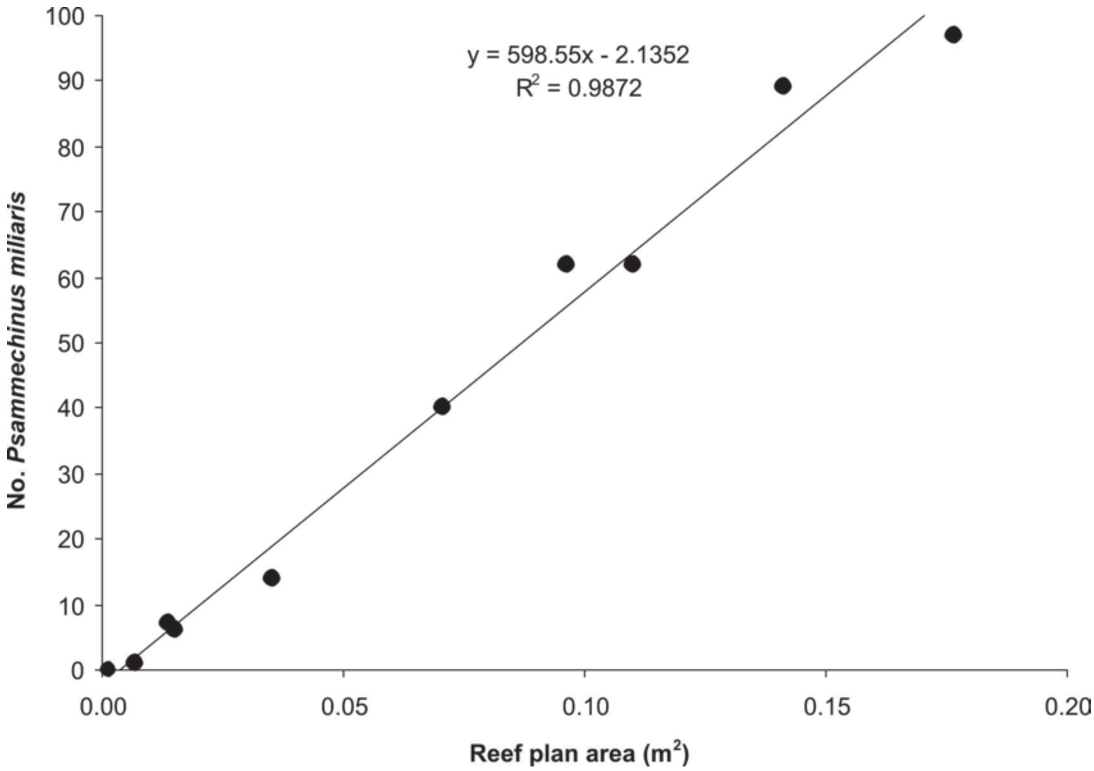

Figure 53. The relationship between the abundance of Psammechinus miliaris and reef plan area for 10 reefs from Loch Creran.

From the scenario outlined above it can be predicted that there will be a continuation in the degradation of the serpulid reefs in Loch Creran until suitable colonisation surfaces become available or predation pressure declines. It is also a corollary of this thesis that the life cycle of serpulid reefs in the loch is limited, such that there may have not been continuity in their presence from the earliest record of 1882 (Smith, 1887) to the present day. This latter idea was put forward by Hughes (2011) who suggested that *Serpula vermicularis* aggregations may be transient features, appearing and disappearing over decadal timescales. According to Hughes (2011) this would serve to explain the lack of build-up of serpulid skeletal debris in the loch. Unfortunately there is now a considerable amount of such skeletal material in the loch, but this is largely of recent origin and was not the case in 2005.

Investigations are at an early stage in assessing the continuity of reef presence in the loch through analysis of core samples. Cores taken in 2016 of just under 1 m in length from 8 locations around the loch all contained *Serpula vermicularis* tube fragments, and at two sites fragments were found in all 10 cm sections of the core to a depth of 80 cm (Harbour, 2017). Unfortunately the sediment accumulation rate is unknown and so further progress awaits dating of the tube fragments.

The transient existence of reefs in Loch Creran is consistent with their history in other Scottish lochs. In Linne Mhuirich, Loch Sween, reefs present in 1975 (R. Mitchell, Nature Conservancy Council, pers. comm.) had disappeared by the 1990s (see Moore *et al*., 1998). In Loch Teacuis, an arm of Loch Sunart, reefs first recorded in 2006 (Mercer *et al*., 2007) had largely disappeared by 2015 (Kamphausen, 2015).

Figure 54. <u>Psammechinus miliaris</u> grazing on the smooth bedrock outcrop off south Rubha Garbh (upper photo) and on an experimental unit boulder at the main study site in Sea Life Centre Bay (lower photo). Note the origin of most of the serpulid tubes is from the base of the boulder.

Horse mussel beds

Between the years of 2005 and 2018 a decline in *Modiolus* density (from 7.40% to 3.23% cover) was recorded along transect MM01 through the Upper Basin bed, at three of the four stations along transect MM05 through the Creagan West bed (from 37.75% to 8.00% cover) and a reduction in density and spatial extent of the bed in the vicinity of transects MM06 and MM08 near the mouth of the loch. While the magnitude of the changes and the lack of any indications of temporal increases, localised or otherwise, along any of the transects are suggestive of broad trends, the findings are only strictly applicable to the local areas through which the transects passed and should not be extrapolated to entire beds.

Possibly linked to the density reduction recorded in the upper basin is the lack of significant recruitment to the population over at least the last six years. The size frequency analyses from 1999 (Mair *et al*., 2000) and 2005 (Moore *et al*., 2006) indicate that this has been the case over a much longer period, with the population strongly dominated by old individuals. This is not unusual for *Modiolus* beds. Very irregular recruitment, with gaps of many years, has been reported for populations in Norway (Wiborg, 1946) and Canada (Rowell, 1967) and in low-current conditions in the Firth of Clyde (Comely, 1978). By contrast, temporal monitoring of the tide-swept *Modiolus* population in shallow waters (2 - 3 m depth) at Creagan (Comely, 1978) revealed a population containing a high proportion of medium and small sized mussels (<70 mm), and small but regular spat settlement throughout the year.

While there is localised reduction in *Modiolus* cover on the Creagan West bed, how representative transect MM05 might be of the bed as a whole is open to question. Unlike the Upper Basin bed, the Creagan West bed spans a broad range of conditions from very strongly tide-swept gravel, pebbles and cobbles in the east where few epifaunal species can survive (apart from the semi-infaunal horse mussels and the stone-encrusting fauna), to the matrix of shells, mussels and flame shells supporting a dense cover of ophiuroids to the west, where tidal currents are slacker. The development of the flame shell byssal turf has been implicated as a possible cause of the decline of a *Modiolus* bed in Loch Alsh (Moore *et al*., 2012). While this is also a possibility at Creagan, there is insufficient information to gauge the scale of temporal change in the byssal turf or *Limaria* density at this location.

The patchwork of *Modiolus* beds in the Shian channel has only come to light as a result of the current survey work and the extent of the habitat remains poorly known. It does appear, however, that these patches are largely restricted to the periphery of the flame shell bed, which raises the possibility of a functional relationship between the two species in this location also.

There was a marked temporal reduction in abundance and extent of the *Modiolus* bed in the vicinity of the transects worked off Druim Cairine at the mouth of the loch (MM06, MM08). The distribution of this bed, both historically and currently, remains unknown and so does the possible spatial scale of the change. The location of this tide-swept site suggests that the likelihood of localised, anthropogenic negative impacts on this area is slender.

The condition of the community associated with horse mussel beds was only examined at one location in the upper basin of the loch, where it was found that there was no distinct temporal change in species composition between the 2005 baseline survey and 2017. The slight enhancement of some diversity indices recorded at the site was considered to be possibly related to temporal differences in sample size.

4.2 Flame shell beds

The history of flame shell beds in Loch Creran is poorly known. Following the observation of scattered *Limaria hians* in the vicinity of South Shian, Heriot-Watt University carried out a search for a *Limaria* bed here in 2005 recording 100% *Limaria* nest cover to the east of Eriska Island (Moore, unpublished). Shortly after the discovery of this bed, scattered *Limaria* nests were found at the western entrance to the Creagan Narrows (Burgess, 2007). The only previous indication of the distribution of the beds resulted from surveys at both these locations carried out in 2012 (Moore *et al*., 2013). The current work considerably expanded the known extent of these beds and recorded the presence of an additional bed to the east of the Creagan bridge. There is no good evidence, however, that there has been spatial expansion of the beds over the time period of these observations. Differences between the recorded distribution of the beds in 2012 and 2017 - 2018 are consistent with an increase in the spatial spread of survey sites.

There is also no evidence for a temporal change in the percentage cover of *Limaria* byssus at the Shian and Creagan West sites, although the current survey was not designed to assess such change through formal statistical testing. Assessment of *Limaria* density through destructive sampling was not carried out in the current survey.

No marked temporal change in the community associated with the flame shell habitat was recorded on the Shian bed. A reduction in the density of the invasive red alga *Dasysiphonia japonica* was observed, but no significant change in any measures of diversity.

4.3 Condition assessment of the SAC designated feature 'reefs'

Site condition monitoring of the reef feature should consider assessment of the attributes of the feature listed in Table 1, of which three are mandatory for all monitored sites. The full suite of attributes specific to Loch Creran SAC are presented in the Site Attribute Table (SAT) (see Annex 4, adapted from Moore *et al*., (2006)).

Following monitoring of the feature, its condition is assessed by assignment to one of seven categories (SNH, 2010):

- Favourable Maintained – the attribute targets set for the natural features have been met, and the natural feature is likely to be secure on the site under present conditions.
- Favourable Recovered – the condition of the natural feature has recovered from a previous unfavourable condition, and attribute targets are now being met.
- Unfavourable Recovering – one or more of the attribute targets have not been met on the site, but management measures are in place to improve the condition.
- Unfavourable No Change – one or more of the attribute targets have not been met, and recovery is unlikely under the present management or other activity on the site.
- Unfavourable Declining – one or more of the attribute targets have not been met, evidence suggests that condition will worsen unless remedial action is taken.
- Partially Destroyed – something has happened on the site which has removed part of the natural features, there is no prospect of restoring the destroyed area.
- Totally Destroyed – the natural feature is no longer present, there is no prospect of restoring it.

This section derives an assessment of condition following consideration of the degree to which the targets set for each of the measured attributes have been met. For each attribute, the targets, methods for assessment of adherence to the target, and the results of assessment are summarised in Annex 4.

4.3.1 Extent

The reefs feature incorporates the bedrock reefs of the loch, as well as the serpulid reef and horse mussel habitats. Condition assessment of non-biogenic reefs was not within the remit of the current investigation and so no quantitative estimates can be made of temporal change in the extent of the entire feature. However, it is clear that total extent of the reefs feature will have been reduced since the 2005 baseline survey as a result of changes to the serpulid reef and horse mussel bed sub-features, and these changes are detailed in the following, relevant sections dealing with sub-features.

4.3.2 Biotope composition

The SAT stipulates the set of reef biotopes that should be found within the SAC, which includes the biogenic reef biotopes **SS.SBR.PoR.Ser**, **SS.SBR.SMus.ModHAs** and **SS.SBR.SMus.ModT**. All were recorded during the current monitoring programme. The original draft SAT (Moore *et al*., 2006) refers to recording their presence along fixed or relocatable transects but the broader category of 'monitoring transects' (which would also include MNCR phase 2 sites) is more appropriate.

4.3.3 Distribution and spatial pattern of biotopes at specified locations

Figure 55 illustrates the range of reef material currently present in areas of the loch that have historically supported the serpulid reef biotope. It is considered inappropriate to ascribe areas of scattered, broken, unpopulated, reef fragments to the same biotope as areas of well-formed, densely populated, upright reefs, even though there may be a degree of similarity in the epibiota. Similarly, areas of scattered, dead *Modiolus* shells would not be ascribed to a *Modiolus* bed biotope. No sharp distinction can be drawn between prime and degraded reef habitats, there being a continuum, and so here the serpulid reef biotope is considered to have been lost when the condition score falls to 8 (i.e. >90% broken reef material with a height <10 cm and tube occupancy <1%). Such areas probably most closely approach the biotope **SS.SMx.IMx** or locally could be considered to represent mosaics of **SS.SMx.IMx** and **SS.SSa.IMuSa**.

The same biogenic reef biotopes (**SS.SBR.PoR.Ser**, **SS.SBR.SMus.ModHAs** and **SS.SBR.SMus.ModT**) found along monitoring transects in 2005 were present in the same areas in 2014 - 18, except for the absence of **SS.SBR.PoR.Ser** in South Creagan Bay, which means that the target of maintenance of the distribution of biotopes has not been met.

Figure 55. Comparison of range of habitats supporting serpulid reef material in 2018. Upper photo Rubha Riabhach Bay, lower photo South Creagan Bay.

4.3.4 Extent of sub-feature or representative or notable biotopes

The SAT target for biogenic reefs is no change in the extent of the serpulid reef and horse mussel sub-features. Here, serpulid reef extent is taken to relate to the biotope, **SS.SBR.PoR.Ser**, which includes the reefs and the substrate on which they form, rather than the reefs alone.

Since the last SCM survey in 2005, activities or events considered to have the potential for reduction in the extent of the reefs feature relate only to the sub-feature serpulid reefs. These include the installation of three pontoons, two at Barcaldine and one at the Sea Life Centre. Pre-installation surveys of serpulid reefs are believed to have taken place in all three cases in accordance with the SAC management plan (Argyll and Bute Council, 2007) in order to avoid damage from the associated ground tackle. The only known activity identified with a high degree of likely damage is yacht anchoring in South Creagan bay, although only one such event has been witnessed between 2005 and 2019 by the first author.

The extent of serpulid reef habitat in the loch was estimated as 108 ha in 2005. No areal estimate of extent can be provided from the current study but 20% of the 40 serpulid condition transects examined by diving produced condition scores of 8 and this can be considered indicative of the scale of loss in extent.

The SAT stipulates confirmation of the results of the diver survey using sidescan sonar at Rubha Mór, South Shian, Sea Life Centre Bay and South Creagan Bay. The 2015 sonar imagery (Geusurv, 2015) indicated that the damage identified by diving was widespread at all four locations, although no measure of extent reduction can be derived from the sonar data.

As regards horse mussel beds, no reductions in extent have been recorded during the current survey work, apart from a gross reduction on one bed at the mouth of the loch. The spatial extent of this bed and hence the potential significance of the recorded habitat loss remains unknown. There is no reason to believe that any loss is not compatible with natural temporal fluctuations in population density.

4.3.5 Species composition of representative or notable biotopes

The MNCR phase 2 survey revealed little temporal change in species composition of the Upper Basin *Modiolus* bed between 2005 and the current 2017/18 survey work but a slight increase in some diversity indices for the biota associated with mussel clumps, possibly related to sample size differences.

4.3.6 Presence and abundance of specified species

Between 2005 and 2018 declines in *Modiolus* density were recorded along transects through the Upper Basin bed (from 7.40% to 3.23% cover), the Creagan West bed (from 37.75% to 8.00% cover) and the Druim Cairine bed at the mouth of the loch (from a SACFOR value of superabundant to common). How representative these figures are for the parent beds is unknown, but there are no indications to believe that such changes are not within the scope of natural temporal variability.

Marked temporal reductions in serpulid tube occupancy were recorded along three of the four serpulid reef MNCR phase 2 transects between 2005 and 2014, from >50% at all sites in 2005 to <1% at South Creagan Bay, 1-10% at Rubha Mór and South Shian and 10 - 50% at Sea Life Centre Bay.

4.3.7 Overall condition assessment

The uncertainty surrounding the cause of the currently degraded status of the serpulid reefs sub-feature of Loch Creran and the potential for restoration means that the reefs feature cannot be readily accommodated within the range of seven condition categories. The most likely explanation for the degradation is that the reefs are in a long-term phase of decay which may be influenced by natural ecological factors such as suitable substrate availability and grazing pressure. The most likely prognosis is that reef habitat loss will continue, perhaps reaching a tipping point once larval supply becomes critical. Even if all failing attribute targets can be ascribed to natural ecological change, the sub-feature cannot be considered to be secure and so be categorised as in Favourable condition. The condition categories most applicable would appear to be Unfavourable Declining or Partially Destroyed, depending upon the efficacy of possible remedial measures or existence of a natural cyclical development of the reefs which may eventually lead to spontaneous recovery. So Unfavourably Declining may be the closest fit to the condition status.

4.4 Condition assessment of the MPA designated feature 'flame shell beds'

The current survey recorded the presence of three flame shell beds in Loch Creran covering an area of 35 ha. The previous survey in 2012 (Moore *et al*., 2013) found two of these beds with a total extent of 19 ha. The difference in coverage values is explicable in terms of an increase in the spatial spread of survey sites, rather than a temporal change in bed extent. There is no evidence for localised retraction in bed extent. On the two beds examined in both surveys mean byssal coverage values were similar for both survey periods indicating the absence of gross temporal change in the density of *Limaria hians*. No marked temporal change in the community associated with the flame shell habitat was recorded on the Shian bed. A reduction in the density of the invasive red alga *Dasysiphonia japonica* was observed, but no significant change in any measures of diversity. The evidence suggests there has been no reduction in any of the measures of condition of the flame shell bed habitat between 2012 and 2017 - 18 and these measures are indicative of a bed in good condition. The feature can be declared to be currently in Favourable Condition.

4.5 Recommendations

Based on the results from the introduction of suitable colonisation substrates to the loch (Cook, 2016 and subsequent work reported herein), some restoration of the serpulid reef habitat may be possible, although it may be considered undesirable in view of the artificial manipulation of what may be a natural cycle of reef development and decay. A medium scale, localised, restoration programme could be established in an area where the reefs have effectively become extinct (such as South Creagan Bay). This could indicate the potential for this approach and could be used as an experimental and supply site for reef studies, such as those discussed below.

Conservation of serpulid reefs should be underpinned by a better knowledge of the factors influencing reef development and senescence. Relevant issues include the extent to which grazing and other forms of predation control reef development on different substrates such as rock and serpulid reef material at different stages of integrity, and the possible role of substrate availability in limiting reef development. The precariousness of reef persistence could be better assessed with a knowledge of the population dynamics of *Serpula vermicularis* in the loch. Further insight into the factors influencing reef condition might be gained from comparative studies with other serpulid reef locations, most notably, Ardbear Lough, Ireland.

With improving knowledge of the distribution of horse mussel beds in the loch, the future design of monitoring requires revision. To ensure representative monitoring of whole beds, monitoring sites would benefit from being increased in number and more spatially dispersed, and would probably benefit from focussing on mussel density, rather than percentage cover. There are, however, practical considerations in this approach, particularly the difficulty in servicing geographically distant sites by diving during narrow slack water windows. A better understanding of horse mussel bed distribution in the lower basin of the loch would contribute to better focussed monitoring.

Under the Inshore Fishing (Prohibition of Fishing and Fishing Methods) (Scotland) Order 2015 the use of most forms of fishing gear except for handlines and rod and line is banned from the area covered by the Loch Creran SAC/MPA (Figure 56). An exception is made for creel fishing for the central, deeper regions of the upper and lower basins (Figure 56). This affords protection to the serpulid and rocky reefs, flame shell beds and horse mussel beds insofar as their distribution was understood at the time of the legislation. It is now clear, however, that a significant extent of the flame shell habitat, as well as horse mussel bed patches are exposed to potential disturbance from creeling (Figure 56).

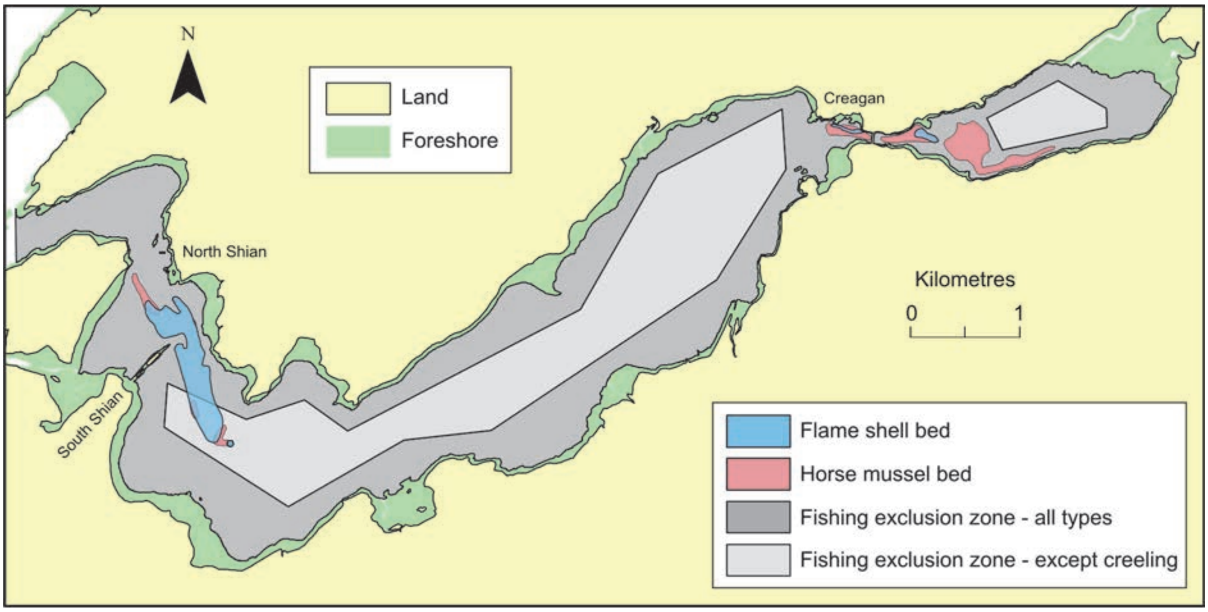

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Figure 56. Distribution of flame shell and horse mussel beds in relation to fishing exclusion zones in Loch Creran.

With the recent decline of the nearby major flame shell bed at Port Appin (Moore *et al.*, 2012; Cook, 2016), the Shian bed may now represent the principal source of larval supply for the Loch Linnhe system. Any form of physical abrasion of the flame shell byssal turf habitat is likely to cause damage, not only from mobile fishing gear (e.g. Hall-Spencer & Moore, 2000; Moore *et al.*, 2018; Trigg & Moore, 2009) but also from static gear such as creels. Creeling has been implicated as a possible contributor to the demise of the Port Appin bed through not only direct impact, but also the removal of kelp rooted in the byssal turf (Moore *et al.*, 2012).

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ANNEX 1: SERPULID REEF SURVEY DATA

Table 1.1. Details of MNCR phase 2 transects through serpulid reef habitat in Loch Creran in 2005 (Moore et al., 2006) and from which video was collected in 2005 and in 2014 (Tulbure, 2015) and analysed during the current study.

	Transect			
	SV01	**SV02**	**SV03**	**SV04**
Location	Rubha Mór	South Shian	Sea Life Centre Bay	South Creagan
Latitude start	56.51378	56.51782	56.52252	56.54533
Longitude start	-5.38290	-5.39768	-5.33368	-5.29932
Latitude end	56.51396	56.51764	56.52243	56.54553
Longitude end	-5.38314	-5.39793	-5.33331	-5.29915
Bearing (ºT)	324	219	114	24
Depth below CD (m)	7.6-8.0	7.7-7.8	6.5-6.6	5.7-6.1
Date (2005)	23/07/2005	24/07/2005	25/07/2005	26/07/2005
Date (2014)	15/11/2014	16/11/2014	16/11/2014	16/11/2014

Table 1.2. Physical, locational and temporal details of serpulid reef condition transects worked in the lower basin of Loch Creran.

Site	**Transect**	**Date**	**Bearing (°M)**	**Start time (UT)**	**Start latitude**	**Start longitude**	**Depth below CD start (m)**	**End time (UT)**	**End latitude**	**End longitude**	**Depth below CD end (m)**
S1	S1.1	21/08/2018	270	10:34:15	56.545408	-5.298348	6.0	10:40:10	56.545387	-5.298725	5.9
S1	S1.2	21/08/2018	90	10:44:10	56.545480	-5.298724	6.2	10:50:40	56.545481	-5.298385	6.3
S2	S2.1	14/06/2017	270	08:29:20	56.545351	-5.299084	5.8	08:38:00	56.545335	-5.299433	5.9
S2	S2.2	14/06/2017	90	08:42:30	56.545443	-5.299445	6.2	08:49:15	56.545446	-5.299137	6.2
S3	S3.1	13/06/2017	0	12:03:45	56.523210	-5.333322	7.4	12:12:00	56.523408	-5.333306	7.9
S3	S3.2	13/06/2017	180	12:15:45	56.523427	-5.333161	7.6	12:27:30	56.523228	-5.333127	7.2
S4	S4.1	20/08/2018	270	08:45:50	56.522423	-5.333194	5.5	08:55:30	56.522390	-5.333607	6.3
S4	S4.2	20/08/2018	90	09:00:15	56.522506	-5.333616	6.6	09:08:45	56.522511	-5.333254	5.8
S5	S5.1	14/06/2017	270	16:40:50	56.520230	-5.337743	5.8	16:48:45	56.520243	-5.338002	6.6
S5	S5.2	14/06/2017	90	16:53:00	56.520315	-5.338086	7.3	16:59:50	56.520328	-5.337826	6.7
S6	S6.1	20/08/2018	270	10:42:45	56.511947	-5.380231	7.5	10:50:45	56.511930	-5.380635	8.1
S6	S6.2	20/08/2018	90	10:54:45	56.512035	-5.380608	9.0	11:02:30	56.512035	-5.380251	8.5
S7	S7.1	15/06/2017	0	10:42:45	56.512889	-5.382108	7.8	10:51:30	56.513080	-5.382108	7.5
S7	S7.2	15/06/2017	180	10:55:15	56.513082	-5.381922	8.0	11:02:15	56.512875	-5.381916	8.2
S8	S8.1	15/06/2017	0	09:11:00	56.513817	-5.383077	8.2	09:17:20	56.514016	-5.383105	9.5
S8	S8.2	15/06/2017	180	09:20:45	56.514033	-5.382934	10.0	09:27:30	56.513834	-5.382922	8.6
S9	S9.1	22/08/2018	270	08:11:40	56.517133	-5.395215	9.8	08:17:50	56.517133	-5.395588	9.3
S9	S9.2	22/08/2018	90	08:21:15	56.517218	-5.395531	10.2	08:27:10	56.517209	-5.395193	10.7
S10	S10.1	13/06/2017	0	14:41:45	56.517618	-5.397847	8.4	14:50:30	56.517806	-5.397869	6.9
S10	S10.2	13/06/2017	180	14:54:30	56.517803	-5.397666	8.0	15:02:05	56.517635	-5.397700	9.1
S11	S11.1	20/08/2018	0	14:44:30	56.518711	-5.397607	5.0	14:52:20	56.518955	-5.397561	6.0
S11	S11.2	20/08/2018	180	14:55:20	56.518940	-5.397402	6.4	15:01:45	56.518723	-5.397401	5.4
S12	S12.1	14/06/2017	0	14:44:00	56.520129	-5.398702	6.9	14:52:50	56.520323	-5.398691	6.8
S12	S12.2	14/06/2017	180	14:57:10	56.520327	-5.398529	7.1	15:04:15	56.520132	-5.398488	7.3
S13	S13.1	22/08/2018	270	10:57:40	56.526296	-5.373796	3.5	11:05:20	56.526274	-5.374209	4.8
S13	S13.2	22/08/2018	90	11:09:00	56.526387	-5.374218	4.4	11:16:30	56.526381	-5.373825	3.4
S14	S14.1	14/06/2017	0	11:55:45	56.525578	-5.373689	6.1	12:02:30	56.525741	-5.373676	4.7

Table 1.2 continued

Site	Transect	Date	Bearing (°M)	Start time (UT)	Start latitude	Start longitude	Depth below CD start (m)	End time (UT)	End latitude	End longitude	Depth below CD end (m)
S14	S14.2	14/06/2017	180	12:07:20	56.525752	-5.373529	4.1	12:14:35	56.525568	-5.373528	5.4
S15	S15.1	28/01/2019	0	13:12:04	56.522847	-5.334511	8.1	13:22:04	56.522925	-5.334556	8.4
S15	S15.2	28/01/2019	180	13:26:14	56.522962	-5.334421	8.2	13:34:04	56.522823	-5.334427	7.9
DR01	DR01	24/08/2018	95	08:03:00	56.545300	-5.299550	5.5	08:08:00	56.545294	-5.299149	5.4
DR02	DR02	25/08/2018	225	07:54:00	56.522433	-5.334350	7.7	08:18:00	56.522269	-5.334617	6.8
DR03	DR03	27/08/2018	285	09:05:00	56.520250	-5.350783	2.5	09:24:00	56.520275	-5.351163	2.7
DR04	DR04	27/08/2018	100	15:05:00	56.513083	-5.374650	7.7	15:27:00	56.513056	-5.374251	8.1
DR05	DR05	27/08/2018	320	14:11:00	56.512083	-5.382067	7.7	14:33:00	56.512245	-5.382341	7.1
DR06	DR06	27/08/2018	50	10:35:00	56.513333	-5.383050	6.7	10:55:00	56.513273	-5.383424	5.6
DR07	DR07	26/08/2018	185	14:44:00	56.518050	-5.397733	6.5	15:05:00	56.517829	-5.397747	8.5
DR08	DR08	22/08/2018	180	12:58:00	56.523917	-5.397783	6.9	13:20:00	56.523709	-5.397688	5.8
DR09	DR09	26/08/2018	231	09:20:00	56.525883	-5.374267	7.8	09:45:00	56.525729	-5.374518	6.0
DR10	DR10	24/08/2018	270	15:55:00	56.533050	-5.340233	6.5	16:15:00	56.532992	-5.340598	6.4

Table 1.3. Biological details of serpulid reef condition transects worked in the lower basin of Loch Creran.

Transect	% reef cover	% broken reef	% occupied tubes	% vertical tubes	Mean reef canopy height (cm)	Maximum reef height (cm)	Pristine reefs present	% reef >30 cm high	Condition score	Notes
S1.1	1-5	100	0-1	0-1	<10	9	N	0	8	
S1.2	<1	100	0-1	0-1	<10	13	N	0	8	
S2.1	10-20	100	0-1	0-1	<10	10	N	0	8	% reef cover at lower end of this range
S2.2	<1	90-99	0-1	0-1	<10	16	N	0	8	cover of serpulid material (living or dead) <<1%. But one small (16 cm, ~10 tubes) reef
S3.1	20-40	90-99	1-10	1-10	<10	37	N		7	
S3.2	20-40	90-99	1-10	1-10	<10	26	N	0	7	
S4.1	1-5	50-90	10-50	>50	10-30	35	Y	1-10	4	
S4.2	1-5	<50	>50	>50	10-30	42	Y	10-50	2	
S5.1	10-20	90-99	1-10	1-10	10-30	20	N	0	6	% reef cover at lower end of this range
S5.2	10-20	90-99	1-10	1-10	10-30	28	N	0	6	
S6.1	10-20	90-99	1-10	1-10	<10	25	N	0	7	
S6.2	5-10	90-99	1-10	1-10	<10	27	N	0	7	
S7.1	20-40	50-90	1-10	1-10	10-30	28	N	0	5	% reef cover at lower end of this range. % broken reef, % occupied tubes & % vertical tubes each at upper end of the ranges given. Pristine reef present but <30 cm
S7.2	20-40	50-90	1-10	1-10	10-30	38	Y	<1	5	% reef cover at lower end of this range. % broken reef at upper end of the range
S8.1	5-10	100	0-1	0-1	<10	14	N	0	8	
S8.2	10-20	100	0-1	0-1	<10	14	N	0	8	% reef cover at lower end of this range
S9.1	5-10	100	0-1	0-1	<10	14	N	0	8	
S9.2	5-10	100	0-1	0-1	<10	21	N	0	8	
S10.1	20-40	90-99	1-10	0-1	<10	15	N	0	7	
S10.2	10-20	90-99	0-1	0-1	<10	21	N	0	8	
S11.1	<1	90-99	1-10	1-10	<10	27	N	0	7	
S11.2	<1	100	0-1	0-1	<10	10	N	0	8	

Table 1.3 continued

Transect	% reef cover	% broken reef	% occupied tubes	% vertical tubes	Mean reef canopy height (cm)	Maximum reef height (cm)	Pristine reefs present	% reef >30 cm high	Condition score	Notes
S12.1	20-40	50-90	>50	10-50	10-30	33	Y	1-5	3	% broken at lower end of this range, % vertical tubes at upper end of this range, shotline landed ~3 m south of two very large cubic mooring blocks, well developed reefs on blocks but sparse on surrounding seabed, swam north ~10-15 m to get clear of spars
S12.2	20-40	50-90	>50	10-50	10-30	42	Y	1-5	3	% reef cover at upper end of this range
S13.1	5-10	<50	>50	>50	10-30	50	Y	10-50	2	
S13.2	1-5	<50	>50	>50	10-30	40	Y	10-50	2	
S14.1	10-20	<50	>50	>50	>30	65	Y	~80	1	% reef cover at lower end of this range
S14.2	5-10	<50	>50	>50	>30	62	Y	~75	1	% reef cover at upper end of this range
S15.1	5-10	90-99	1-10	1-10	<10	25	N	0	7	
S15.2	10-20	90-99	1-10	1-10	<10	30	N	0-1	7	
DR01	1-5	100	0-1	0-1	<10	6	N	0	8	
DR02	10-20	90-99	1-10	1-10	<10	36	N	0-1	7	
DR03	5-10	50-90	>50	>50	10-30	28	N	0	3	
DR04	20-40	90-99	0-1	0-1	<10	22	N	0	8	mostly dead rubble. Heavy overgrowth of red algae & *Pyura*
DR05	5-10	50-90	10-50	10-50	10-30	30	N	0-1	4	
DR06	5-10	50-90	10-50	10-50	10-30	20	N	0	4	
DR07	1-5	100	0-1	0-1	<10	11	N	0	8	mostly rubble, a few small to medium reefs (off transect)
DR08	20-40	50-90	10-50	10-50	10-30	35	Y	1-10	4	
DR09	10-20	<50	>50	>50	10-30	64	Y	10-50	2	
DR10	1-5	90-99	0-1	0-1	<10	28	N	0	8	

Table 1.4. Physical, locational and temporal details of serpulid reef zigzag condition sites worked in the upper basin of Loch Creran. Surveyors are: DH (Dan Harries), KT (Kieran Tulbure).

Site	Surveyor	Date	Bearing (°M)	Start time (UT)	Start latitude	Start longitude	Depth below CD start (m)	End time (UT)	End latitude	End longitude	Depth below CD end (m)
S94	DH	25/08/2018	~270	11:24:45	56.549515	-5.276367	5.4	11:41:10	56.549494	-5.278594	4.8
S97	KT	25/08/2018	~45	15:43:30	56.552982	-5.267011	5.6	16:06:45	56.553526	-5.265853	4.8
S99	KT	25/08/2018	~270	09:42:00	56.552760	-5.257171	4.9	10:08:18	56.553041	-5.258227	2.6
S106	KT	24/08/2018	~90	11:56:10	56.546515	-5.264756	5.5	12:23:17	56.546676	-5.263761	3.5
S107	DH	24/08/2018	~270	13:21:20	56.545560	-5.267527	6.0	13:35:30	56.545333	-5.269120	3.3
S109	DH	24/08/2018	~270	10:45:30	56.545142	-5.276020	4.4	11:02:15	56.545339	-5.278198	4.4

Table 1.5. Biological details of serpulid reef zigzag condition sites worked in the upper basin of Loch Creran.

Site	% reef cover maximum	% broken reef	% occupied tubes	% vertical tubes	Mean reef canopy height (cm)	Maximum reef height (cm)	Pristine reefs present	% reef >30 cm high	Single tubes	Small reefs	Medium reefs	Large reefs	Notes
S94	<1	50-90	>50	>50	<10	12	N	0	Y	Y	N	N	a few scattered small reefs of 4 or 5 tubes
S97	<1	<50	>50	>50	<10	13	N	0	Y	Y	N	N	
S99	<1	<50	>50	>50	<10	10	N	0	Y	Y	N	N	
S106	<1	50-90	>50	10-50	<10	20	N	0	Y	Y	Y	N	
S107	<1	<50	>50	>50	<10	6	N	0	Y	Y	N	N	reefs limited to a few small clusters at the base of the boulders in the shallows
S109	<1	100	0-1	0-1	<10	3	N	0	Y	N	N	N	

Table 1.6. Dimensions of 33 serpulid reefs measured in situ in 2001 from off Rubha Mór, Loch Creran. Measurements are maximum height, maximum width (major axis) and maximum width perpendicular to the major axis (minor axis) of well-formed, intact reefs. Plan area is derived, based on an ellipsoidal model.

Height (cm)	**Width (cm)**	**Breadth (cm)**	**Area (cm^2)**
11.0	5.0	3.5	13.74
11.0	10.0	9.0	70.69
18.0	14.0	12.0	131.95
18.0	15.0	11.5	135.48
20.0	14.0	14.0	153.94
21.0	20.0	9.5	149.23
22.0	10.0	8.0	62.83
26.0	18.0	16.0	226.19
26.0	20.0	18.0	282.74
28.0	20.0	18.0	282.74
30.0	25.0	18.0	353.43
34.0	28.0	26.0	571.77
34.0	38.0	30.0	895.35
35.0	30.0	30.0	706.86
35.0	40.0	35.0	1099.56
36.0	30.0	28.0	659.73
36.0	34.0	22.0	587.48
36.0	34.0	22.0	587.48
36.0	34.0	32.0	854.51
36.0	36.0	30.0	848.23
36.0	56.0	48.0	2111.15
40.0	46.0	42.0	1517.39
40.0	66.0	54.0	2799.16
40.0	35.0	35.0	962.11
42.0	48.0	30.0	1130.97
42.0	45.0	40.0	1413.72
44.0	48.0	46.0	1734.16
45.0	50.0	45.0	1767.15
46.0	54.0	44.0	1866.11
46.0	54.0	38.0	1611.64
48.0	66.0	30.0	1555.09
50.0	60.0	40.0	1884.96
54.0	60.0	42.0	1979.20

Table 1.7. Measurements of aggregations of <u>Serpula vermicularis</u> colonizing replicates of experimental substrates of five types (treatments) at Main site in Sea Life Centre Bay and colonizing one type (scallop shell large bag) at five locations in Loch Creran. Substrates deployed 27-28 March 2012, measured 13-15 June 2017.

Site name	**Location**	**Replicate**	**Treatment**	**Clump max. height (cm)**	**% cover of *S. vermicularis* reef**	**Approx. number of reef clumps**	**Appprox. tube abundance per clump**	**Notes**
Main site	Sea Life Centre Bay	A	Boulder	0	0	0	0	*Spirobranchus* 1-5% on steep sides, 1 or 2 individual *Serpula* encrusting
Main site	Sea Life Centre Bay	B	Boulder	2.5	2	3	3-5	
Main site	Sea Life Centre Bay	C	Boulder	0	0	0	0	*Spirobranchus* 1-5% on steep sides, ~4 individual *Serpula* encrusting
Main site	Sea Life Centre Bay	D	Boulder	0	0	0	0	*Spirobranchus* 1-5% on steep sides, ~5 individual *Serpula* encrusting, one raised~1 cm
Main site	Sea Life Centre Bay	E	Boulder	2	<1	1	3	*Spirobranchus* 1-5% on steep sides, ~6 individual *Serpula* encrusting (inc clump)
Main site	Sea Life Centre Bay	F	Boulder	0	0	0	0	*Spirobranchus* 1-5% on steep sides, ~20 individual Serpula encrusting, *Serpula* cover ~1-5%
Main site	Sea Life Centre Bay	A	Cobbles large bag	9	10	10	5-15	High occupancy, small individuals present
Main site	Sea Life Centre Bay	B	Cobbles large bag	12	15	22	3-15	
Main site	Sea Life Centre Bay	C	Cobbles large bag	11	15	19	3-22	Small individuals present
Main site	Sea Life Centre Bay	D	Cobbles large bag	13	20	20	4-15	
Main site	Sea Life Centre Bay	E	Cobbles large bag	12	15	13	5-15	
Main site	Sea Life Centre Bay	F	Cobbles large bag	12	17	22	4-17	

Table 1.7 continued

Site name	**Location**	**Replicate**	**Treatment**	**Clump max. height (cm)**	**% cover of *S. vermicularis* reef**	**Approx. number of reef clumps**	**Appprox. tube abundance per clump**	**Notes**
Main site	Sea Life Centre Bay	A	Pile of scallop shell	0	0	0	0	*Spirobranchus* ~1%
Main site	Sea Life Centre Bay	B	Pile of scallop shell	0	0	0	0	*Spirobranchus* ~1%
Main site	Sea Life Centre Bay	C	Pile of scallop shell	0	0	0	0	*Spirobranchus* ~1%
Main site	Sea Life Centre Bay	D	Pile of scallop shell	0	0	0	0	*Spirobranchus* ~1%
Main site	Sea Life Centre Bay	E	Pile of scallop shell	0	0	0	0	*Spirobranchus* ~1%, ~4 individual *Serpula* encrusting
Main site	Sea Life Centre Bay	F	Pile of scallop shell	0	0	0	0	*Spirobranchus* ~1-5%, <1% *Serpula*, one raised ~3 cm
Main site	Sea Life Centre Bay	A	Scallops small bag	9	5	3	3-5	High occupancy
Main site	Sea Life Centre Bay	B	Scallops small bag	<1	0	0	0	
Main site	Sea Life Centre Bay	C	Scallops small bag	5	3	1	~6	
Main site	Sea Life Centre Bay	D	Scallops small bag	0	0	0	0	Single tube raised ~1 cm
Main site	Sea Life Centre Bay	E	Scallops small bag	0	0	0	0	
Main site	Sea Life Centre Bay	F	Scallops small bag	8	3	3	2-4	
Main site	Sea Life Centre Bay	A	Scallop shell large bag	12	10	12	4-20	
Main site	Sea Life Centre Bay	B	Scallop shell large bag	7	3	11	3-6	
Main site	Sea Life Centre Bay	C	Scallop shell large bag	11	7	8	3-15	
Main site	Sea Life Centre Bay	D	Scallop shell large bag	12	12	?	4-20	

Table 1.7 continued

Site name	**Location**	**Replicate**	**Treatment**	**Clump max. height (cm)**	**% cover of *S. vermicularis* reef**	**Approx. number of reef clumps**	**Appprox. tube abundance per clump**	**Notes**
Main site	Sea Life Centre Bay	E	Scallop shell large bag	17	12	16	4-20	
Main site	Sea Life Centre Bay	F	Scallop shell large bag	13	20	22	4-30	
Rubha Mór	N of Rubha Mór	A	Scallop shell large bag	6	5	2	2,2	
Rubha Mór	N of Rubha Mór	B	Scallop shell large bag	9	15	6	4,4,3,8,2,2	
Rubha Mór	N of Rubha Mór	C	Scallop shell large bag	8	20	7	10,4,4,2,10,7	
Rubha Mór	N of Rubha Mór	D	Scallop shell large bag	9	10	7	33,9,4,4,3	
Rubha Mór	N of Rubha Mór	E	Scallop shell large bag	6	5	4	4,2,3,2	
Rubha Mór	N of Rubha Mór	F	Scallop shell large bag	9	10	5	19,2,2,2,3	
Kelco	Rubh' an Tigh-shalainn	A	Scallop shell large bag	8	10	7	10,3,7,15,4,5	High proportion of dead (unoccupied) tubes and damaged tubes; all counts are for occupied tubes
Kelco	Rubh' an Tigh-shalainn	B	Scallop shell large bag	6	1	2	4,3	High proportion of dead (unoccupied) tubes and damaged tubes; all counts are for occupied tubes
Kelco	Rubh' an Tigh-shalainn	C	Scallop shell large bag	0	<1	0	0	High proportion of dead (unoccupied) tubes and damaged tubes; all counts are for occupied tubes
Kelco	Rubh' an Tigh-shalainn	D	Scallop shell large bag	4	2	2	4,3	High proportion of dead (unoccupied) tubes and damaged tubes; all counts are for occupied tubes
Kelco	Rubh' an Tigh-shalainn	E	Scallop shell large bag	6	5	5	4,4,4,3	High proportion of dead (unoccupied) tubes and damaged tubes; all counts are for occupied tubes
Kelco	Rubh' an	F	Scallop shell	4	2	2	5,4	High proportion of dead (unoccupied)

Table 1.7 continued

Site name	**Location**	**Replicate**	**Treatment**	**Clump max. height (cm)**	**% cover of *S. vermicularis* reef**	**Approx. number of reef clumps**	**Appprox. tube abundance per clump**	**Notes**
	Tigh-shalainn		large bag					tubes and damaged tubes; all counts are for occupied tubes
Mussel farm	Ardnaclach	A	Scallop shell large bag	4	<1	1	2	
Mussel farm	Ardnaclach	B	Scallop shell large bag	0	0	0	0	
Mussel farm	Ardnaclach	C	Scallop shell large bag	0	0	0	0	
Mussel farm	Ardnaclach	D	Scallop shell large bag	0	0	0	0	
Mussel farm	Ardnaclach	E	Scallop shell large bag	4	5	2	3,2	
Mussel farm	Ardnaclach	F	Scallop shell large bag	0	0	0	0	
Upper basin	Upper basin S coast	A	Scallop shell large bag	3	5	1	3	Heavily encrusted with *Spirobranchus*; *S. vermicularis* present
Upper basin	Upper basin S coast	B	Scallop shell large bag	0	0	0	0	Heavily encrusted with *Spirobranchus*; *S. vermicularis* present
Upper basin	Upper basin S coast	C	Scallop shell large bag	14	15	4	7,7,4,8	Heavily encrusted with *Spirobranchus*; *S. vermicularis* present
Upper basin	Upper basin S coast	D	Scallop shell large bag	0	0	0	0	Heavily encrusted with *Spirobranchus*; *S. vermicularis* present
Upper basin	Upper basin S coast	E	Scallop shell large bag	0	0	0	0	Heavily encrusted with *Spirobranchus*; *S. vermicularis* present

ANNEX 2: HORSE MUSSEL BED SURVEY DATA

Table 2.1. Site details and abundance of Modiolus modiolus (SACFOR) at stations along eight transects in Loch Creran. Surveyors are DH (Dan Harries), GS (Graham Saunders), JB (Jo Beaton), KT (Kieran Tulbure), LK (Lisa Kamphausen), LP (Lewis Press).

Transect	Station	Date	Time (UT)	Latitude	Longitude	Depth below CD (m)	SACFOR	Surveyor	Substrate
MM01	MM01/0	19/08/2018	14:32:35	56.545495	-5.268731	5.5	C	LP, GS	
MM01	MM01/1	19/08/2018	14:25:15	56.545656	-5.268759	8.4	C	LP, GS	
MM01	MM01/2	19/08/2018	14:18:55	56.545813	-5.268744	11.5	C	LP, GS	
MM01	MM01/3	19/08/2018	14:12:01	56.546037	-5.268716	15.5	C	LP, GS	
MM01	MM01/4	19/08/2018	14:08:14	56.546155	-5.268802	20.9	C	LP, GS	
MM01	MM01/5	19/08/2018	13:54:39	56.546305	-5.268836	26.8	C	LP, GS	
MM02	MM02/0	24/08/2018	14:39:38	56.544474	-5.273774	5.7	O	LP	Cobble & shell on muddy sand
MM02	MM02/1	24/08/2018	14:32:12	56.544735	-5.273830	17.8	C	LP	Shelly mud
MM02	MM02/2	24/08/2018	14:26:51	56.544869	-5.273814	17.4	A	LP	Shelly mud
MM02	MM02/3	24/08/2018	14:21:36	56.545086	-5.273889	21.2	A	LP	Shelly muddy sand
MM02	MM02/4	24/08/2018	14:14:59	56.545341	-5.273925	24.6	F	LP	Shelly mud
MM02	MM02/5	24/08/2018	14:07:30	56.545642	-5.273905	26.4	N	LP	Muddy shelly sand
MM03	MM03/0	21/08/2018	13:20:46	56.544898	-5.271271	3.0	N	LP	Muddy gravelly shell with kelp
MM03	MM03/1	21/08/2018	13:14:00	56.545070	-5.271355	7.9	C	LP	Muddy gravelly shell
MM03	MM03/2	21/08/2018	13:07:10	56.545293	-5.271349	13.7	A	LP	Pebbles with shells & mud
MM03	MM03/3	21/08/2018	13:01:02	56.545420	-5.271379	18.3	A	LP	Pebbles with shells & mud
MM03	MM03/4	21/08/2018	12:56:12	56.545557	-5.271307	21.4	C	LP	Very shelly mud
MM03	MM03/5	21/08/2018	12:45:59	56.545717	-5.271336	26.6	O	LP	Shelly mud
MM04	MM04/0	28/01/2019	09:58:14	56.546050	-5.266149	3.7	O	DH	Boulders & cobbles (~80%) with muddy sand infill
MM04	MM04/1	28/01/2019	09:48:24	56.546251	-5.266195	10.2	C	DH	Surface gravel (~80%) and pebbles (~10%) on muddy sediment
MM04	MM04/2	28/01/2019	09:38:44	56.546467	-5.266220	15.4	C	DH	Mud with 10-20% cover dead Modiolus shell

Table 2.1 continued

Transect	Station	Date	Time (UT)	Latitude	Longitude	Depth below CD (m)	SACFOR	Surveyor	Substrate
MM04	MM04/3	28/01/2019	09:30:34	56.546681	-5.266256	25.5	F	DH	Mud with 30-40% cover dead Modiolus shell
MM04	MM04/4	28/01/2019	09:24:24	56.546895	-5.266290	30.2	N	DH	Mud
MM05	MM05/0	21/08/2018	14:54:40	56.548334	-5.294942	5.2	C	DH, KT	Pebbles 10%, sand & shell gravel 90%
MM05	MM05/1	21/08/2018	14:49:40	56.548170	-5.295015	7.1	A	DH, KT	Pebbles 30%, sand & shell gravel 70%
MM05	MM05/2	21/08/2018	14:31:20	56.547968	-5.295142	8.5	C	DH, KT	Pebbles 50%, sand & shell gravel 50%
MM05	MM05/3	21/08/2018	14:10:20	56.547792	-5.295146	10.2	C	DH, KT	Pebbles 90%, sand & shell gravel 10%
MM06	MM06/0	22/08/2018	10:03:10	56.540160	-5.405374	10.4	N	LP, JB	Shell gravel with boulders
MM06	MM06/1	22/08/2018	09:59:49	56.539960	-5.405311	11.8	N	LP, JB	Shell gravel with boulders
MM06	MM06/2	22/08/2018	09:51:33	56.539603	-5.405291	17.6	N	LP, JB	Bedrock, cobble & shell
MM06	MM06/3	22/08/2018	09:44:05	56.539395	-5.404949	26.7	N	LP, JB	Boulders, cobbles & shell
MM06	MM06/4	22/08/2018	09:39:31	56.539230	-5.404838	28.7	R	LP, JB	Boulders / cobbles
MM07	MM07/0	20/08/2018	13:53:50	56.535871	-5.394791	3.2	N	GS	Muddy shell gravel
MM07	MM07/1	20/08/2018	13:46:50	56.535900	-5.395361	11.0	N	GS	Shell gravel
MM07	MM07/2	20/08/2018	13:42:40	56.535913	-5.395580	12.1	A	GS	Shells & shell debris
MM07	MM07/3	20/08/2018	13:37:40	56.535929	-5.396011	13.0	C	GS	Shells & shell debris
MM07	MM07/4	20/08/2018	13:33:12	56.535913	-5.396169	13.9	C	GS	Shell gravel
MM07	MM07/5	20/08/2018	13:29:15	56.535907	-5.396450	14.8	O	GS	Shell gravel
MM07	MM07/6	20/08/2018	13:25:25	56.535883	-5.396774	16.8	O	GS	Shell gravel
MM07	MM07/7	20/08/2018	13:18:20	56.535896	-5.397258	19.3	N	GS	Rock, shell gravel
MM08	MM08/1	27/08/2018	12:46:00	56.539937	-5.405620	11.3	C	LK	80% cobbles, 10% pebbles, 5%shells, 5% shell gravel
MM08	MM08/2	27/08/2018	12:50:29	56.540098	-5.405536	9.9	N	LK	70% pebbles, 20 % cobbles, 5% boulders, 5% shells
MM08	MM08/3	27/08/2018	12:59:18	56.540277	-5.405607	8.1	N	LK	30% shell gravel, 30% pebbles, 20% cobbles, 10% boulders

Table 2.1 continued

Transect	Station	Date	Time (UT)	Latitude	Longitude	Depth below CD (m)	SACFOR	Surveyor	Substrate
MM08	MM08/4	27/08/2018	13:05:00	56.540447	-5.405569	6.1	N	LK	30% shell gravel, 30 % pebbles, 20% cobbles, 20 boulders
MM08	MM08/5	27/08/2018	13:10:00	56.540731	-5.405598	4.4	N	LK	Boulders and kelp
MM08	MM08/6	27/08/2018	13:17:00	56.540796	-5.405521	3.0	N	LK	40% boulders, 40% cobbles, 20% shell and shell gravel
MM08	MM08/7	27/08/2018	13:21:00	56.540901	-5.405389	2.4	N	LK	50% shell gravel, 20% cobbles, 20% boulders, 10% pebbles

Table 2.2. Density of <u>Modiolus modiolus</u> at stations along two transects. Density is given in terms of the number of cross-string intersections of 10 replicate 0.25 m^2 quadrats directly overlying living mussels. Each quadrat has 16 intersections. Surveyors are DH (Dan Harries), GS (Graham Saunders), LP (Lewis Press) and KT (Kieran Tulbure).

Transect	**Station**	**Depth below CD (m)**	**Replicate quadrat**									
			1	2	3	4	5	6	7	8	9	10
MM01	MM01/0	5.5	0	0	0	0	1	0	0	0	1	1
MM01	MM01/1	8.4	1	0	0	2	0	0	1	0	0	0
MM01	MM01/2	11.5	0	0	0	2	0	1	0	0	0	1
MM01	MM01/3	15.5	1	1	0	1	2	0	1	0	1	0
MM01	MM01/4	20.9	1	1	1	3	1	0	0	0	2	0
MM01	MM01/5	26.8	0	0	0	0	2	0	1	1	0	0
MM01	Surveyor		GS	GS	GS	GS	GS	LP	LP	LP	LP	LP
MM05	MM05/0	5.2	0	0	0	0	0	2	1	1	2	0
MM05	MM05/1	7.1	2	1	1	2	0	1	2	1	1	0
MM05	MM05/2	8.5	0	3	0	1	1	0	0	4	1	0
MM05	MM05/3	10.2	1	0	1	1	0	1	0	0	1	0
MM05	Surveyor		DH	DH	DH	DH	DH	KT	KT	KT	KT	KT

Table 2.3. Abundance of <u>Modiolus modiolus</u> at stations along two transects. Abundance is given in terms of the number of live Modiolus within 10 replicate 0.25 m^2 quadrats. These quadrats are the same as those used for cross-string counts (see table above). Surveyors are DH (Dan Harries), GS (Graham Saunders), LP (Lewis Press) and KT (Kieran Tulbure).

Transect	**Station**	**Depth below CD (m)**	**Replicate quadrat**									
			1	2	3	4	5	6	7	8	9	10
MM01	MM01/0	5.5	0	0	0	1	1	0	0	0	1	2
MM01	MM01/1	8.4	1	0	1	2	0	2	1	0	0	2
MM01	MM01/2	11.5	0	2	0	4	0	4	1	0	0	1
MM01	MM01/3	15.5	1	2	1	2	4	2	0	1	1	4
MM01	MM01/4	20.9	2	1	1	6	3	0	0	2	3	1
MM01	MM01/5	26.8	0	1	0	2	2	1	1	1	1	0
MM01	Surveyor		GS	GS	GS	GS	GS	LP	LP	LP	LP	LP
MM05	MM05/0	5.2	0	0	0	0	0	7	1	9	5	0
MM05	MM05/1	7.1	5	3	3	5	3	5	4	9	7	0
MM05	MM05/2	8.5	1	5	2	4	2	1	1	5	3	0
MM05	MM05/3	10.2	1	1	2	1	3	5	1	0	2	1
MM05	Surveyor		DH	DH	DH	DH	DH	KT	KT	KT	KT	KT

Table 2.4. Site details for spot dive survey of Modiolus modiolus distribution in the upper basin of Loch Creran.

Site	Date	Time start (UT	Time end (UT)	Latitude start	Longitude start	Latitude end	Longitude end	Depth start (m BCD)	Depth end (m BCD)
MD01	24/08/2018	12:08:30	12:14:30	56.548168	-5.278868	56.548231	-5.278297	19.1	17.8
MD02	25/08/2018	12:39:30	12:48:00	56.548708	-5.277897	56.548762	-5.277316	10.9	7.0
MD03	25/08/2018	13:16:04	13:20:00	56.548805	-5.275790	56.548842	-5.275578	13.2	13.4
MD04	24/08/2018	14:46:30	14:52:00	56.549147	-5.274194	56.549175	-5.274047	14.7	14.8
MD05	25/08/2018	11:51:30	11:58:00	56.548027	-5.274763	56.548062	-5.274129	18.9	19.9
MD06	24/08/2018	11:35:10	11:42:20	56.547986	-5.276662	56.548013	-5.275631	17.8	18.3
MD07	24/08/2018	13:28:21	13:33:15	56.547023	-5.277779	56.546993	-5.277495	18.8	18.8
MD08	24/08/2018	14:08:10	14:10:40	56.547249	-5.276566	56.547286	-5.276277	18.8	18.4
MD09	25/08/2018	11:16:30	11:21:45	56.547058	-5.274723	56.547061	-5.274676	18.0	17.7
MD11	24/08/2018	09:19:10	09:31:30	56.547046	-5.273476	56.546892	-5.273357	23.7	25.9
MD12	25/08/2018	10:40:30	10:49:00	56.546452	-5.275758	56.546631	-5.275407	18.3	18.9
MD13	24/08/2018	09:56:30	10:02:45	56.545991	-5.277105	56.546011	-5.277068	16.5	15.9
MD14	24/08/2018	10:32:00	10:35:00	56.546061	-5.274469	56.545914	-5.274544	22.1	21.4
MD20	25/08/2018	10:06:40	10:15:10	56.546909	-5.264346	56.547006	-5.263730	14.7	14.5
MD21	25/08/2018	09:35:05	09:39:19	56.547689	-5.261536	56.547692	-5.261490	19.9	19.3
MD22	25/08/2018	10:49:40	10:55:04	56.546287	-5.278444	56.546238	-5.278386	17.1	15.3
MD23	25/08/2018	13:16:30	13:22:30	56.547089	-5.279615	56.547065	-5.279375	16.1	17.0
MD24	25/08/2018	12:27:45	12:38:05	56.547205	-5.280992	56.547257	-5.281058	5.9	5.0

Table 2.5. Habitat data for spot dive survey of Modiolus modiolus distribution in the upper basin of Loch Creran. Surveyors are: AL (Alastair Lyndon), BJ (Ben James), GS (Graham Saunders), KT (Kieran Tulbure), LK (Lisa Kamphausen).

Site	**Substrate**	**Notes**	**Surveyor**	***Modiolus* SACFOR**
MD01	Muddy fine sand with shell gravel and *Modiolus* shells. Substrates became finer with mud but areas of bedrock outcrops also observed to the north.	1-9 / 3x3m Mainly dead shells but a few scattered live individuals	BJ	F
MD02	Fine shelly muddy sand (not burrowed but muddy). *Modiolus* shells and scattered live *Modiolus.* Moved onto bedrock outcrops (at 13:43:30 at 10.7m) with sediment pockets - still with sparser *Modiolus* (live and shells) at end of run.	1-9 / m2 initially but at low end (~1 or 2) Dropped to 1-9 / 3x3m on rockier areas.	BJ	C(F)
MD03	Mud and shell gravel, empty shells (including *Modiolus*), Rare boulders	average 1-9 / m2 though in patches less than 1 / m2	LK	C(F)
MD04	Soft mud with burrows - some large. One *Nephrops* observed in a large burrow - sparse / seapens and a single fireworks anemone.	Nil	BJ	N
MD05	Muddy fine sand and *Modiolus* shells - at start and end	1-9 / m2 at start and end	GS	C
MD06	Muddy shell gravel at start. Muddy fine sand at the end.	1-9 / m2 at start and end	GS	C
MD07	Pebbles (90%) on muddy sand	1-9 / m2 Average 6 / m2	LK	C
MD08	Gravel, pebble and mud at the start. Muddy fine sand, pebbles, cobbles and shell at the end	1 *Modiolus* seen at the start. 1-9 / 10x10m at the end.	GS	O
MD09	Muddy sand with 20% pebbles, empty shells including *Modiolus*	At start 1-9 / 30x30cm, at end per m2	LK	C(A)
MD11	Pebbles and *Modiolus* shells with cobbles and scattered boulders on muddy sand	5 / m^2 initially but no live *Modiolus* seen at end of run	GS	C(N)
MD12	Muddy sand with pebbles and cobbles (small and some larger), live *Modiolus* and lots of shells. Some clumps of live *Modiolus.* More shells than live initially but went over an area where possibly >9 / m2 (Abundant)	1-9 / m2 Average ~4 / m2 Central part possibly 1-9 / 30x30cm	BJ	C(A)
MD13	Muddy fine sand with shell gravel and *Modiolus* (shells and clumps of live - in 3-5s). A single native oyster seen. Only travelled a very short distance (3m interpretation rather than 3 mins!)	1-9 / m2 Average 5 / m2 In parts 1-9 / 30x30cm	BJ	C(A)
MD14	Muddy sand and pebbles (25%)	1-9 / m^2. Average 4 / m2	LK	C

Table 2.5 continued

Site	**Substrate**	**Notes**	**Diver**	***Modiolus* SACFOR**
MD20	Soft mud and *Modiolus* shells initially. Soft mud and *Modiolus* shells with *Nephrops* burrows at the end.	1-9 / m^2 at start and end	GS	C
MD21	100% fine mud, thrown up into mounds of about 50 cm height, *Nephrops* burrows and other burrows, shrimp.	Nil (no shells either)	LK	N
MD22	Muddy shelly cobbles	C	LP	C
MD23	Coarse gravel, dead shells (mostly other species, not *Modiolus*)	1-9 per 30cm X 30 cm	AL	A
MD24	Muddy shelly sand with boulders & cobbles. *Modiolus* shells present. Patchy *Limaria* nests - possibly around 10% cover	1-9 per 3m X 3m	KT	F

Table 2.6. Site and video footage details for dropdown video survey of Modiolus modiolus distribution in the upper basin of Loch Creran.

Site	**SD video name**	**HD video name**	**SD video time-code start**	**SD video time-code end**	**HD video time-code start**	**HD video time-code end**	**Time start (UT)**	**Time end (UT)**	**Latitude start**	**Longitude start**	**Latitude end**	**Longitude end**	**Depth below CD start (m)**	**Depth below CD end (m)**
MD10	MD10.mp4	GOPR1548.MP4, GOPR1549.MP4	00:00:04	00:06:18	00:01:46	00:08:06	09:34:03	09:40:17	56.547993	-5.272950	56.547910	-5.272948	28.5	28.9
MD16	MD16.mp4	GOPR2911.MP4, GOPR2912.MP4	00:00:04	00:05:40	00:01:18	00:07:01	09:56:47	10:02:25	56.547148	-5.271760	56.547065	-5.271642	32.3	32.5
MD15	MD15.mp4	GOPR2913.MP4, GOPR2914.MP4	00:00:04	00:05:01	00:01:20	00:06:24	10:50:08	10:55:06	56.545990	-5.272303	56.545868	-5.272067	31.3	30.2
MD17	MD17.mp4	GOPR2915.MP4, GOPR2916.MP4	00:00:04	00:05:02	00:02:19	00:07:24	11:14:38	11:19:38	56.546580	-5.270242	56.546463	-5.269778	29.8	27.0
MD18	MD18.mp4	GOPR2917.MP4, GOPR2918.MP4	00:00:11	00:04:40	00:02:41	00:07:16	12:34:51	12:39:21	56.546783	-5.268157	56.546707	-5.267588	34.7	32.8
MD19	MD19.mp4	GOPR2919.MP4, GOPR2920.MP4	00:00:05	00:05:14	00:01:32	00:07:03	12:47:27	12:52:37	56.547328	-5.266335	56.547340	-5.265560	33.3	29.7

Table 2.7. Habitat data for dropdown video survey of <u>Modiolus modiolus</u> distribution in the upper basin of Loch Creran.

Site	**Substrate**	**Biota**	**Biotope**	**Modiolus SACFOR**	**Comments**
MD10	Shelly, muddy sand with scattered shells (8%) including Modiolus	Sparse fauna. Paguridae sp. (P).	SS.SMu.CSaMu	N	Uncertain biotope. Could be CMuSa
MD16	Shelly, muddy sand with sparse shells (<1%)	Sparse fauna. Paguridae sp. (P). Very sparse megafaunal burrows and small mounds.	SS.SMu.CSaMu	N	Uncertain biotope. Could be CMuSa
MD15	Mixed substrate of silty sand with scattered gravel (10%), pebbles (20%), shells (10%, especially *Modiolus*) and occasional cobbles	Stones supporting serpulid worms (P). Paguridae spp. (F, including *Pagurus bernhardus*), *Munida rugosa* (F), *Ophiura albida*? (F), *Asterias rubens* (P), *Psammechinus miliaris* (P).	SS.SMx.CMx	N	
MD17	Slightly mixed substrate of silty sand with scattered pebbles (5%) and shells (10%, mostly Modiolus)	Paguridae sp. (P), *Liocarcinus depurator* (F), *Aequipecten opercularis* (O), *Psammechinus miliaris* (P), Gobiidae spp. (P).	SS.SMx.CMx	N	Uncertain biotope
MD18	Slightly shelly, sandy mud	Lightly burrowed by megafauna including *Nephrops norvegicus* (F).	SS.SMu.CFiMu.SpnMeg	N	
MD19	Mud	Lightly burrowed by megafauna including *Nephrops norvegicus* (F). *Aequipecten opercularis* (P), Paguridae p. (P), *Asterias rubens* (P).	SS.SMu.CFiMu.SpnMeg	N	

Table 2.8. Epibiota with SACFOR abundance recorded along MNCR phase 2 transect at horse mussel bed site ML01/3A. Taxon names follow WoRMS nomenclature. Brackets denote local abundance.

Taxon	**SACFOR**
Clathrina coriacea	R
Pione vastifica	P
Suberites sp.	R
Amphilectus fucorum	R
Iophon nigricans	P
Mycale (Carmia) macilenta	P
Myxilla (Myxilla) rosacea	R
Porifera sp. encrusting	R
Bougainvillia muscus	O
Kirchenpaueria pinnata	R
Alcyonium digitatum	R
Eupolymnia nebulosa	O
Spirobranchus triqueter	P
Serpula vermicularis	P
Protula tubularia	P
Balanus balanus	C
Balanus crenatus	P
Verruca stroemia	P
Pandalus sp.?	O
Munida rugosa	F
Pagurus bernhardus	O
Macropodia tenuirostris	P
Hyas sp.	P
Liocarcinus depurator	F
Emarginula fissura	P
Gibbula tumida	P
Buccinum undatum	O(F)
Pododesmus patelliformis	F

Taxon	**SACFOR**
Pecten maximus	O
Talochlamys pusio	P
Mimachlamys varia	O
Aequipecten opercularis	F(O)
Hiatella arctica	P
Modiolus modiolus	C(A)
Mya truncata	P
Sepia sp.	R
Scrupocellaria scruposa	R
Disporella hispida	P
Antedon bifida	F(C)
Crossaster papposus	O
Asterias rubens	F
Henricia sp.	P
Ophiothrix fragilis	F
Psammechinus miliaris	O
Thyone fusus	P
Pyura microcosmus	O
Dendrodoa grossularia	F(C)
Ascidia mentula	O
Ascidia virginea	O
Ascidiella aspersa	O
Corella parallelogramma	R
Scyliorhinus sp.	P
Pholis gunnellus	R
Corallinaceae pink crusts	R
Phaeophyceae brown crust	R
Saccharina latissima	R

Table 2.9. Species abundance data for four clumps of <u>Modiolus modiolus</u> from site ML01/C.. Taxon names follow WoRMS nomenclature. + denotes presence.

Taxon	**Replicate**			
	MM01/C.1	**MM01/C.2**	**MM01/C.3**	**MM01/C.4**
Folliculina sp.	+		+	+
Cliona celata			+	
Cliona caledoniae				+
Clathrina coriacea	+		+	
Suberitidae sp.		+	+	
Crella sp.?	+		+	
Amphilectus lobatus?				+
Sarsia sp.	+			
Calycella syringa		+		
Clytia hemisphaerica		+		
Halecium sp.			+	
Alcyonium digitatum	+			+
Cnidaria sp. juv.	1		4	3
Platyhelminthes spp			1	1
Nemertea spp	1	2		3
Tubulanus polymorphus	1			2
Cerebratulus spp	2	2		4
Golfingia spp juv/indet				1
Golfingia (Golfingia) elongata			1	
Golfingia (Golfingia) vulgaris	1			
Phascolion (Phascolion) strombus			1	
Harmothoe spp juv/indet	2	5	19	10
Harmothoe extenuata			1	
Harmothoe fragilis	4	1	1	3
Harmothoe impar			3	
Lepidonotus squamatus	10	1	1	4
Pholoe inornata	10	9	11	17
Pholoe baltica	1	1	9	3
Eulalia bilineata				1
Eumida/Eulalia spp juv/indet	1			1
Eumida bahusiensis	2			
Eumida sanguinea				4
Glycera spp juv	1			1
Glycera alba	1	2		2
Glycera lapidum			1	
Goniada maculata	3	4	1	
Amphiduros fuscescens		1		
Psamathe fusca	1			1
Nereimyra punctata	1	3	3	

Table 2.9 continued				
Taxon	**Replicate**			
	MM01/C.1	**MM01/C.2**	**MM01/C.3**	**MM01/C.4**
Oxydromus flexuosus			1	1
Oxydromus pallidus	7	8	6	3
Syllis armillaris				3
Syllis hyalina	1	1		1
Syllis columbretensis				2
Syllides bansei	1		1	
Sphaerosyllis taylori		1	1	
Myrianida spp	3	1		3
Platynereis dumerilii			1	
Nephtys kersivalensis			1	
Lysidice unicornis				1
Lumbrineris aniara	7	2	7	5
Ougia subaequalis		1		
Parougia eliasoni			1	
Protodorvillea kefersteini	2	4		
Levinsenia gracilis		6		1
Paradoneis lyra	5	4	4	1
Apistobranchus tullbergi		1		1
Aonides oxycephala	1			
Laonice sp juv	1			
Prionospio cirrifera	1	1	1	
Dipolydora coeca	4	4	5	17
Dipolydora caulleryi	1			3
Dipolydora flava	1		12	4
Prionospio fallax	3	6		3
Pseudopolydora cf. *paucibranchiata*			2	
Pseudopolydora pulchra	1			
Spiophanes kroyeri			3	
Magelona minuta		1		
Tharyx killariensis				1
Dodecaceria spp	1	2	1	2
Flabelligeridae spp juv		1		
Flabelligera affinis			2	3
Therochaeta flabellata			7	2
Pherusa plumosa	4	3	1	
Macrochaeta clavicornis				1
Capitella spp	1			
Mediomastus fragilis	12	15	4	19
Maldanidae sp juvs	1			

Table 2.9 continued

Taxon	**Replicate**			
	MM01/C.1	**MM01/C.2**	**MM01/C.3**	**MM01/C.4**
Praxillella affinis			1	
Polyphysia crassa				1
Scalibregma inflatum	3	4	3	2
Pectinariidae spp juvs	1		2	
Amphictene auricoma			2	
Melinna palmata	2		4	
Ampharete lindstroemi		1	1	1
Amphicteis gunneri	1	1	1	
Sosane sulcata	5	3	4	2
Terebellides sp juv		1	1	1
Terebellides stroemii	2		1	6
Trichobranchus glacialis	2	2	1	1
Terebellinae spp juv/indet	1	1		
Amphitrite cirrata				1
Eupolymnia nebulosa		1	2	3
Neoamphitrite figulus			1	
Phisidia aurea				1
Pista mediterranea	3	1	2	
Polycirrus norvegicus	3	8	1	3
Polycirrus plumosus	1	1		
Branchiomma bombyx				1
Chone duneri				1
Chone filicaudata	1			
Jasmineira caudata				1
Laonome kroyeri	1		1	1
Pseudopotamilla reniformis	1		1	4
Serpulidae spp juv/indet				1
Spirobranchus spp juv/indet	2			
Spirobranchus triqueter	20	14	20	17
Serpula/Hydroides spp indet	1		1	
Paradexiospira (Spirorbides) vitrea			1	
Spirorbinae sp.			2	1
Tubificoides amplivasatus	1	3	1	3
Barentsia sp.	+			
Pedicellina cernua	+		+	+
Verruca stroemia	8	8	12	24
Balanus balanus	29	17	8	6
Balanus crenatus		2	2	2
Balanus spp. spat	29		4	
Copepoda spp	1	2	1	1
Ostracoda spp	7	14	24	38

Table 2.9 continued				
Taxon	**Replicate**			
	MM01/C.1	**MM01/C.2**	**MM01/C.3**	**MM01/C.4**
Amphipoda sp A	2			
Deflexilodes subnudus	1		1	2
Leucothoe sp juv		1		
Metaphoxus fultoni		2		
Lysianassidae spp juvs/indet		1		
Lysianassa plumosa	1		3	
Orchomene humilis		1		1
Liljeborgia pallida	1		1	
Ampelisca tenuicornis	1		1	2
Microdeutopus versiculatus	1			
Crassicorophium bonellii	13	1	1	2
Phtisica marina		2		
Pseudoprotella phasma			3	1
Anthura gracilis	3		2	
Janira maculosa				1
Tanaopsis graciloides	1	4	1	3
Vaunthompsonia cristata			1	
Eudorella truncatula				1
Galatheoidea 'megalopa'	4	7		
Pisidia longicornis	7	1	31	23
Leptochiton asellus	5	5	14	7
Stenosemus albus			1	1
Emarginula sp				1
Steromphala cineraria		1		
Alvania beanii				1
Alvania punctura	1	1		
Onoba semicostata	3		1	
Capulus ungaricus	1		1	
Trophonopsis barvicensis				1
Mangelia costulata	1			
Cylichna cylindracea	1			1
Bivalvia spp indet				1
Nucula nitidosa	1	2	1	1
Mytilus edulis juvs	3	2	9	4
Modiolus modiolus adults	6	2	5	2
Pectinidae sp juv			2	1
Mimachlamys varia	1			
Aequipecten opercularis			2	
Anomiidae spp juv			5	1
Pododesmus patelliformis	1	1		1
Pododesmus squama			1	

Table 2.9 continued

Taxon	**Replicate**			
	MM01/C.1	**MM01/C.2**	**MM01/C.3**	**MM01/C.4**
Heteranomia squamula		2	2	6
Myrtea spinifera	1			
Thyasira flexuosa			1	1
Kurtiella bidentata	1	3	2	20
Parvicardium pinnulatum			3	1
Abra alba	3	1	1	3
Polititapes rhomboides				1
Timoclea ovata	2	1	3	2
Mysia undata		1		
Mya truncata	4	3	6	3
Corbula gibba	1	4	2	4
Hiatella arctica	4	4	10	1
Phoronis ovalis		26	1	
Fenestrulina malusii				+
Escharella immersa			+	+
Alcyonidium mamillatum?			+	
Tubulipora sp.	+		+	
Disporella hispida	+	+	+	+
Antedon bifida				2
Ophiothrix fragilis		1	1	3
Amphiura filiformis				1
Amphipholis squamata			2	6
Ophiuridae spp juv				1
Ophiura albida	1	2	1	
Psammechinus miliaris	1	1	2	
Enteropneusta spp	2	3		
Ascidia sp. juv.	1			
Ascidiella sp. juv.				1
Pyura tessellata	4	1		1
Dendrodoa grossularia	8	12	25	26
Corallinaceae pink crusts	+	+	+	+

Table 2.10. Size measurements for 51 Modiolus modiolus from station MM01/C.

Length (mm)	Breadth (mm)	Height (mm)
8	3	4
32	12	17
72	27	36
75	28	40
79	29	41
80	34	44
80	33	43
82	32	43
85	33	42
85	35	46
87	35	43
89	37	43
90	33	42
90	38	46
93	41	49
93	41	48
97	39	41
100	41	47
100	39	50
100	42	50
100	44	51
100	44	50
100	38	48
101	45	51
101	43	40

Length (mm)	Breadth (mm)	Height (mm)
101	42	48
102	40	49
102	41	48
103	45	52
103	47	55
103	46	51
103	43	53
104	42	53
106	47	52
106	43	53
109	49	46
110	43	53
110	44	57
111	46	54
113	46	54
113	44	56
113	51	57
114	46	65
115	45	51
115	43	53
115	45	54
117	49	56
119	54	54
119	50	53
127	53	59
127	51	57

ANNEX 3: FLAME SHELL BED SURVEY DATA

Table 3.1. Temporal, positional and other physical data for all sites examined during the diver drift flame shell bed survey. N/R = not recorded, N/A = not applicable. Positional data take layback into account.

Site	Location	Date	SMB Length (m)	Transect bearing (°M)	SMB Bearing (°M)	Time (UT)	Depth below CD (m)	Latitude	Longitude
DD01.1	South Shian	08/08/2017	20	330	10	11:47:15	4.2	56.528842	-5.394263
DD01.2	South Shian	08/08/2017	20	330	10	11:54:50	9.1	56.529259	-5.394449
DD01.3	South Shian	08/08/2017	20	330	300	12:01:30	8.9	56.529685	-5.394709
DD01.4	South Shian	08/08/2017	20	330	350	12:07:00	9.1	56.530071	-5.395443
DD01.5	South Shian	08/08/2017	20	330	350	12:12:45	8.9	56.530529	-5.395895
DD01.6	South Shian	08/08/2017	20	330	320	12:21:00	8.9	56.530980	-5.396313
DD01.7	South Shian	08/08/2017	20	330	310	12:28:50	9.4	56.531377	-5.396925
DD01.8	South Shian	08/08/2017	20	330	300	12:36:30	10.1	56.531801	-5.397485
DD01.9	South Shian	08/08/2017	20	330	310	12:44:50	10.4	56.532161	-5.398129
DD01.10	South Shian	08/08/2017	20	330	260	12:54:00	10.7	56.532645	-5.398875
DD02.1	South Shian	08/08/2017	15	325	30	08:55:10	6.2	56.528871	-5.391095
DD02.2	South Shian	08/08/2017	15	325	35	09:02:39	7.3	56.529263	-5.391755
DD02.3	South Shian	08/08/2017	15	325	35	09:10:27	7.5	56.529804	-5.392385
DD03A.1	South Shian	08/08/2017	15	325	330	10:21:36	6.6	56.530185	-5.390579
DD03A.2	South Shian	08/08/2017	15	325	330	10:26:26	5.5	56.530448	-5.390922
DD03A.3	South Shian	08/08/2017	15	325	330	10:29:50	7.7	56.530823	-5.391488
DD03A.4	South Shian	08/08/2017	15	325	330	10:33:30	10.5	56.531167	-5.392070
DD03A.5	South Shian	08/08/2017	15	325	330	10:37:50	11.6	56.532070	-5.393921
DD03B.1	South Shian	08/08/2017	15	145	150	14:28:59	3.9	56.532689	-5.394691
DD03B.2	South Shian	08/08/2017	15	145	160	14:37:40	10.5	56.532264	-5.394197
DD03B.3	South Shian	08/08/2017	15	145	N/A	14:43:43	12.5	56.531937	-5.393804
DD03B.4	South Shian	08/08/2017	15	145	N/A	14:52:40	12.4	56.531659	-5.393426
DD03B.5	South Shian	08/08/2017	15	145	N/A	14:56:34	11.3	56.531476	-5.393232
DD03B.6	South Shian	08/08/2017	15	145	150	15:08:14	10.5	56.531088	-5.392483
DD03B.7	South Shian	08/08/2017	15	145	155	15:13:42	8.7	56.530809	-5.391824
DD03B.8	South Shian	08/08/2017	15	145	150	15:18:50	6.6	56.530630	-5.391462
DD03B.9	South Shian	08/08/2017	15	145	140	15:24:24	5.2	56.530308	-5.390938

Table 3.1 continued

Site	Location	Date	SMB Length (m)	Transect bearing (°M)	SMB Bearing (°M)	Time (UT)	Depth below CD (m)	Latitude	Longitude
DD04.1	South Shian	08/08/2017	25	150	205	13:34:31	12.9	56.527016	-5.392484
DD04.2	South Shian	08/08/2017	25	150	228	13:36:45	13.4	56.526724	-5.392547
DD04.3	South Shian	08/08/2017	25	150	220	13:41:50	13.2	56.526243	-5.392393
DD04.4	South Shian	08/08/2017	25	150	205	13:46:58	12.4	56.525707	-5.391825
DD04.5	South Shian	08/08/2017	25	150	228	13:51:20	12.9	56.525413	-5.391324
DD05.1	Creagan	09/08/2017	12	270	N/A	13:16:00	1.8	56.547840	-5.292236
DD05.2	Creagan	09/08/2017	12	270	N/A	13:22:00	4.2	56.547833	-5.292475
DD05.3	Creagan	09/08/2017	12	270	N/A	13:29:00	3.6	56.547830	-5.292737
DD05.4	Creagan	09/08/2017	12	270	290	13:36:00	3.2	56.547826	-5.293038
DD05.5	Creagan	09/08/2017	12	270	300	13:43:00	3.2	56.547793	-5.293333
DD05.6	Creagan	09/08/2017	12	270	270	13:49:00	4.7	56.547838	-5.293566
DD05.7	Creagan	09/08/2017	12	270	290	13:53:00	6.7	56.547816	-5.293778
DD05.8	Creagan	09/08/2017	12	270	300	13:59:00	9.5	56.547813	-5.293916
DD05.9	Creagan	09/08/2017	12	270	N/A	14:04:00	10.6	56.547809	-5.294153
DD05.10	Creagan	09/08/2017	12	270	N/A	14:11:00	10.3	56.547822	-5.294386
DD05.11	Creagan	09/08/2017	12	270	N/A	14:18:00	9.8	56.547816	-5.294962
DD06A.1	Creagan	09/08/2017	12	270	270	13:03:32	7.0	56.547993	-5.293493
DD06A.2	Creagan	09/08/2017	12	270	N/A	13:08:50	7.7	56.547964	-5.293850
DD06A.3	Creagan	09/08/2017	12	270	270	13:12:40	8.0	56.547972	-5.293877
DD06A.4	Creagan	09/08/2017	12	270	270	13:18:30	7.8	56.548056	-5.294225
DD06A.5	Creagan	09/08/2017	12	270	270	13:25:40	7.4	56.548091	-5.294571
DD06A.6	Creagan	09/08/2017	12	270	290	13:30:00	6.5	56.548125	-5.294819
DD06A.7	Creagan	09/08/2017	12	270	270	13:37:00	6.5	56.548173	-5.295197
DD06A.8	Creagan	09/08/2017	12	270	270	13:44:30	6.8	56.548153	-5.295581
DD06A.9	Creagan	09/08/2017	12	270	270	13:50:00	5.5	56.548145	-5.295910
DD06A.10	Creagan	09/08/2017	12	270	270	13:56:30	6.8	56.548160	-5.296254
DD06A.11	Creagan	09/08/2017	12	270	N/A	14:07:30	6.0	56.548115	-5.297148
DD06B.1	Creagan	09/08/2017	12	90	N/A	14:50:20	7.8	56.547968	-5.295132
DD06B.2	Creagan	09/08/2017	12	90	N/A	14:58:10	8.2	56.547967	-5.295051

Table 3.1 continued

Site	Location	Date	SMB Length (m)	Transect bearing (°M)	SMB Bearing (°M)	Time (UT)	Depth below CD (m)	Latitude	Longitude
DD06B.3	Creagan	09/08/2017	12	90	N/A	15:06:20	8.4	56.547976	-5.294883
DD06B.4	Creagan	09/08/2017	12	90	N/A	15:16:45	8.3	56.547993	-5.294661
DD06B.5	Creagan	09/08/2017	12	90	N/A	15:21:05	8.2	56.548013	-5.294524
DD06B.6	Creagan	09/08/2017	12	90	90	15:25:10	8.2	56.548012	-5.294365
DD06B.7	Creagan	09/08/2017	12	90	90	15:29:30	8.2	56.548015	-5.294203
DD06B.8	Creagan	09/08/2017	12	90	90	15:33:30	8.0	56.548058	-5.294048
DD07.1	Creagan	09/08/2017	12	90	130	14:39:00	5.6	56.548327	-5.297350
DD07.2	Creagan	09/08/2017	12	90	90	14:44:00	5.5	56.548274	-5.297167
DD07.3	Creagan	09/08/2017	12	90	142	14:49:00	2.6	56.548361	-5.296791
DD07.4	Creagan	09/08/2017	12	90	120	14:52:00	2.3	56.548334	-5.296806
DD07.5	Creagan	09/08/2017	12	90	120	14:58:00	3.9	56.548308	-5.296475
DD07.6	Creagan	09/08/2017	12	90	120	15:01:00	3.1	56.548324	-5.296190
DD07.7	Creagan	09/08/2017	12	90	100	15:06:00	5.3	56.548311	-5.295947
DD08.1	South Shian	10/08/2017	25	345	N/A	07:47:40	22.6	56.524153	-5.388809
DD08.2	South Shian	10/08/2017	25	345	N/A	07:55:40	23.2	56.524552	-5.389104
DD08.3	South Shian	10/08/2017	25	345	N/A	08:01:10	20.5	56.525016	-5.389558
DD08.4	South Shian	10/08/2017	25	345	N/A	08:07:10	18.3	56.525588	-5.389703
DD08.5	South Shian	10/08/2017	25	345	0	08:13:00	12.2	56.526071	-5.390000
DD08.6	South Shian	10/08/2017	25	345	20	08:19:10	7.0	56.526590	-5.390594
DD08.7	South Shian	10/08/2017	25	345	30	08:24:40	13.0	56.527126	-5.390935
DD08.8	South Shian	10/08/2017	25	345	150	08:28:11	11.3	56.527783	-5.391171
DD09.1	South Shian	10/08/2017	25	340	N/A	08:56:20	19.4	56.525580	-5.387922
DD09.2	South Shian	10/08/2017	25	340	N/A	09:05:10	16.0	56.525981	-5.388249
DD09.3	South Shian	10/08/2017	25	340	N/A	09:15:20	11.2	56.526362	-5.388595
DD09.4	South Shian	10/08/2017	25	340	355	09:24:20	5.6	56.526717	-5.388984
DD09.5	South Shian	10/08/2017	25	340	355	09:35:20	4.1	56.527365	-5.389505
DD09.6	South Shian	10/08/2017	25	340	10	09:37:50	8.5	56.527590	-5.389820
DD10.1	South Shian	10/08/2017	30	345	315	10:08:35	15.7	56.522227	-5.387807
DD10.2	South Shian	10/08/2017	30	345	N/A	10:17:30	17.9	56.522710	-5.388361
DD10.3	South Shian	10/08/2017	30	345	N/A	10:27:30	19.4	56.523216	-5.388634

Table 3.1 continued

Site	Location	Date	SMB Length (m)	Transect bearing (°M)	SMB Bearing (°M)	Time (UT)	Depth below CD (m)	Latitude	Longitude
DD10.4	South Shian	10/08/2017	30	345	N/A	10:35:22	19.8	56.523733	-5.389054
DD11.1	South Shian	10/08/2017	30	325	N/A	11:07:50	19.4	56.520034	-5.384587
DD11.2	South Shian	10/08/2017	30	325	180	11:11:40	20.6	56.520413	-5.384750
DD11.3	South Shian	10/08/2017	30	325	180	11:17:30	24.8	56.520889	-5.385224
DD11.4	South Shian	10/08/2017	30	325	180	11:23:50	25.3	56.521634	-5.385829
DD11.5	South Shian	10/08/2017	30	325	190	11:29:58	22.2	56.522323	-5.386243
DD11.6	South Shian	10/08/2017	30	325	190	11:32:50	16.8	56.522557	-5.386682
DD12.1	South Shian	27/08/2018	30.5	155	N/A	14:45:30	22.4	56.524767	-5.387050
DD12.2	South Shian	27/08/2018	30.5	155	N/A	14:54:35	22.3	56.524359	-5.386727
DD12.3	South Shian	27/08/2018	30.5	155	N/A	15:02:00	22.8	56.523939	-5.386158
DD12.4	South Shian	27/08/2018	30.5	155	N/A	15:08:30	22.3	56.523578	-5.385554
DD13.1	South Shian	26/08/2018	30.5	154	277	12:54:03	21.0	56.523553	-5.390468
DD13.2	South Shian	26/08/2018	30.5	154	N/A	13:07:05	21.0	56.523287	-5.390441
DD13.3	South Shian	26/08/2018	30.5	154	N/A	13:12:10	21.0	56.523060	-5.390328
DD13.4	South Shian	26/08/2018	30.5	154	N/A	13:14:12	21.0	56.522968	-5.390252
DD13.5	South Shian	26/08/2018	30.5	154	N/A	13:18:30	20.6	56.522766	-5.390162
DD13.6	South Shian	26/08/2018	30.5	154	208	13:24:00	20.6	56.522659	-5.390037
DD14.1	South Shian	26/08/2018	30.5	160	N/A	14:27:30	17.2	56.525687	-5.393180
DD14.2	South Shian	26/08/2018	30.5	160	N/A	14:38:45	13.3	56.525008	-5.392671
DD14.3	South Shian	26/08/2018	30.5	160	35	14:47:30	15.0	56.524564	-5.392558
DD14.4	South Shian	26/08/2018	30.5	160	45	14:56:30	21.5	56.524219	-5.392508
DD16.1	South Shian	27/08/2018	30.5	330	330	09:15:00	22.1	56.519456	-5.385627
DD16.2	South Shian	27/08/2018	30.5	330	330	09:20:25	23.5	56.519879	-5.386063
DD16.3	South Shian	27/08/2018	30.5	330	330	09:29:20	25.5	56.520510	-5.386730
DD16.4	South Shian	27/08/2018	30.5	330	N/R	N/R	N/R	56.520534	-5.386756
DD17.1	South Shian	26/08/2018	20	340	310	09:44:30	12.3	56.531358	-5.397768
DD17.2	South Shian	26/08/2018	20	340	315	09:51:15	12.1	56.531687	-5.398205
DD17.3	South Shian	26/08/2018	20	340	320	09:59:00	11.4	56.532216	-5.398555
DD17.4	South Shian	26/08/2018	20	340	320	10:11:30	10.3	56.532999	-5.399179
DD17.5	South Shian	26/08/2018	20	340	340	10:20:30	9.2	56.533497	-5.399813

Table 3.1 continued

Site	Location	Date	SMB Length (m)	Transect bearing (°M)	SMB Bearing (°M)	Time (UT)	Depth below CD (m)	Latitude	Longitude
DD17.6	South Shian	26/08/2018	20	340	320	10:25:45	8.7	56.533963	-5.399848
DD18.1	South Shian	27/08/2018	15	330	330	12:02:10	6.2	56.530693	-5.393895
DD18.2	South Shian	27/08/2018	15	330	330	12:06:45	7.1	56.530908	-5.394157
DD18.3	South Shian	27/08/2018	15	330	330	12:10:43	7.1	56.531134	-5.394442
DD18.4	South Shian	27/08/2018	15	330	330	12:13:08	7.2	56.531301	-5.394683
DD18.5	South Shian	27/08/2018	15	330	330	12:15:36	7.0	56.531463	-5.395016
DD18.6	South Shian	27/08/2018	15	330	330	12:18:23	5.9	56.531653	-5.395433
DD19.1	South Shian	27/08/2018	30.5	334	310	11:38:55	13.3	56.532210	-5.393579
DD19.2	South Shian	27/08/2018	30.5	334	310	11:46:55	11.6	56.532394	-5.393944
DD19.3	South Shian	27/08/2018	30.5	334	300	11:56:05	6.1	56.532623	-5.394243
DD19.4	South Shian	27/08/2018	30.5	334	300	12:04:05	5.4	56.532825	-5.394753
DD19.5	South Shian	27/08/2018	30.5	334	300	12:11:00	2.7	56.533159	-5.395304
DDLD1.1	Upper basin	25/08/2018	16.5	130	N/A	14:15:00	2.9	56.548187	-5.283305
DDLD1.2	Upper basin	25/08/2018	16.5	130	100	14:24:00	3.0	56.547927	-5.282747
DDLD1.3	Upper basin	25/08/2018	16.5	130	100	14:31:10	3.3	56.547760	-5.282194
DDLD1.4	Upper basin	25/08/2018	16.5	130	100	14:37:45	3.9	56.547583	-5.281544
DDLD1.5	Upper basin	25/08/2018	16.5	130	100	14:44:45	5.7	56.547357	-5.281001
DDLD1.6	Upper basin	25/08/2018	16.5	130	90	14:51:30	9.6	56.547096	-5.280591
DDLD2.1	Upper basin	25/08/2018	N/R	85	N/A	14:22:28	2.4	56.547306	-5.288032
DDLD2.2	Upper basin	25/08/2018	N/R	85	N/A	14:25:07	1.7	56.547469	-5.286619
DDLD2.3	Upper basin	25/08/2018	N/R	85	N/A	14:28:01	1.0	56.547634	-5.285752
DDLD2.4	Upper basin	25/08/2018	N/R	85	N/A	14:29:58	0.7	56.547692	-5.285173
DDLD2.5	Upper basin	25/08/2018	N/R	85	N/A	14:33:15	2.9	56.547726	-5.284699
DDLD2.6	Upper basin	25/08/2018	N/R	85	N/A	14:37:20	1.6	56.547659	-5.284138
DDLD2.7	Upper basin	25/08/2018	N/R	85	N/A	14:44:47	1.1	56.547576	-5.282915
DDLD2.8	Upper basin	25/08/2018	N/R	85	N/A	14:48:00	2.4	56.547536	-5.282629
DDLD2.9	Upper basin	25/08/2018	N/R	85	N/A	14:54:00	4.0	56.547405	-5.282039
DDLD2.10	Upper basin	25/08/2018	N/R	85	N/A	15:00:45	4.4	56.547373	-5.28111
DDLD3.1	Upper basin	28/01/2019	12	100	N/A	10:31:33	3.1	56.547349	-5.291858
DDLD3.2	Upper basin	28/01/2019	12	100	N/A	10:42:04	3.0	56.547279	-5.291131

Table 3.1 continued

Site	Location	Date	SMB Length (m)	Transect bearing (°M)	SMB Bearing (°M)	Time (UT)	Depth below CD (m)	Latitude	Longitude
DDLD3.3	Upper basin	28/01/2019	12	100	N/A	10:50:29	4.0	56.547267	-5.290264
DDLD3.4	Upper basin	28/01/2019	12	100	N/A	10:57:09	3.4	56.547316	-5.289638
DDLD3.5	Upper basin	28/01/2019	12	100	N/A	11:05:34	2.2	56.547393	-5.289219
DDLD3.6	Upper basin	28/01/2019	12	100	N/A	11:12:25	1.9	56.547531	-5.288719

*Table 3.2. Biological data for all sites examined during the diver drift flame shell bed survey. SACFOR abundances in brackets denote local abundance. L. hyp = Laminaria hyperborea, S. lat = Saccharina latissima. Surveyors are AL (Alastair Lyndon), BJ (Ben James), DH (Dan Harries), GS (Graham Saunders), KT (Kieran Tulbure), LK (Lisa Kamphausen), LP (Lewis Press), RC (Rob Cook). Biotopes are Lim (**SS.SMx.IMx.Lim**), ModT (**SS.SBR.Mus.ModT**), OphMx (**SS.SMx.CMx.OphMx**).*

Site	Limaria nest cover (%)	Nest thick-ness (cm)	*Limaria* seen	*Limaria* density <1/0.1 m^{-2}	*Modiolus* (SACFOR)	Brittlestars (SACFOR)	Algal turf (%)	*L. hyp* (SAC-FOR)	*S. lat* (SAC-FOR)	Substrate	Biotopes	Surv-eyor
DD01.1	0	0	N	Y	N	N	25	A	N	Bedrock		DH
DD01.2	95	5	Y	N	N	O	75	N	N	Poorly sorted silty sand	Lim	DH
DD01.3	95	4	Y	N	N	0	75	N	N	Poorly sorted silty sand	Lim	DH
DD01.4	95	4	Y	N	N	0	75	N	N	Poorly sorted silty sand	Lim	DH
DD01.5	95	5	Y	N	N	0	80	C	N	Poorly sorted silty sand	Lim	DH
DD01.6	50	5	Y	N	C(A)	C	15	A	N	Gravelly sand with pebbles & cobbles (~50%)	Lim, ModT	DH
DD01.7	55	5	Y	N	A(C)	A	8	A	N	Gravelly sand with pebbles & cobbles (~50%)	Lim, ModT	DH
DD01.8	75	5	Y	N	C(A)	C(A)	15	A(C)	N	Gravelly sand with pebbles & cobbles (~40%)	Lim, ModT	DH
DD01.9	3	4	Y	Y	C(A)	N	15	F(C)	N	Gravelly sand with pebbles & cobbles (~80%)	ModT	DH
DD01.10	0	0	N	Y	C	N	25	F(C)	F	Gravelly sand with pebbles & cobbles (~80%)	ModT	DH
DD02.1	100	3	Y	N	C	N	80	C	N	Muddy shell gravel	Lim, ModT	GS
DD02.2	100	4	Y	N	N	N	80	F	N	Muddy shell gravel	Lim	GS
DD02.3	100	4	Y	N	N	N	85	F	P	Muddy shell gravel	Lim	GS
DD03A.1	5	5	Y	Y	C	N	20	N	S	Gravel and pebbles	ModT	RC
DD03A.2	40	8	Y	N	C	N	10	A	N	Sand and gravel	Lim, ModT	RC
DD03A.3	70	10	Y	N	F	N	70	C	N	Sand and gravel	Lim	RC
DD03A.4	100	12	Y	N	F	N	0	N	N	Sand, gravel and shell	Lim	RC
DD03A.5	10	5	Y	N	A	N	0	N	N	Pebbles and modiolus reef	Lim, ModT	RC

Table 3.2 continued

Site	Limaria nest cover (%)	Nest thick-ness (cm)	*Limaria* seen	*Limaria* density <1/0.1 m^{-2}	*Modiolus* (SACFOR)	Brittlestars (SACFOR)	Algal turf (%)	*L. hyp* (SAC-FOR)	*S. lat* (SAC-FOR)	Substrate	Biotopes	Surv-eyor
DD03B.1	0	0	N	Y	N	N	25	S	N	Bedrock, boulders		KT
DD03B.2	0	0	N	Y	N	N	75	N	N	Coarse sand, boulders, pebbles, shells		KT
DD03B.3	10	10	N	Y	C	N	10	N	N	Coarse sand, pebbles, shells	Lim, ModT	KT
DD03B.4	40	15	Y	N	P	N	10	N	N	Coarse sand, shells	Lim	KT
DD03B.5	55	10	Y	N	P	N	15	N	N	Coarse sand, shells	Lim	KT
DD03B.6	97	11	Y	N	N	N	35	N	N	Coarse sand, shells	Lim	KT
DD03B.7	70	12	Y	N	N	N	70	N	N	Coarse sand, shells	Lim	KT
DD03B.8	50	10	Y	N	N	P	70	A	N	Coarse sand, shells	Lim	KT
DD03B.9	40	12	Y	N	N	N	75	S	A	Coarse sand, shells	Lim	KT
DD04.1	100	6	Y	N	N	N	0	C	C	Muddy sand	Lim	RC
DD04.2	50	8	Y	N	N	N	0	C	C	Sand	Lim	RC
DD04.3	60	6	Y	N	F	N	0	F	N	Shelly sand	Lim	RC
DD04.4	70	6	Y	N	N	N	0	F	N	Pebbles and gravel with lots of dead shell	Lim	RC
DD04.5	5	4	Y	Y	N	N	0	N	N	Shell gravel		RC
DD05.1	15	5	Y	Y	C(A)	N	20	A(C)	N	Coarse sand / gravel with pebbles (~30%). adjacent bedrock.	Lim, ModT	DH
DD05.2	70	7	Y	N (on sediment ignoring adjacent rock reefs)	A(C)	S	<1	C	N	Coarse sand / gravel with pebbles (~30%). adjacent bedrock.	Lim, ModT, OphMx	DH
DD05.3	80	10	Y	N	C(A)	S	<1	F(C)	N	Coarse sand / gravel with pebbles (~30%).	Lim, ModT, OphMx	DH

Table 3.2 continued

Site	**Limaria nest cover (%)**	**Nest thick-ness (cm)**	***Limaria* seen**	***Limaria* density <1/0.1 m^{-2}**	***Modiolus* (SACFOR)**	**Brittlestars (SACFOR)**	**Algal turf (%)**	***L. hyp* (SAC-FOR)**	***S. lat* (SAC-FOR)**	**Substrate**	**Biotopes**	**Surv-eyor**
DD05.4	50	6	Y	N	C	S	<1	C(A)	C	Coarse sand / gravel with pebbles (~30%).	Lim, ModT, OphMx	DH
DD05.5	10	5	Y	Y	C	C(S)	1	C(A)	F	Coarse sand / gravel with pebbles (~50%).	Lim, ModT	DH
DD05.6	70	6	Y	N	F	S	<1	C(A)	N	Coarse sand / gravel with pebbles (~50%).	Lim, OphMx	DH
DD05.7	50	5	Y	N	C	S	<1	C	N	Coarse sand / gravel with pebbles (~50%).	Lim, ModT, OphMx	DH
DD05.8	40	5	Y	N	C(A)	S	<1	O	N	Coarse sand / gravel with pebbles (~50%).	Lim, ModT, OphMx	DH
DD05.9	40	5	Y	N	C(A)	S	0	O	N	Coarse sand / gravel with pebbles (~50%).	Lim, ModT, OphMx	DH
DD05.10	20	4	Y	Y	C(A)	S	0	N	N	Coarse sand / gravel with pebbles (~50%).	Lim, ModT, OphMx	DH
DD05.11	5	4	Y	Y	C(A)	S	0	N	N	Coarse sand / gravel with pebbles (~50%).	ModT, OphMx	DH
DD06A.1	0	0	N	Y	C	S	0	N	N	Shell gravel	ModT, OphMx	GS
DD06A.2	0	0	N	Y	A	S	0	N	N	Shell gravel, cobbles (hedgehog stones common)	ModT, OphMx	GS
DD06A.3	0	0	N	Y	A	S	0	P	N	Muddy shell gravel, cobbles	ModT, OphMx	GS
DD06A.4	0	0	N	Y	A	S	0	P	N	Pebbles, cobbles and shell over mud	ModT, OphMx	GS
DD06A.5	***0***	0	Y	N?	A	S	0	N	N	Muddy shell gravel, cobbles	ModT, OphMx	GS
DD06A.6	60	3	Y	N	A	S	0	P	N	Cobbles and shell over mud	Lim, ModT, OphMx	GS
DD06A.7	50	3	Y	N	A	S	0	P	N	Muddy shell gravel	Lim, ModT, OphMx	GS
DD06A.8	***50***	3	Y	N	A	S	0	N	N	Muddy shell gravel	Lim, ModT,	GS

Table 3.2 continued

Site	Limaria nest cover (%)	Nest thick-ness (cm)	*Limaria* seen	*Limaria* density <1/0.1 m^{-2}	*Modiolus* (SACFOR)	Brittlestars (SACFOR)	Algal turf (%)	*L. hyp* (SAC-FOR)	*S. lat* (SAC-FOR)	Substrate	Biotopes	Surv-eyor
											OphMx	
DD06A.9	***50***	5	Y	N	A	S	0	N	N	Muddy shell gravel	Lim, ModT, OphMx	GS
DD06A.10	***50***	?	Y	N	A	S	0	N	N	Muddy shell gravel	Lim, ModT, OphMx	GS
DD06A.11	0	0	N	Y	C	S	0	P	N	Muddy shell gravel, cobbles	ModT, OphMx	GS
DD06B.1	***25***	10	Y	N	A	S	0	N	N	Coarse sand, pebbles, shells, bedrock	Lim, ModT, OphMx	KT
DD06B.2	***35***	7	Y	N	A	S	0	N	N	Coarse sand, pebbles, shells	Lim, ModT, OphMx	KT
DD06B.3	***10***	10	Y	N	A	S	0	N	N	Coarse sand, pebbles, shells	Lim, ModT, OphMx	KT
DD06B.4	***10***	12	Y	N	A	S	0	N	N	Coarse sand, pebbles, shells	Lim, ModT, OphMx	KT
DD06B.5	***8***	11	Y	N	A	S	0	N	N	Coarse sand, pebbles, shells	ModT, OphMx	KT
DD06B.6	***10***	10	Y	Y	A	S	0	N	N	Coarse sand, pebbles, shells	Lim, ModT, OphMx	KT
DD06B.7	***7***	8	Y	Y	A	S	0	N	N	Coarse sand, pebbles, shells	ModT, OphMx	KT
DD06B.8	0	0	N	Y	C	A	0	N	N	Coarse sand, pebbles, shells	ModT, OphMx	KT
DD07.1	0	0	N	N	C	A	0	C	N	Gravel, pebbles and cobbles	ModT, OphMx	RC
DD07.2	0	0	N	N	F	A	0	F	F	Gravel, pebbles and cobbles with bedrock	OphMx	RC
DD07.3	0	0	N	N	N	S	0	F	N	Bedrock	OphMx	RC
DD07.4	90	10	Y	N	F	S	0	F	N	Muddy sand and gravel	Lim, OphMx	RC
DD07.5	80	10	Y	N	A	S	0	F	N	Shell gravel	Lim, ModT, OphMx	RC
DD07.6	80	10	Y	N	A	S	0	F	F	Shell gravel	Lim, ModT, OphMx	RC

Table 3.2 continued

Site	Limaria nest cover (%)	Nest thick-ness (cm)	*Limaria* seen	*Limaria* density <1/0.1 m^{-2}	*Modiolus* (SACFOR)	Brittlestars (SACFOR)	Algal turf (%)	*L. hyp* (SAC-FOR)	*S. lat* (SAC-FOR)	Substrate	Biotopes	Surv-eyor
DD07.7	60	5	Y	N	C	S	0	F	N	Muddy sand between modiolus reef	Lim, ModT, OphMx	RC
DD08.1	90	5	Y	N	F	N	0	N	N	Poorly sorted silty sand with shell frags 10-20%	Lim	DH
DD08.2	90	5	Y	N	F	N	0	N	N	Poorly sorted silty sand with shell frags 10-20%	Lim	DH
DD08.3	30	4	Y	N	F	N	0	N	N	Gravely sand with pebbles and cobbles 80%	Lim	DH
DD08.4	30	3	Y	N	F	N	0	N	N	Gravely sand with pebbles and cobbles 80%	Lim	DH
DD08.5	30	4	Y	N	F	N	3	N	N	Gravely sand with pebbles and cobbles 80%	Lim	DH
DD08.6	90	6	y	N	N	N	90	C	N	Silty sand with gravel 10% pebbles	Lim	DH
DD08.7	80	5	y	N	N	N	5	N	N	Gravelly sand with pebbles 90%	Lim	DH
DD08.8	100	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	Lim	DH
DD09.1	0	0	N	N	N	N	1	N	N	Pebbles and cobbles		KT
DD09.2	70	9	Y	N	P	N	15	N	N	Silty coarse sand with shell cobbles pebbles	Lim	KT
DD09.3	97	8	Y	N	N	N	50	N	N	Coarse sand with shell?	Lim	KT
DD09.4	20	10	Y	N	N	N	30	A	N	Coarse sand with shell?	Lim	KT
DD09.5	0	0	N	N	N	N	30	A	N	Coarse sand pebbles		KT
DD09.6	98	7	Y	N	N	N	40	N	N	Coarse sand with shell	Lim	KT
DD10.1	75	4	Y	N	N	N	2	P	N	Shell gravel	Lim	GS
DD10.2	50	5	Y	N	N	N	0	N	N	Shell gravel	Lim	GS
DD10.3	95	5	Y	N	N	S	0	P	N	Muddy fine sand	Lim, OphMx	GS
DD10.4	100	4	Y	N	N	S	0	N	N	Muddy fine sand	Lim, OphMx	GS

Table 3.2 continued

Site	Limaria nest cover (%)	Nest thick-ness (cm)	*Limaria* seen	*Limaria* density <1/0.1 m^{-2}	*Modiolus* (SACFOR)	Brittlestars (SACFOR)	Algal turf (%)	*L. hyp* (SAC-FOR)	*S. lat* (SAC-FOR)	Substrate	Biotopes	Surv-eyor
DD11.1	<1	0	Y	Y	N	N	0	N	N	Pebbles, cobbles on gravel		RC
DD11.2	60	8	Y	N	C	C	0	N	N	Sandy gravel	Lim, ModT	RC
DD11.3	0	0	N	N	F	N	0	N	N	Pebbles and gravel		RC
DD11.4	0	0	N	N	C	C	0	N	N	Shell gravel and pebbles and cobbles	ModT	RC
DD11.5	80	5	Y	N	F	F	0	N	N	Muddy sand	Lim	RC
DD11.6	100	10	Y	N	N	N	0	N	N	Muddy sand	Lim	RC
DD12.1	0	0	N		N		0			Pebbles, cobbles, shells, gravel		GS
DD12.2	0	0	N		N		<1			Shell gravel, pebbles cobbles, shells		GS
DD12.3	<1	0	Y		N		0			Shell gravel, pebbles cobbles, shells		GS
DD12.4	0	0	N		N		0			Muddy shell gravel, pebbles cobbles, shells		GS
DD13.1	50	7	Y		C		5			Shell gravel	Lim, ModT	LK
DD13.2	75	7	Y		A		5			Shell gravel	Lim, ModT	LK
DD13.3	75	7	Y		A		5			Shell gravel	Lim, ModT	LK
DD13.4	0	0	N		N/R		5			Shell gravel and empty shells, 50% pebbles, 10% cobbles		LK
DD13.5	50	7	Y		A		0			Shell gravel	Lim, ModT	LK
DD13.6	10	6	Y		C		0			Shell gravel and pebbles	Lim, ModT	LK
DD14.1	0	0	N		N		0			Silty, shelly sand with pebbles and shells		BJ
DD14.2	0	0	Y		F		10			Cobbles, boulders, pebbles and shell gravel		BJ

Table 3.2 continued

Site	Limaria nest cover (%)	Nest thick-ness (cm)	*Limaria* seen	*Limaria* density <1/0.1 m^{-2}	*Modiolus* (SACFOR)	Brittlestars (SACFOR)	Algal turf (%)	*L. hyp* (SAC-FOR)	*S. lat* (SAC-FOR)	Substrate	Biotopes	Surv-eyor
DD14.3	0	0	N		F		0			Cobbles, boulders, pebbles and silty shell gravel		BJ
DD14.4	0	0	N		F		0			Silty sandy gravel with scattered pebbles		BJ
DD16.1	0	0	N		N		0			Muddy gravel, pebble, shell		GS
DD16.2	0	0	N		N		<1			Muddy gravel, pebble, shell		GS
DD16.3	2	3	Y		C		0			Muddy gravel, pebble, shell	ModT	GS
DD16.4	100										Lim	GS
DD17.1	60	7	Y		C		70			Cobbles, pebbles and shelly sand - coarse	Lim, ModT	BJ
DD17.2	0	0	Y		C		25			Cobbles, pebbles and shelly sand with shells	ModT	BJ
DD17.3	0	0	N		C		20			Cobbles, pebbles and shelly sand with shells	ModT	BJ
DD17.4	0	0	Y		C		30			Cobbles, pebbles and shelly sand with shells	ModT	BJ
DD17.5	0	0	N		C		25			Shelly gravel with shells and pebbles	ModT	BJ
DD17.6	0	0	N		C		35			Shelly gravel with lots of shells and then cobbles and large boulders	ModT	BJ
DD18.1	100	10	Y		N		80			Cobbles & muddy shell sand	Lim	AL, LP
DD18.2	100	5	Y		N		90			Cobbles & muddy shell sand	Lim	AL, LP
DD18.3	95	5	Y		N		95			Cobbles & muddy shell sand	Lim	AL, LP
DD18.4	95	5	Y		N		95			Cobbles & muddy shell sand	Lim	AL, LP
DD18.5	100	5	Y		N		100			Pebbles & muddy shell sand	Lim	AL, LP
DD18.6	0	0	N		N		0			Dead shells & coarse shell sand		AL, LP

Table 3.2 continued

Site	Limaria nest cover (%)	Nest thick-ness (cm)	*Limaria* seen	*Limaria* density <1/0.1 m^{-2}	*Modiolus* (SACFOR)	Brittlestars (SACFOR)	Algal turf (%)	*L. hyp* (SAC-FOR)	*S. lat* (SAC-FOR)	Substrate	Biotopes	Surv-eyor
DD19.1	65	6	Y		A		15			Cobbles (60%); pebbles (15%); shells (5%); silty gravel (20%)	Lim, ModT	BJ
DD19.2	0	0	Y		F		10			Boulders (55%); cobbles (30%); pebbles (10%); shelly gravel (5%)		BJ
DD19.3	0	0	N		N		60			Boulders (75%) and cobbles (25%) on bedrock rise		BJ
DD19.4	0	0	N		N		5			Shelly gravel (90%); shells (5%) and pebbles (5%)		BJ
DD19.5	0	0	N		F		0			Bedrock		BJ
DDLD1.1	10	4	Y		C		3			Shell gravel with 10-20% cover of modiolus shell	Lim, ModT	DH
DDLD1.2	70	5	Y		C		35			Shell gravel	Lim, ModT	DH
DDLD1.3	80	6	Y		C		35			Shell gravel	Lim, ModT	DH
DDLD1.4	90	6	Y		C		65			Shell gravel	Lim, ModT	DH
DDLD1.5	40	5	Y		F		55			~50% small boulders with shell gravel infill	Lim	DH
DDLD1.6	3	4	Y		F		3			40% cobbles, 20% pebbles with shell gravel infill		DH
DDLD2.1	0	0			C(A)					Dense pebbles and shells	ModT	GS
DDLD2.2	0	0			A					Dense pebbles and shells	ModT	GS
DDLD2.3	0	0			A					Gravel with dense pebbles and shells	ModT	GS
DDLD2.4	0	0			A					Dense shells and pebbles with occasional cobbles	ModT	GS
DDLD2.5	0	0	N		A		5		C	Dense shells and pebbles	ModT	GS

Table 3.2 continued

Site	Limaria nest cover (%)	Nest thick-ness (cm)	*Limaria* seen	*Limaria* density <1/0.1 m^{-2}	*Modiolus* (SACFOR)	Brittlestars (SACFOR)	Algal turf (%)	*L. hyp* (SAC-FOR)	*S. lat* (SAC-FOR)	Substrate	Biotopes	Surv-eyor
DDLD2.6	***10***	10	Y		C		5		A	Dense pebbles and shells with cobbles	Lim, ModT	GS
DDLD2.7	0	0	N		C(A)		5	C	C	Dense pebbles and shells	ModT	GS
DDLD2.8	***50***	5	Y		C(A)		0		C	Silty coarse sand with dense shells, pebbles and occasional cobbles	Lim, ModT	GS
DDLD2.9	65	7	Y		N		50		A	Silty coarse sand with pebbles and shells consolidated by byssal turf and cobbles	Lim	GS
DDLD2.10	60	7	Y		C		50	F	O	Silty coarse sand with pebbles (30%), cobbles (5%) and shells (15%) consolidated by byssal turf	Lim, ModT	GS
DDLD3.1	0	0	N		A	N	0	S	N	Pebbles>cobbles>gravel encrusted with Lithothamnion and serpulids	ModT	LP
DDLD3.2	0	0	N		A	N	0	S	N	Cobbles>pebbles>gravel encrusted with Lithothamnion and serpulids	ModT	LP
DDLD3.3	0	0	N		N	N	0	A	N	Cobbles>boulders>pebbles encrusted with Lithothamnion and serpulids		LP
DDLD3.4	0	0	N		O	N	0	C	N	Pebbles>gravel>cobbles encrusted with serpulids and Lithothamnion		LP

Table 3.2 continued

Site	Limaria nest cover (%)	Nest thick-ness (cm)	*Limaria* seen	*Limaria* density <1/0.1 m^{-2}	*Modiolus* (SACFOR)	Brittlestars (SACFOR)	Algal turf (%)	*L. hyp* (SAC-FOR)	*S. lat* (SAC-FOR)	Substrate	Biotopes	Surv-eyor
DDLD3.5	0	0	N		C	N	0	C	N	Pebbles>cobbles>gravel encrusted with serpulids and Lithothamnion	ModT	LP
DDLD3.6	0	0	N		F	N	0	F	C	Shell gravel>cobbles>pebbles>boulders encrusted with Lithothamnion and serpulids		LP

Table 3.3. Details of grab samples taken (using 0.1 m^2 van Veen) for assessment of Limaria hians density.

Site	Date	Time (UT)	Latitude	Longitude	Depth below CD (m)	*Limaria* density (no./0.1 m^2)	*Limaria* SACFOR
G1	08/09/2017	10:30:00	56.521750	-5.388883	15.7	3	C
G2	08/09/2017	13:55:00	56.520750	-5.388367	20.9	1	C
G3	08/09/2017	14:54:00	56.522233	-5.385083	26.6	0	N

Table 3.4. Epibiota with SACFOR abundance recorded along MNCR phase 2 transect at flame shell bed site FS03. Taxon names follow WoRMS nomenclature. Brackets denote local abundance.

Taxon	**SACFOR**
Sycon ciliatum	R
Amphilectus fucorum	R
Haliclona (Rhizoniera) viscosa?	R
Haliclona sp.?	R
Myxilla sp.	R
Obelia geniculata	P
Obelia sp.?	P
Amphisbetia operculata	R
Hydrallmania falcata?	R
Abietinaria filicula	R
Sagartia elegans	O(F)
Urticina felina	O
Lineus sp.	P
Eupolymnia nebulosa	O
Sabella pavonina	R
Polychaeta sp. indet.	(F)
Balanus sp.	R
Verruca stroemia	R
Pagurus bernhardus	O
Macropodia sp.	P
Carcinus maenas	R
Liocarcinus depurator	P
Necora puber	O(F)
Cancer pagurus	P
Anomiidae sp.	P
Pecten maximus	R
Aequipecten opercularis	O
Limaria hians	A
Membranipora membranacea	R
Electra pilosa	P
Antedon bifida	F(C)
Crossaster papposus	F
Asterias rubens	P

Taxon	**SACFOR**
Henricia sp.	R
Thyone sp.?	O
Diplosoma listerianum	P
Lissoclinum sp.	R
Ascidiella aspersa	O
Gobiusculus flavescens	P
Teleostei sp.	F
Colaconema sp.	R
Corallinaceae pink crusts	R
Metacallophyllis laciniata	R
Calliblepharis ciliata	O
Plocamium cartilagineum	S
Bonnemaisonia asparagoides	R
Bonnemaisonia hamifera	R
Cystoclonium purpureum	R
Cryptopleura ramosa	R
Ptilota gunneri	R
Membranoptera alata	R
Delesseria sanguinea	R
Phycodrys rubens	P
Heterosiphonia plumosa	R
Dasysiphonia japonica	F
Vertebrata byssoides	R
Vertebrata fucoides	R
Rhodomela confervoides	R
Pylaiella littoralis	R
Desmarestia aculeata	R
Dictyota dichotoma	R
Saccharina latissima	F
Laminaria hyperborea	F(C)
Ulva compressa	R
Ulva lactuca	R

Table 3.5. Species abundance data for four replicate cores of area 83 cm² through the South Shian flame shell bed at site FS03. Taxon names follow WoRMS nomenclature. + denotes presence.

Taxon	**Replicate**			
	FS03.1	**FS03.2**	**FS03.3**	**FS03.4**
Astrorhiza limicola	1			
Sycon ciliatum	+	+	+	
Pione vastifica			+	
Leucosolenia sp.	+	+		
Campanulinidae sp.		+	+	
Clytia hemisphaerica		+	+	+
Calycella syringa		+		
Sertulariidae sp.			+	
Nemertea spp	2	1	1	1
Cerebratulus spp	1	1	1	4
Nematoda	6	6	20	9
Golfingia spp juv/indet	27	34	45	46
Golfingia (Golfingia) elongata		1		1
Golfingia (Golfingia) vulgaris	2	1	3	1
Harmothoe spp juv/indet	8	6	5	5
Harmothoe fragilis			1	4
Harmothoe impar		1		1
Malmgrenia andreapolis			1	
Lepidonotus squamatus	1	1	2	1
Pholoe inornata	41	49	36	26
Pholoe baltica	10	9	3	7
Eteone longa	1	1	2	
Eulalia expusilla			2	
Eumida/Eulalia spp juv/indet	1	2		1
Eumida bahusiensis	1		1	2
Eumida sanguinea				1
Glycera spp juv	2	1		
Glycera lapidum		2	2	5
Sphaerodorum gracilis	4	6	2	1
Psamathe fusca	15	13	8	10
Nereimyra punctata	7	6	3	7
Syllis armillaris	1	1	1	1
Odontosyllis ctenostoma	1			
Odontosyllis gibba		1		
Syllides bansei			1	
Syllides benedicti			1	1
Sphaerosyllis sp . A	1	1	7	1
Sphaerosyllis hystrix	21	8	13	4
Sphaerosyllis taylori	4	3	3	

Table 3.5 continued

Taxon	Replicate			
	FS03.1	**FS03.2**	**FS03.3**	**FS03.4**
Prosphaerosyllis tetralix	2	2	5	7
Myrianida spp		2		
Nereis pelagica	1			
Platynereis dumerilii		1		
Lysidice unicornis		1	1	6
Lumbrineris aniara	2	1	1	
Protodorvillea kefersteini			1	1
Schistomeringos rudolphi				1
Paradoneis lyra	1			1
Aonides oxycephala	16	16	13	12
Aonides paucibranchiata			2	
Malacoceros fuliginosus	1	1	3	1
Dipolydora coeca			1	
Dipolydora caulleryi		2		
Dipolydora flava			1	
Microspio mecznikowianus		1	2	1
Cirratulus spp		4		
Flabelligera affinis	22	11	14	15
Pherusa plumosa	5		1	
Capitella spp	2	2	1	2
Mediomastus fragilis	5	12	7	23
Arenicola sp juv		2		1
Asclerocheilus intermedius		1	2	2
Polyphysia crassa		1		2
Terebellides stroemii	1	1		2
Trichobranchus glacialis	1	1	1	6
Terebellinae spp juv/indet		1		
Phisidia aurea	1			
Polycirrus norvegicus	12	10	8	5
Thelepus cincinnatus				1
Sabellidae sp juv/indet			1	
Tubificoides pseudogaster	3	2	1	2
Enchytraeidae sp	2		19	6
Grania sp	1		1	
Verruca stroemia	3	6	2	10
Balanus balanus			2	
Balanus crenatus			+	
Copepoda spp	2		18	2
Ostracoda spp	23	29	25	31
Heteromysis (Heteromysis) norvegica	1	1		
Peltocoxa damnoniensis			1	
Stenothoe monoculoides		2		

Table 3.5 continued

Taxon	Replicate			
	FS03.1	**FS03.2**	**FS03.3**	**FS03.4**
Metaphoxus fultoni	4	3	2	6
Lysianassidae spp juvs/indet			1	
Lysianassa ceratina	11	21		1
Dexamine spinosa		2		1
Ampelisca tenuicornis				1
Bathyporeia elegans	2			
Crassicorophium bonellii	2	1	1	
Caprella linearis	5	1		1
Phtisica marina				2
Cymodoce truncata	1			
Munna spp	22	8	7	9
Leptognathia breviremis			1	
Pseudoparatanais batei		1		
Vaunthompsonia cristata		1		1
Nannastacus unguiculatus	1	1		2
Caridea spp indet		1		
Pisidia longicornis	1	2	2	
Maja squinado juv				1
Eurynome aspera			1	
Leptochiton asellus		3	1	1
Lacuna vincta				1
Pusillina sarsii				2
Rissoa parva	9	7	3	8
Alvania beanii	4		2	4
Onoba semicostata	14	19	12	32
Brachystomia eulimoides			2	1
Nucula nucleus	2	4	3	2
Mytilus edulis juvs	4	9	9	1
Crenella decussata	1			1
Musculus subpictus	2	2	2	1
Modiolula phaseolina	5	8	11	13
Limaria hians	4	5	3	4
Heteranomia squamula	2	1	1	
Lucinoma borealis	1			
Kurtiella bidentata	4	17	7	7
Parvicardium pinnulatum			1	1
Abra alba	14	2	1	4
Timoclea ovata		1		
Mya truncata	1	1	4	
Hiatella arctica	14	12	6	6
Thracia phaseolina	3	1	2	1
Scruparia ambigua				+
Alcyonidium hirsutum		+		

Table 3.5 continued

Taxon	Replicate			
	FS03.1	**FS03.2**	**FS03.3**	**FS03.4**
Amphiuridae spp juv	7	3		3
Amphipholis squamata	29	21	13	22
Didemnidae sp.	+			
Plocamium cartilagineum	+	+	+	+
Rhodophyllis divaricata				+
Peyssonnelia dubyi?				+
Corallinaceae pink crust	+	+		+
Bonnemaisonia hamifera		+	+	+
Vertebrata byssoides		+	+	+
Dasysiphonia japonica		+	+	
Aglaothamnion bipinnatum			+	
Pseudolithoderma extensum		+	+	

ANNEX 4: SITE ATTRIBUTE TABLE FOR THE REEF HABITATS OF LOCH CRERAN SAC

Attribute	Target	Method	Result of Monitoring
Extent	No change in extent of inshore sublittoral rock	At six year intervals review activities and events with the potential to reduce extent of feature such as land reclamation and shoreline development, fishing and recreational activity	Extent reduced as a consequence of reductions in extent of the sub-features serpulid reefs and horse mussel beds. Change thought likely to be accounted for by natural temporal variation, although with a possible minor contribution from anchoring.
Biotope composition of inshore sublittoral rock	Maintain the variety of biotopes identified for the site, allowing for natural succession or known cyclic change. The following biotopes must be found within the SAC: **SS.SBR.PoR.Ser**, **SS.SBR.SMus.ModHAs**, **SS.SBR.SMus.ModT**, **IR.MIR.KR.LhypT.Ft**, **IR.MIR.KR.LhypT.Pk**, **IR.LIR.KVS.LsacPsaVS**, **CR.LCR.BrAs.AmenCio**, **CR.HCR.XFa**	At six year intervals assess the continued existence of reef biotopes recorded along the monitoring transects.	All biogenic reef biotopes present.
Distribution of biotopes. Spatial arrangement of biotopes at specified locations	Maintain the distribution and spatial arrangement of biotopes, allowing for natural succession or known cyclic change	At six year intervals confirm the geographic distribution of reef biotopes along the monitoring transects	The same biogenic reef biotopes (**SS.SBR.PoR.Ser**, **SS.SBR.SMus.ModHAs** and **SS.SBR.SMus.ModT**) found along monitoring transects in 2005 were present in the same areas in 2014 - 18, except for the absence of **SS.SBR.PoR.Ser** in South Creagan Bay.
Extent of sub-feature or representative/notable biotopes	No change in extent of *Serpula vermicularis* reefs allowing for natural succession or known cyclic change	At six year intervals review activities and events with the potential to reduce extent of feature such as land reclamation and shoreline development, fishing and recreational activity	Possible damaging activities include installation of three pontoons and small vessel anchoring. Only the latter is considered to have possibly contributed to extent reduction at one site, South Creagan Bay.

Attribute	Target	Method	Result of Monitoring
	No change in extent of *Serpula vermicularis* reefs allowing for natural succession or known cyclic change	At six year intervals assess the extent of *Serpula vermicularis* reefs by diver transect survey	No current estimate derived for extent of serpulid reefs but reduction in extent of habitat confirmed and of the order of 20%.
	No change in extent of *Serpula vermicularis* reefs allowing for natural succession or known cyclic change	At 12 year intervals confirm the results of the diver survey and assess reef damage at the following sites using sidescan sonar: Rubha Mór, South Shian, Sea Life Centre Bay, South Creagan Bay.	2015 sidescan survey confirmed extent loss at Rubha Mór, South Shian, Sea Life Centre Bay and South Creagan Bay.
	No change in extent of *Modiolus modiolus* (horse mussel) beds allowing for natural succession or known cyclic change	At six year intervals review activities and events with the potential to reduce extent of feature such as land reclamation and shoreline development, fishing and recreational activity	No relevant activities identified.
	No change in extent of *Modiolus modiolus* beds allowing for natural succession or known cyclic change	At six year intervals assess the extent of *Modiolus modiolus* beds by point station video or diver survey	Current extent of Upper Basin, Creagan West and Creagan East beds assessed as 16.3, 4.3 and 3.5 ha respectively but no previous estimates. Localised reduction in extent of bed at mouth of loch possibly associated with natural temporal variability.
Species composition of representative or notable biotopes	No decline in biotope quality due to change in species composition or loss of notable species allowing for natural succession or known cyclic change. No change in species composition and diversity (allowing for natural succession or known cyclic change) in the following biotopes at the transects where they were recorded in the baseline survey: **SS.SBR.PoR.Ser**, **SS.SBR.SMus.ModHAs**, **SS.SBR.SMus.ModT**, **IR.MIR.KR.LhypT.Ft**, **CR.HCR.XFa**	Every six years assess species composition and diversity by means of MNCR Phase 2 surveying and presence/absence survey of biota on serpulid reefs.	No change in species richness of *Modiolus* bed community in upper basin (**SS.SBR.SMus.ModHAs** biotope) between 2005 and 2018. Species composition also similar apart from decrease in SACFOR abundance of *Modiolus* from abundant to common. No species composition surveys of the other listed biotopes carried out.

Attribute	Target	Method	Result of Monitoring
	No decline in biotope quality due to change in species composition or loss of notable species allowing for natural succession or known cyclic change. No change in associated community composition and diversity (allowing for natural succession or known cyclic change) of the biotope **SS.SBR.SMus.ModHAs**	Every six years collect four replicate clumps of *Modiolus* from station 3 on transect 1 in the upper basin and assess species composition and diversity of associated biota.	Little temporal change in species composition between 2005 and 2017. Slight but significant increase in some diversity indices, possibly related to sample size differences.
Presence and abundance of specified species	Maintain presence and abundance of specified species. No reduction in the abundance of live *Modiolus modiolus* and *Serpula vermicularis* at specified survey locations	At six year intervals assess the abundance of *Modiolus modiolus* at monitoring sites in the Upper Basin and Creagan West *Modiolus* beds and the abundance of *Serpula vermicularis* at monitoring sites at Rubha Mór, South Shian, Sea Life Centre Bay and South Creagan Bay	Between 2005 and 2017/18 declines in *Modiolus* density were recorded along transects through the Upper Basin bed (from 7.40% to 3.23% cover), the Creagan West bed (from 37.75% to 8.00% cover) and the Druim Cairine bed at the mouth of the loch (from a SACFOR value of superabundant to common), probably resulting from natural temporal variability. Serpulid tube occupancy decreased sharply at three of the four serpulid monitoring sites from >50% to <10%.

ANNEX 5: SINGLE BEAM SONAR TRIAL

The utility of high-precision, single beam sonar to augment sidescan sonar and diver assessment of serpulid reef degradation was assessed using Neptune T166 33 MHz (16.5 degree beam width) and T137 210 MHz (7.5 degree beam width) transducers linked to a Knudsen Mini Sounder with positional and heave data derived from a Hemisphere VS300 Vector Sensor employing dual antennas to produce a horizontal accuracy of 0.3 m (using WAAS/EGNOSS). The Knudsen sounder has a resolution of 1 cm over the working depth range.

The main antenna was mounted at a horizontal distance of c.0.3 m from the transducer, with an additional bluetooth DGPS receiver mounted above this to supply positional data to the plotter used for steering (Figure 5.1).

Figure 5.1. Configuration of Hemisphere VS300 Vector Sensor antennas, with transducer mounted outboard between the two and steering DGPS receiver above the main antenna (in bucket).

The system was tested on 19-20 April 2018 at three locations:

- Rubha Garbh Bay (colloquially *Trailliella* Bay) - embayment on the north side of the loch (close to site DR09).
- Sea Life Centre Bay (close to site DR02).
- Rubha Mór (close to site DR05).

At each site an area was surveyed using a lawnmower pattern employing a range of settings, such as gain, power and sensitivity, and both transducers. The system provided a recorded echogram (Figure 5.2) and digitised depths and positional data at a selected frequency of 10 Hz.

The digitised depth and navigational data were imported into Excel, where the depth data were filtered to screen out spurious returns (particularly from the surface metre of the water column). The echogram and digitised depth plots were useful aids in the identification of such data.

Seabed target heights were obtained by the following sequence of manipulations of the data, also depicted in Figure 5.3.

A: A plot of filtered depth against ping number was produced (Figure 5.3A) at the raw frequency of 10 Hz. A copy of this data set was then reduced to a frequency of 1 Hz using a VBasic macro within Excel. The derived points at 1 s intervals were plotted over the existing depth plot.

B: The 1 Hz data points were manually adjusted vertically on the Excel graph to correspond to the perceived line of the seabed. This adjustment automatically modifies the original vertical coordinate (depth value) of the point within the source Excel cell. (Note: this capability was discontinued for versions of Excel after 2003).

C: The modified 1 Hz seabed depth values were converted to a frequency of 10 Hz by linear interpolation using a VBasic macro within Excel. This produced a smoothed seabed trace.

D: The 10 Hz seabed trace was subtracted from the original 10 Hz depth trace from step 'A' to produce a plot of target height.

Ping number can be replaced by cumulative distance to better characterise the pattern of reef topography. To achieve this the positional coordinates for each ping were employed to determine horizontal, inter-ping distance through the use of the haversine formula, given by:

$$\text{distance} = 2r \arcsin\left(\sqrt{\sin^2\left(\frac{\varphi_2 - \varphi_1}{2}\right) + \cos(\varphi_1)\cos(\varphi_2)\sin^2\left(\frac{\lambda_2 - \lambda_1}{2}\right)}\right)$$

where r = radius of the earth (6371 km), φ and λ are respectively latitude and longitude at points 1 and 2 (in radians).

Distance plots of target heights along all three sonar runs used in the body of this report are given in Figure 5.4.

Spatial plots of heights for overlaying on sidescan sonar mosaics were produced within ArcGIS 10.2 (see e.g. Figures 15, 23, 28).

All results shown in Figures 5.2 - 5.4 and used in this report were obtained using the lower frequency, wider beam width transducer, which was found to be much superior in distinguishing reef material, although its power to resolve individual reef structures might be expected to be less.

As can be seen from the western end of the Sea Life Centre Bay trace (Figure 5.4), the variability in target heights on the smooth, muddy seabed present in this area is very small (within +/- 2.5 cm). This result was achieved in a calm sea. More attention to heave compensation would probably be required in rougher conditions.

Although there is an element of subjectivity in discerning the line of the seabed, the approach taken here is thought to be probably superior to any form of algorithmic automation of the process.

While spatial coverage of the seabed is poorer per unit time than sidescan sonar, the single beam approach has the advantage of precise geolocation and the reduction of certain limitations experienced by towed sidescan, such as in navigationally difficult areas (e.g. due to small embayments size or the presence of hazards) or in areas of rapidly changing bathymetry. As with other forms of sonar, it would, however, require a degree of groundtruthing.

The single beam approach would seem to have the potential for the production of good quantitative data on the height spectrum of reef material for the purpose of spatial and temporal comparisons. This could for example involve the derivation of indices such as the proportion of material in size range categories. This would, however, require some standardisation in methodology, such as employment of similar beam-width transducers.

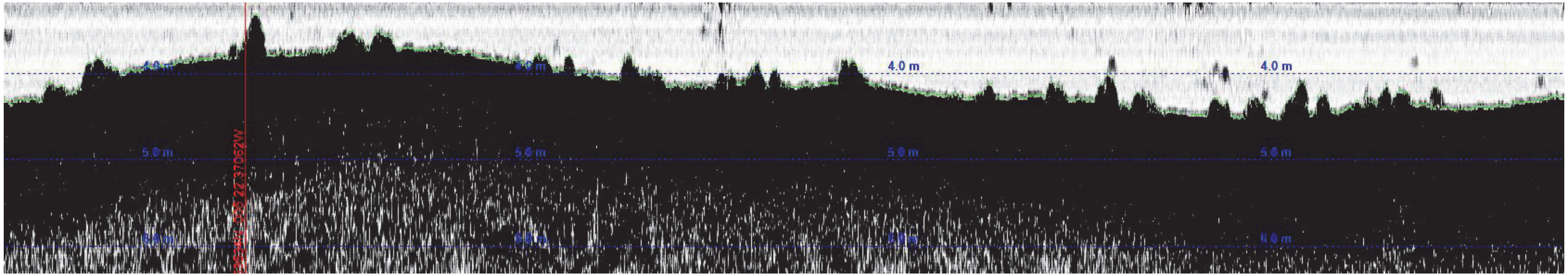

Figure 5.2. Raw echogram from line 8, Rubha Garbh Bay, 33 MHz transducer.

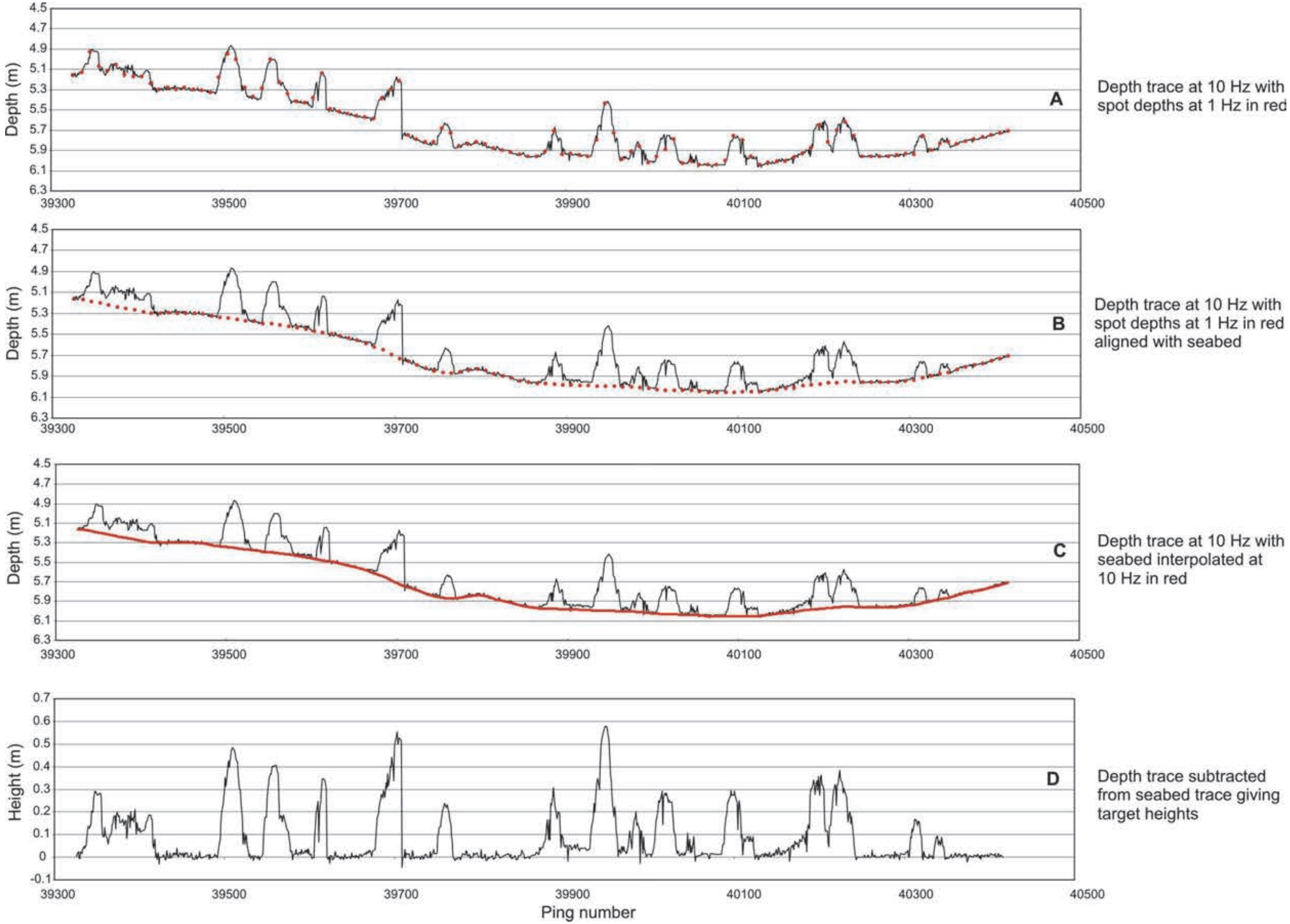

Figure 5.3. The sequence of sonar return data processing to produce seabed target heights (data from line 4, Rubha Garbh Bay).

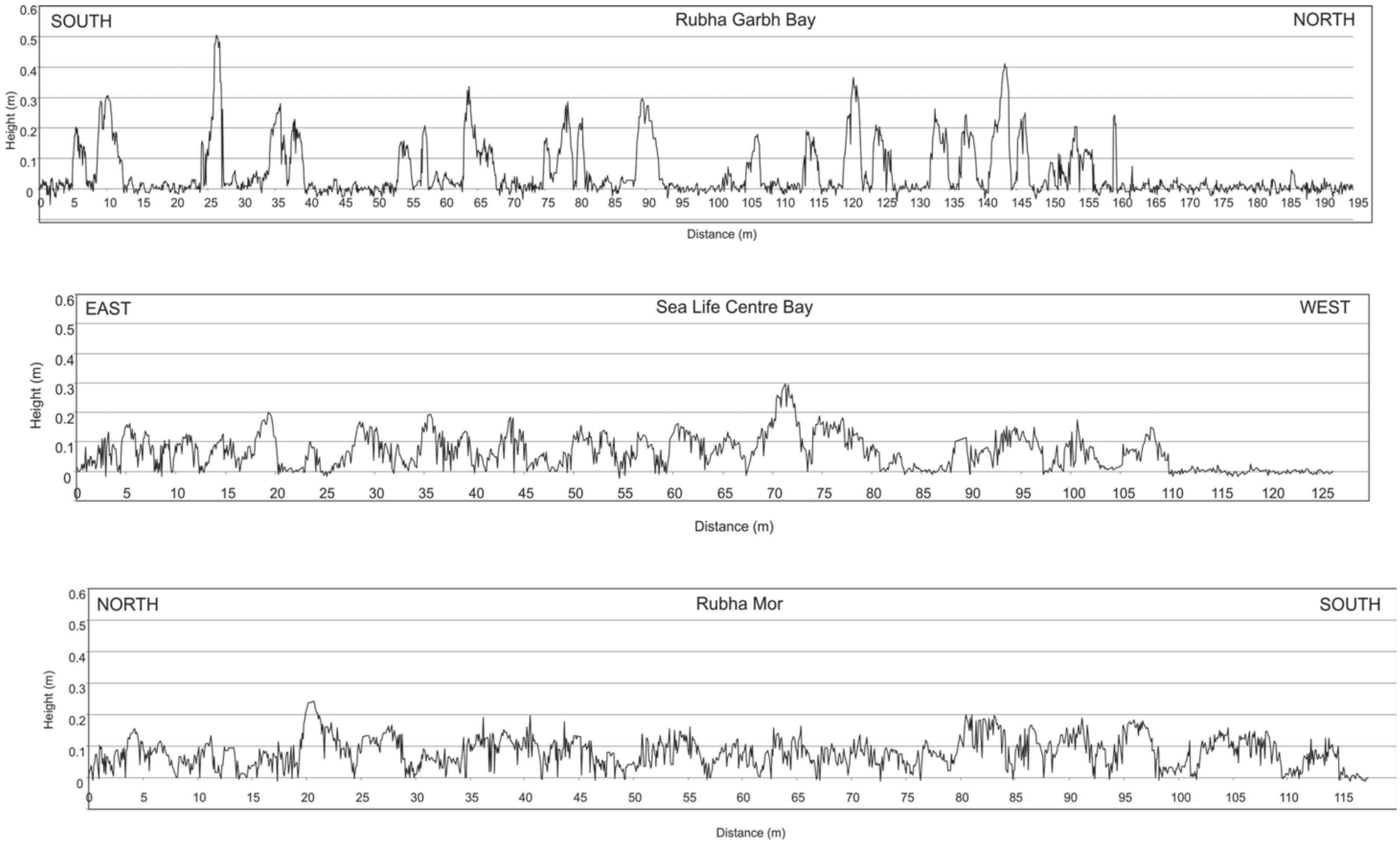

Figure 5.4. Target heights along examples of survey lines at Rubha Garbh Bay (line 8), Sea Life Centre Bay (line 2) and Rubha Mór (line 3).

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