SEAWILDING
Community-led Marine Habitat Restoration

Seagrass Restoration 2022 Project Update

By Katherine Knight and Eric Holden

This report contains a summary of the seagrass restoration activities undertaken by Seawilding during 2022.

Images by Philip Price & Katherine Knight courtesy of Seawilding

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2023 Seagrass Restoration Project Update

Overview

Seawilding is a community-led charity delivering marine habitat restoration. In 2021, from its base in Argyll on the west coast of Scotland, Seawilding began a ground breaking project to undertake the first seagrass restoration in Scotland. The first year of the project, running from April 2021-22, was undertaken in partnership with the Scottish Association for Marine Science (SAMS) and the NGO Project Seagrass. It was supported by the NatureScot Biodiversity Challenge Fund. Subsequently funding was secured for a further 2 years of seagrass restoration from NatureScot's Nature Restoration Fund, the Crown Estate Scotland and the Patagonia Environmental Grants Program Fund. This report provides an update on this project at its mid-way point. It summarises the monitoring and research work undertaken to date, answers some of the key short term questions, highlights learnings so far, as well as details the ongoing longer term research questions which the project will work towards answering.

Project location

The project is located in Loch Craignish, Argyll on the west coast of Scotland. As is typical of many sea lochs on Scotland's west coast, Loch Craignish is a fjord style loch. It is relatively shallow throughout with a maximum depth of 20m. It has approximately 80km of coastline, has a busy yachting marina, sea trout farm and a community of approximately 500 people. There are four large islands, two of which form an almost continuous barrier enclosing an area of shallow, sheltered water referred to as the 'lagoon'. Recreational boat moorings are situated both outside the marina and in the lagoon area.

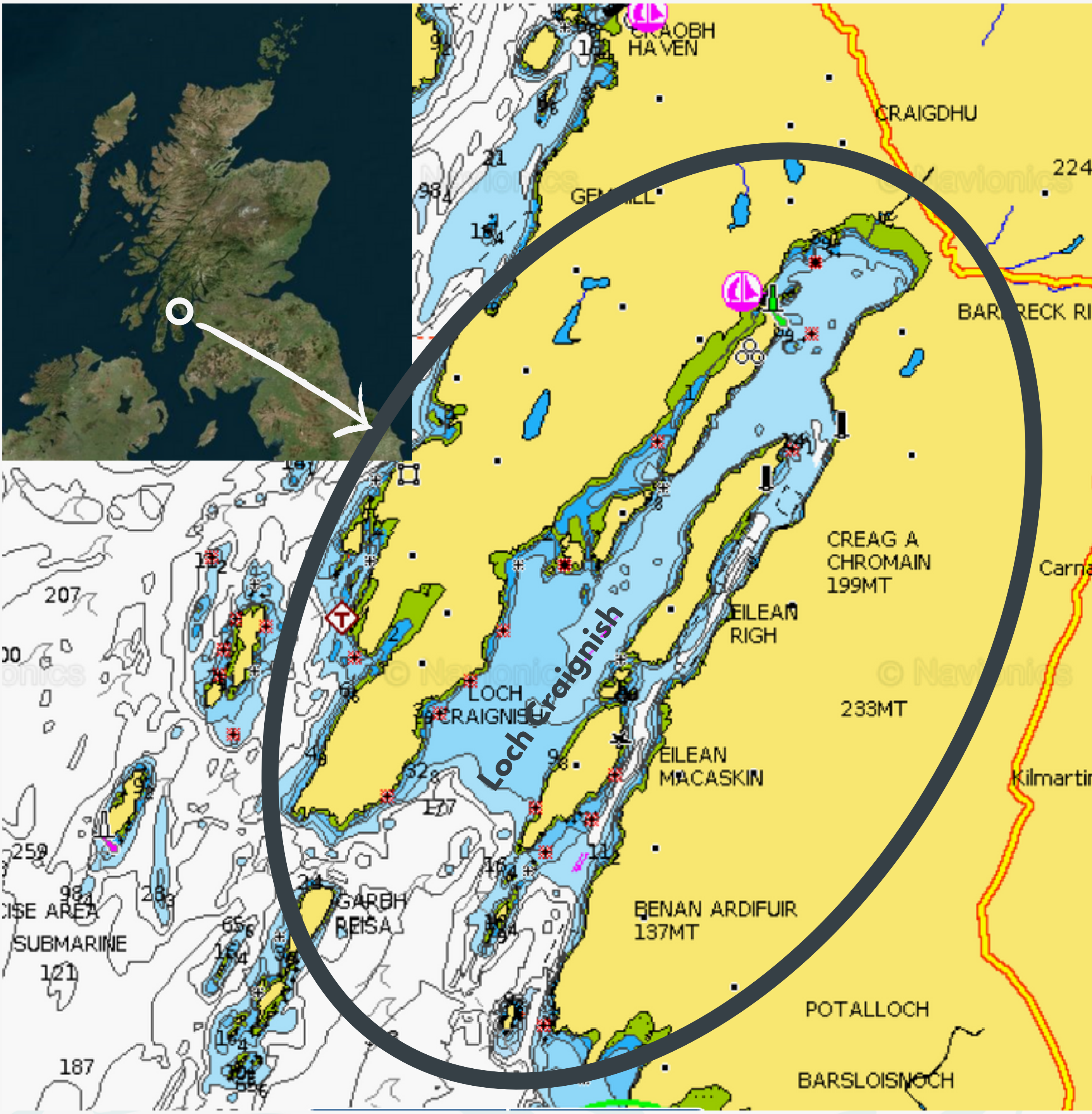


Image 1 - Project location, chart reproduced from Navionics Webapp

Aims of the project

The aims of the project are to:

- Reinforce the seagrass beds in Loch Craignish by planting 125,000 seeds in 2021, planting an additional 250,000 seeds over 2022 and 2023.
- Involve the community in all phases of the restoration process.
- Monitor the health of donor and control seagrass beds.
- Monitor the germination rates of the 2021 seagrass seed planting.
- Provide a role model of community restoration and share learning with other communities.
- Further support the local community through the creation of green jobs.
- Provide an opportunity for training in marine habitat restoration for young people.
- Learn more about the methods of seagrass restoration that produce the best results in the context of Scottish waters.

Key project achievements so far

- 125,000 seagrass were seeds planted in 2021.
- Germination rate assessed as 20-40% for year one planting.
- A further 200,000 seagrass seeds were harvested in 2022.
- 176,000 of these have been planted, the remainder will enter planting trials in the spring.
- A total of 0.35ha of seagrass meadow has been planted
- 9 planting method variations are being trialled, including the first sod transplantation.
- 2 previously unrecorded *Z. Marina* and three *Z. Noltii* beds have been located and mapped in Loch Craignish.
- Over 100 km of connected habitat have been surveyed with 9 additional seagrass beds recorded and mapped.
- Volunteers engaged in 164hrs of work.
- 6 young people participated in a marine habitat restoration training weekend.
- 30 people have attended our community restoration training courses.
- Seawilding has brought together local marine organisations by hosting a Wild Seas weekend of outreach activities in and out of the water.
- Launched an online eLearning course and citizen science project 'Shore Surveyor' in collaboration with the British Sub Aqua Club.
- Developed a Mid-Argyll snorkel trail highlighting seagrass with the Scottish Wildlife Trusts.

Total area planted
0.35ha

300,000
Seagrass seeds planted

Project timeline

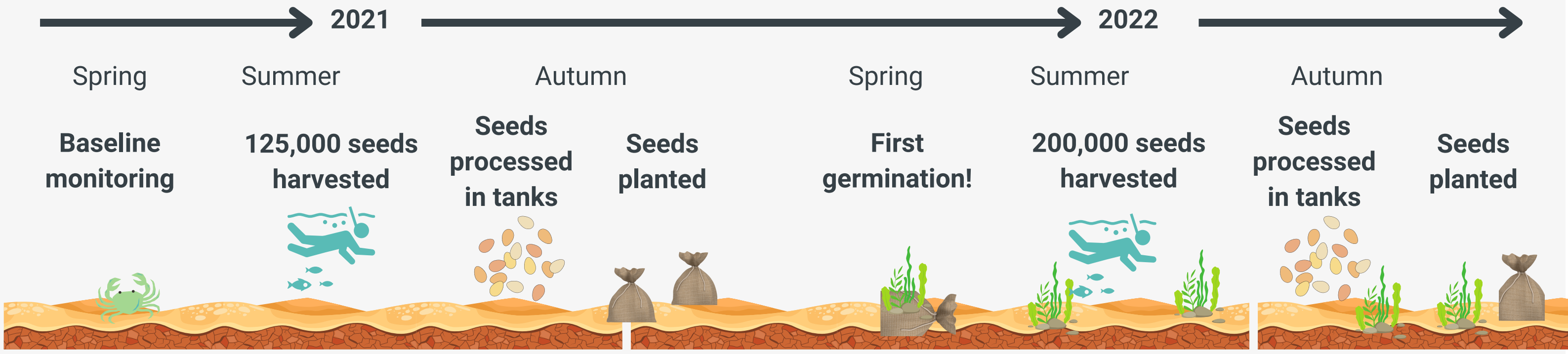


Image 2 Germinating seed bag

Monitoring

Monitoring forms a crucial part of the restoration process. Monitoring allows us to ensure we are not causing harm to existing fragile ecosystems, enables us to quantify ecosystem-services provided by restored seagrass beds, while improving success by increasing our understanding of the restoration process. In this emerging area of marine habitat restoration, it is vital we share our findings and work collaboratively with other restoration practitioners, public bodies and academic research institutions. It is hoped that effective and ongoing monitoring of the seagrass restoration project by both the Seawilding team and the project's academic partners, including SAMS, will enable crucial questions to be answered in the context of seagrass restoration in Scotland and beyond.

This document is intended to provide an overview of the methods and monitoring making up Seawilding's seagrass restoration project. The aim is to provide an accessible account of the activities we have undertaken, the successes and failures we have had along the way and most importantly the key learning points discovered. Whilst this document focuses on the outcomes of the scientific monitoring of the project, it is not intended to be a scientific paper. In-depth details of the survey and planting methodologies are omitted from the main text to allow the findings and learnings to be more easily accessible, although methodological details have been included in the appendix for the interested, scientifically-minded reader. This report is also not a catalogue of the many and wonderful virtues of seagrass. If you are interested in the benefits of this unassuming plant then you will find facts, figures and videos on our website, www.seawilding.org, as well as many other sources.

This report should enable those interested in, or already undertaking seagrass restoration to learn about some of the do's and don'ts as learned by us. It is only by careful and ongoing observation that we can understand how best to grow and restore plants and ecosystems. As a community- based project, Seawilding is in a unique position to provide this continuity of observation. Combining this with standardised scientific survey practices, our hope is this project will contribute significantly to the growing understanding of seagrass restoration.

- **Project monitoring aims to answer key short-term questions to make mid-term adjustments and improve the success of our restoration.**

- **It is also gathering data on longer-term questions in seagrass restoration. It is envisaged that over the next 5-10 years this long-term data set will enable us and the wider scientific community to gain insight into the process of seagrass restoration.**

Image 3 Snorkel surveying in progress

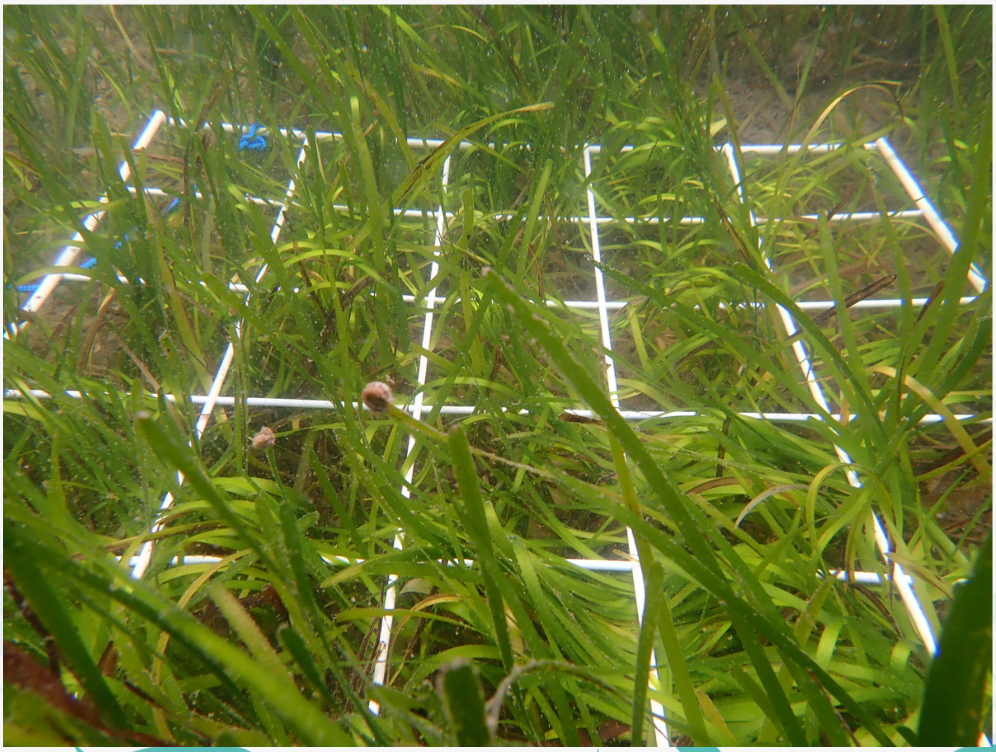
Long term themes

Key long term questions:

- Does harvesting seagrass seeds impact the health of seagrass donor beds?
- What is the germination success of planting seagrass seeds using the hessian bag technique?
- Do alternative planting methodologies provide improved germination results?
- Does planting seagrass beds enhance biodiversity within the restored area?
- Does restoring seagrass beds enhance benthic biodiversity within the restored area?
- Does restoring seagrass beds enhance fish stocks?
- Is there a spill over effect in the increase in biodiversity into areas adjacent to restoration?
- Is there a spill over in the propagation of seagrass into areas adjacent to restoration sites?
- Does seagrass restoration have any effect on the wider bodies of water surrounding the restoration area?
- Can seagrass seeds be germinated in a nursery and planted out successfully in the context of Scottish waters?
- Can the carbon storage by seagrass be quantified?
- Is there a reliable method of using eDNA analysis to determine historic presence of seagrass?

A table of how these themes are currently being investigated by monitoring in Loch Craignish is shown in *appendix 1* and the variables monitored shown in *appendix 2*.

In addition, Seawilding is involved with many other scientific research projects investigating the biological, ecological and socioeconomic factors at play in seagrass restoration by a wide variety of institutions. These include providing seagrass samples for carbon sequestration analysis to quantify the carbon sequestration of *Z. Marina*, making Loch Craignish's seagrass some of the most intensively studied in the UK. The projects are summarised in *appendix 3*.



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Short term questions

2022 monitoring

Monitoring was undertaken in 2022 to address both some of the key short-term questions that provide stepping stones of learning to underpin the ongoing project as well as ongoing monitoring to support longer term research into seagrass restoration.

The following key short-term questions were addressed in 2022:

- **What is the current extent of seagrass beds in Loch Craignish?**
- **How does this compare to potential historical extent?**
- **What is the current extent of seagrass beds in connected local habitats surrounding Loch Craignish? (To establish a baseline as well as locate potential areas for future restoration.)**
- **Do existing seagrass meadows have higher biodiversity than areas of barren sediment in Loch Craignish?**
- **What was the germination success rates of the hessian bag method in 2021?**
- **Do seeds harvested at an immature stage go on to ripen in the processing tanks and what is the viability of these seeds?**
- **What is the viability of seeds going into planting following the tank process?**

Let's take a look at each of these questions and discover what we learnt:

What is the current extent of seagrass beds in Loch Craignish?

The existing seagrass beds in Loch Craignish have been mapped by GPS, and *images 4a&b* show the position and extent of seagrass beds in 2022. The seagrass meadows were located by paddle board survey, regular observation of the loch and drone surveys. Comparing these with Bing satellite imagery and seagrass habitat mapping produced by SAMS, we believe that we have now located and mapped all of the existing meadows in Loch Craignish. This includes 2 new beds of *Z. Marina* and three beds of *Z. Noltii*. Full details of the methodology are given in *appendix 4A*.

GIS analysis was undertaken to calculate the total area of seagrass beds within Loch Craignish. It suggests that in 2022 there was 5.25ha of *Zostera marina* and 0.25ha of *Zostera noltii*.

Z. marina is known to expand vegetatively at a rate of up to 0.5m per year through rhizomal growth. It is anticipated that mapping will be repeated in 2024 or later, when significant changes in bed sizes could be expected to be detected.

Key learning: Currently Loch Craignish has 5.25ha of Z. marina and 0.25ha of Z. noltii.

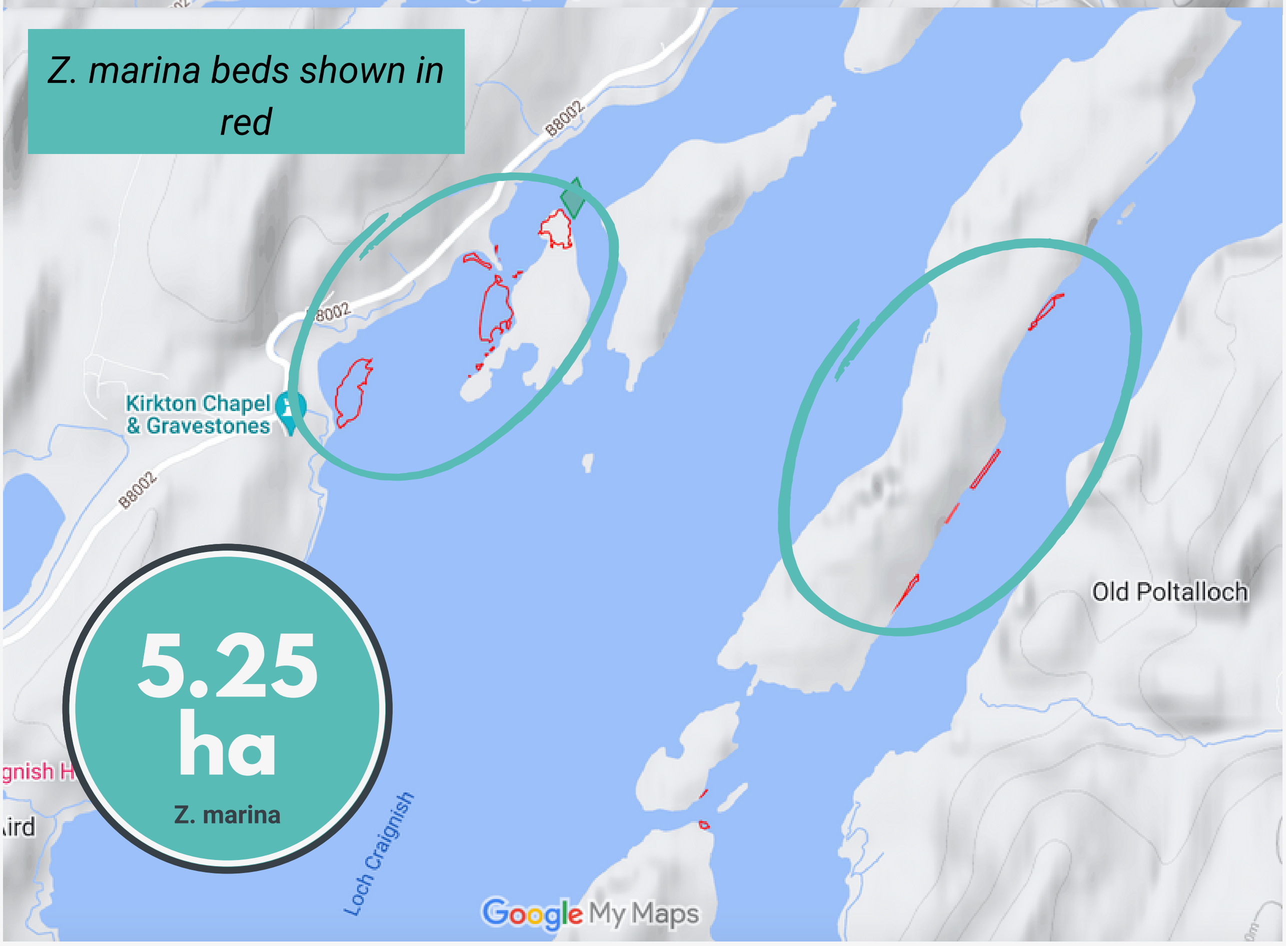


Image 4b Map of seagrass beds in southern Loch Craignish

How does this compare to the historical extent?

Determining the historical extent of seagrass within Loch Craignish is challenging as no detailed historical survey records exist. However anecdotal evidence from members of the community, collected by Seawilding as part of an oral histories project, point to it once having been present in larger quantities in Dunvullaig Bay, being extensive in "the lagoon", as well as being present in the adjacent Loch Beag, where it is currently absent. *Image 6a* shows the potential historical extent of seagrass in comparison to its current extent. The areas highlighted correspond well with habitat suitability modelling undertaken by Burrows, image 6b, *ref 1,* as well as sediment core analysis undertaken by SAMS using eDNA techniques, giving validity to the anecdotal evidence. Combining anecdotal and habitat suitability modelling indicates that there may have been up to 92ha of seagrass in Loch Craignish and Loch Beag.

Image 6a Existing seagrass beds compared with potential historical extent.
Existing seagrass beds are shown in red (Z. Marina) and green (Z. noltii)
Potential historical range is shown in orange

Reduction in seagrass compared with potential historical extent in Loch Craignish

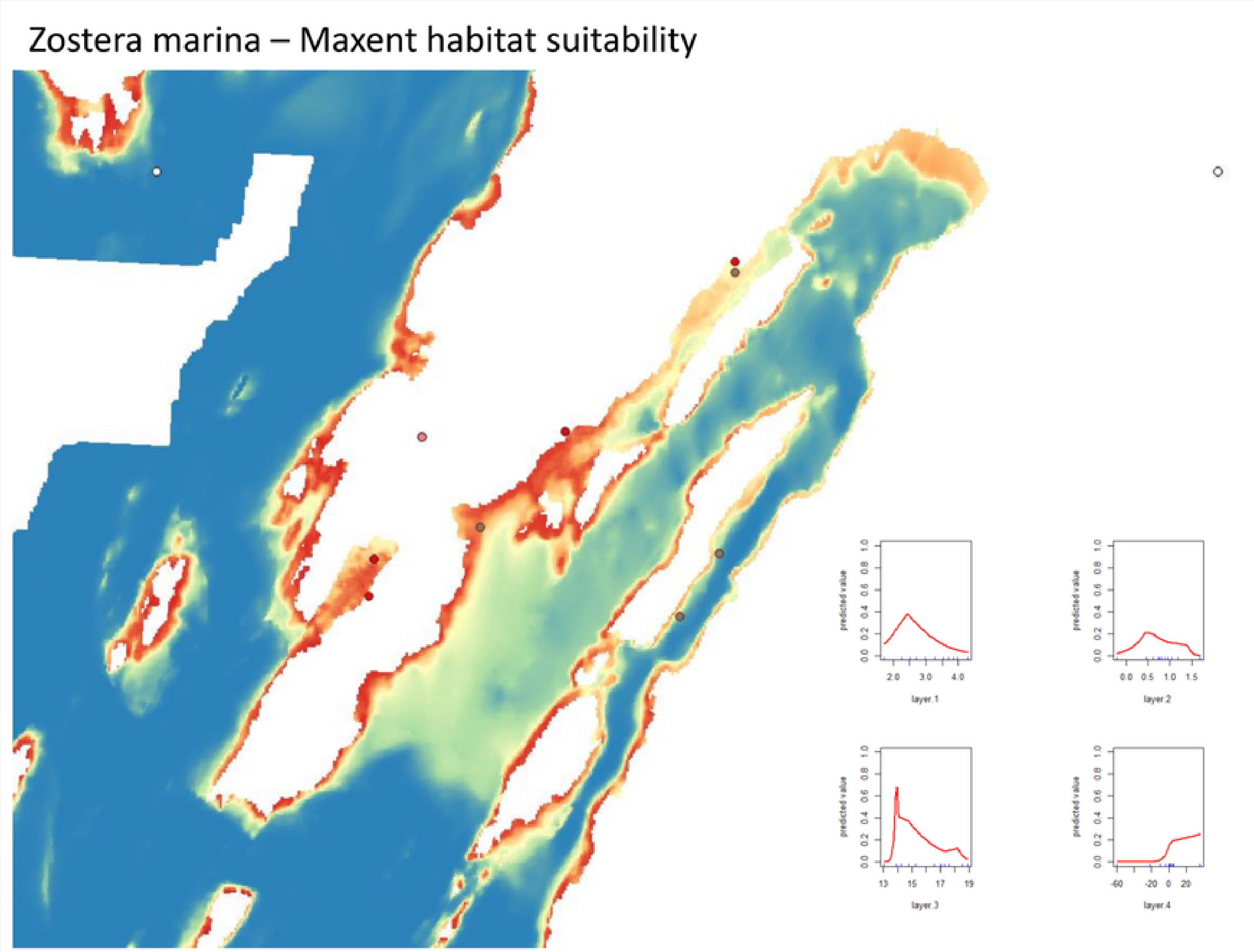


Image 6b Habitat suitability modelling for Z. Marina in Loch Craignish reproduced from Burrows et al, Ref1

Is there a difference in the biodiversity within existing seagrass meadows compared to areas of barren sediment?

Biodiversity was compared between existing seagrass meadows and areas of barren sediment using a variety of techniques including, visual survey by snorkeler, video transect, BRUV and sediment eDNA analysis. The survey methodologies are given in *appendix 4A*.

The visual snorkel surveys found that there were on average twice as many different species in the seagrass beds compared with adjacent areas of barren sediment, with an average of 15.4 species in the seagrass compared with 7.6 in the sediment sites *tables 1& 2*.

The species observed were classified according to their taxon. The number of taxa represented in each transect was calculated - the higher the number of taxa present in an area providing a representation of the diversity of species present. It was found that on average seagrass sites had 7.3 different taxa represented, compared to just 4.4 in the sediment sites, tables 1& 2.

	Seagrass site	Sediment site
No of species	15.4	7.6
No of taxa represented	7.3	4.4

Table 1: Number of species and number of taxa across seagrass and restoration sites

Key learning: Seagrass beds host around twice the biodiversity of adjacent barren sediment sites.

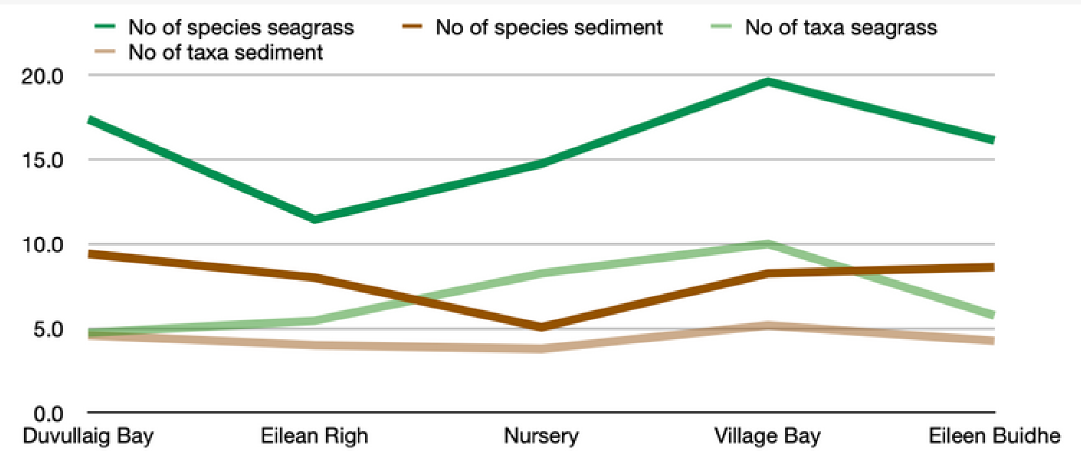


Table 2: Graph to show number of species and number of taxa across seagrass and restoration sites.

Comparison of barren sediment and seagrass bed in adjacent areas of the loch

Species list

To provide as full a picture as possible of the species within Loch Craignish, as well as those species which interact with the ocean ecosystem such as avian and mammalian predators, data was combined from biodiversity surveys, BRUVs, video transects, and casual observations made during Seawilding's project work. Additionally, British Trust for Ornithology bird survey data has been included to create a full species list for Loch Craignish, *Appendix 4A*. In total, 155 different species were recorded, of which 106 were within the seagrass beds compared to 55 on bare sediment sites. The remaining species were recorded in other areas of the loch. This data supports the previous findings that the seagrass beds contain twice as many species of macro fauna and flora compared with barren sediment areas.

155

Species recorded in Loch Craignish

106

Species recorded in seagrass beds

Key learning: Seagrass beds make up 0.4% of the area of the loch and host 68% the biodiversity.

Some species seen in the seagrass

What is the current extent of seagrass beds in connected local habitats surrounding Loch Craignish?

It is increasingly being understood that habitat systems do not work in isolation but that connectivity between habitats is required to support thriving ecosystems. Hence it is important to understand the habitats surrounding the waters of Loch Craignish to put the restoration work into context. Nearshore local habitats were surveyed between Seil Sound in the north and Crinan basin. Further to the south, West Loch Tarbert was also surveyed. *Appendix 4B* details methods used. The aim was to establish the current extent and health of seagrass in adjacent waters in order to:

- Highlight the extent of the current provision of seagrass habitat connectivity.
- Provide a baseline to monitor overspill effects of restoration in Loch Craignish.
- Locate potential areas for future restoration.
- Record INNS and PMFs.

Image 7 shows areas of seagrass located and mapped between Seil Sound and Crinan. Throughout the surveys two small beds of *Z. Marina were* found and no areas of *Z. Noltii* were located, *image 7*. These areas show good correlation with the habitat modelling undertaken by Burrows *ref 1*.

Mapping was also undertaken in West Loch Tarbert where both anecdotal evidence and aerial imagery suggested that *Z. Marina* was likely to be present. *Image 7a* shows the extent of the 7 beds and 3 patches of *Z. Marina* located and mapped. The total area of seagrass mapped in West Loch Tarbert was 31ha. The seven beds were found to be patchy and would be good candidates for further surveying and potential restoration.

Key learning: There are currently 2 small seagrass beds in the waters around Loch Craignish providing weak habitat connectivity.

Key learning: There are extensive areas of potential Z. marina habitat currently without seagrass.

Connected habitat survey extent

Map of areas surveyed showing seagrass beds located and areas identified for phase 2 surveys.

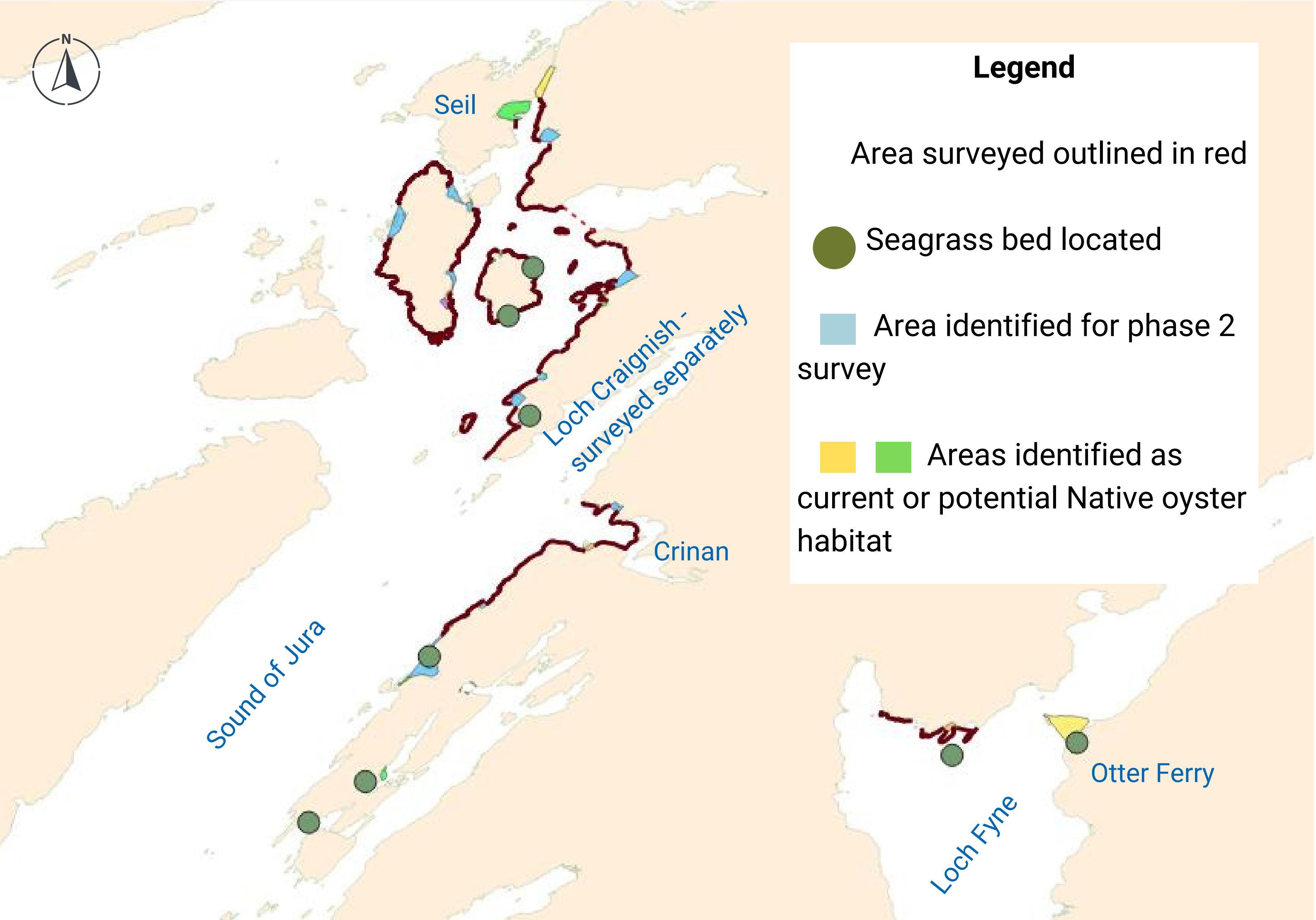


Image 7 Map of connected habitats

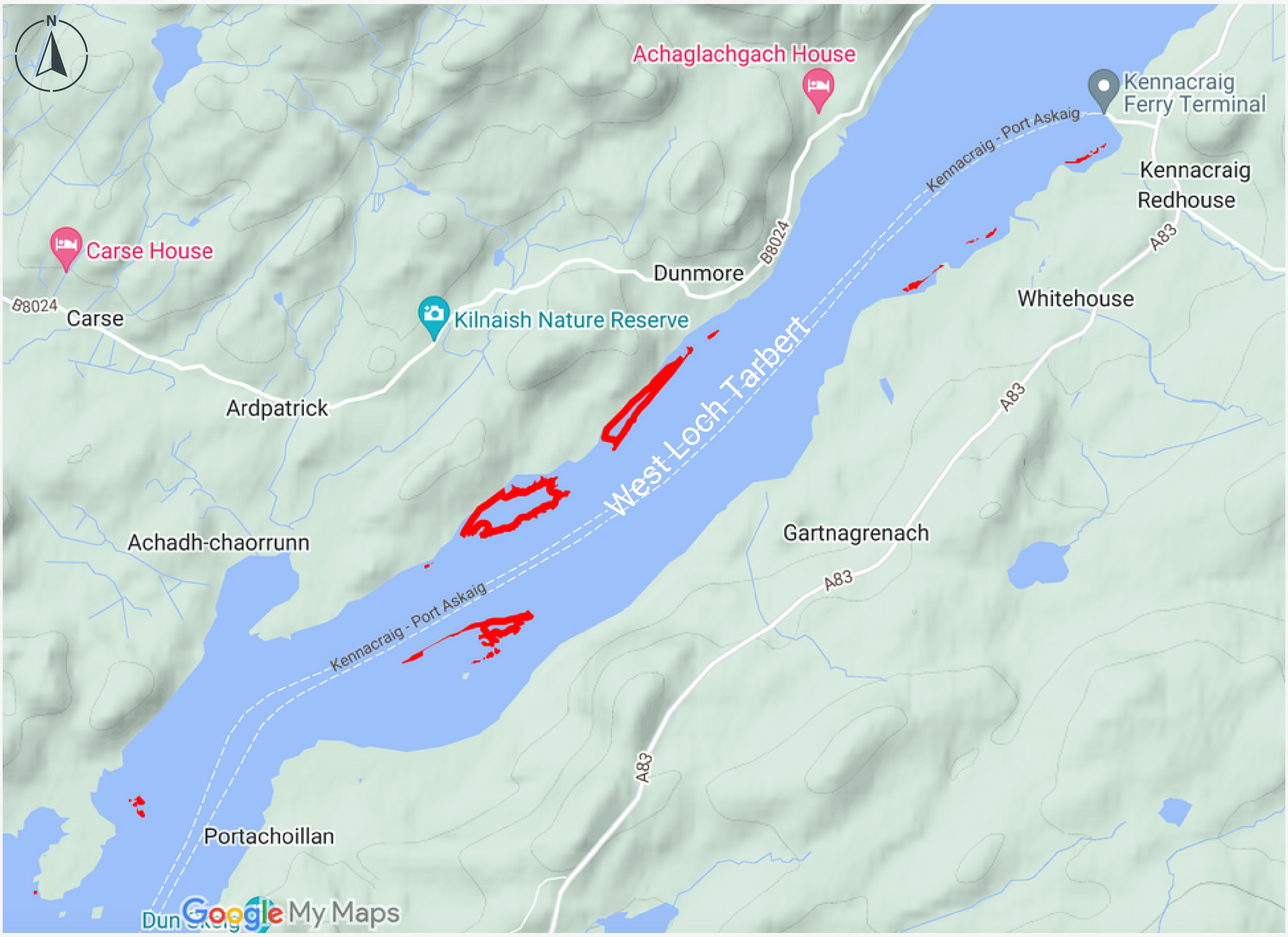


Image 7a Seagrass mapping of West Loch Tarbert

7

Seagrass beds mapped in W Loch tarbert

31ha

Seagrass on West Loch Tarbert

Key learning: West Loch Tarbert has 31ha of seagrass across 7 beds. These beds are patchy and would be good candidates for restoration.

What was the germination success rate of seeds planted using the hessian bag method in 2021?

In 2021 the main restoration methodology was to process the seeds in a tank and plant in hessian bags following the BoSSLine technique advocated by Project Seagrass *ref 2*. Seed harvesting was undertaken by snorkelers from the Seawilding team and a number of volunteers from the local community and further afield. Spathes with ripe seeds were selected, cut from the rest of the plant and collected in mesh bags by the snorkelers. On returning to shore, the spathes were put into a holding tank, *image 8*. To maintain the viability of the seeds whilst the rest of the organic matter broke down, the holding tank had a solar powered bubbler and water was replaced with fresh sea water every 2-3 days.

Periodically organic matter was removed from the bottom of the tank using an aquarium net and seeds were separated initially using a column of pumped water, however it was found that a 'gold panning' style technique was equally effective, more time efficient and required less equipment.

The seeds were stored in a small mesh bag within the main holding tank until planting took place. Subsequently, the seeds were placed into small hessian bags filled with sterile sand. All bags were placed onto the sea bed the same day.
A total 3000 bags containing 120,000 were distributed over 0.25ha of the restoration area.

A total 3000 bags containing 120,000 were distributed over 0.25ha of the restoration area.

Image 8 Seagrass seed being processed in the tank

The Pick and Plant method

The method described above required processing seeds using an expensive and time consuming tank method. Seawilding was keen to trial a simpler and more cost effective method, which if successful may lower the cost barrier to restoration for other community projects. This method was called the 'Pick and Plant' method.

The Pick and Plant method eliminated the need for the seed processing steps. Seagrass seed spathes were collected, and on the same day were placed in hessian bags along with local sediment. The bags were left overnight in seawater to be ensure that they remained cool, and planted in our test beds the following day.

The Pick and Plant trial consisted of demarcated 5m by 5m areas which were planted at a density of 100 bags, with 50 seeds per bag, in each area, obtaining a spacing of 25cm per bag. The trial areas were planted during September by snorkelers placing bags into the sediment by hand. A total of 400 bags containing 20,000 seeds were planted using this method over four test sites.

Measuring germination success

The sites planted in 2021 were re-surveyed in June 2022. Germination success was quantified by divers snorkelling over the restoration area and recording the number of seagrass shoots visible for each hessian bag. The percentage of bags showing germination was calculated for each restoration area, *table 3*.

Image 9. Bag planted in 2021 with germinating seedling in 2022

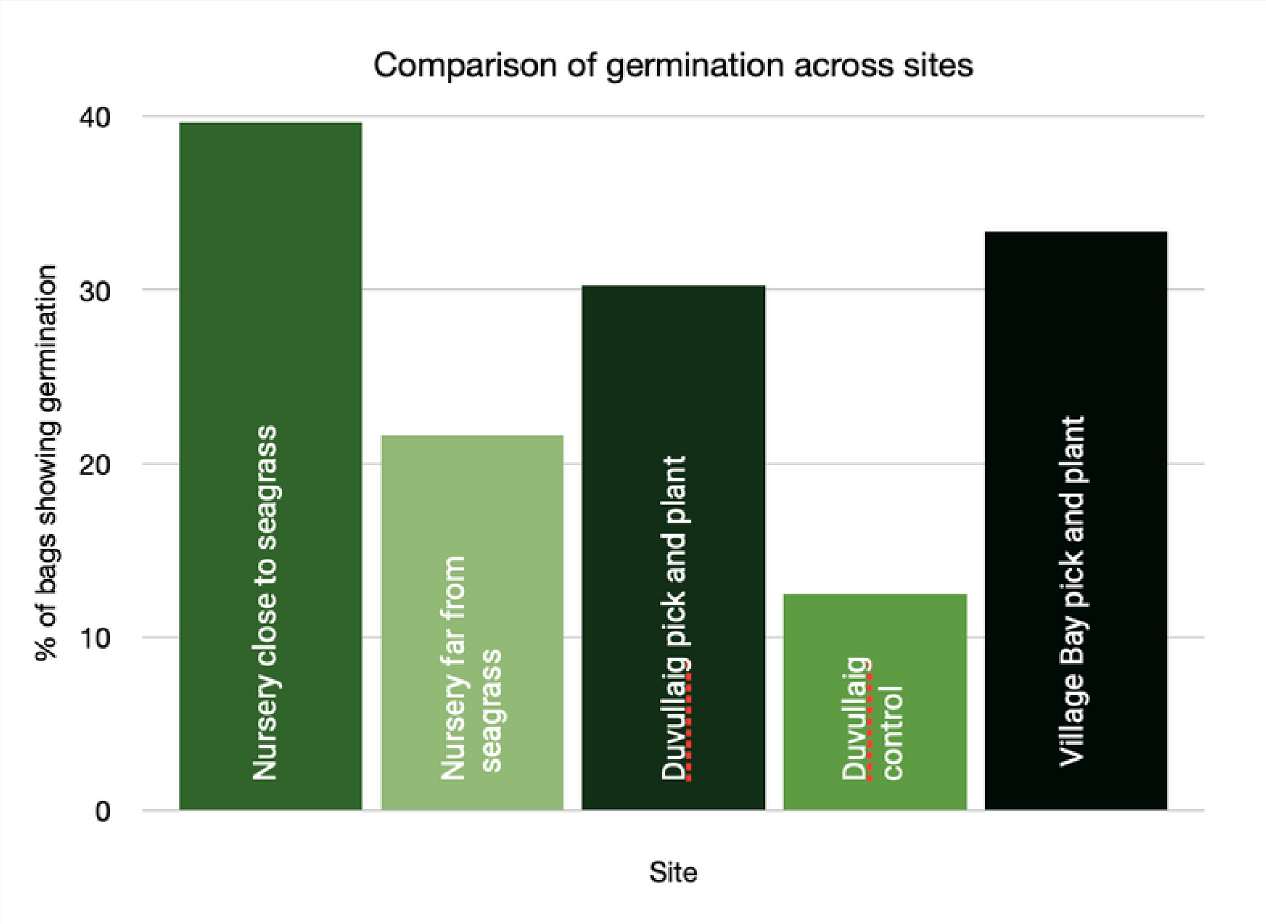


Table 3 - Comparison of percentage of bags showing germination across the sites

The surveys of the germinating bags showed the following:

- There was no apparent difference in germination success between buried bags and those on the surface.

- There was no evidence of predation by crabs on hessian bags which was previously thought to be a concern. *ref 3*.

- The pick and plant bags outperformed the standard hessian bag method using tank processing in Dunvullaig Bay, with more than double the number of bags showing germination. In the shallower Nursery area the pick and plant test beds had germination rates comparable those having undergone the tank processing method. These positive results of the pick and plant method justified including it as part of a larger trial in the 2022 planting test.

- Germination success was highly variable across the sites. This demonstrates that site selection may be an important consideration in the success of seagrass restoration. The Dunvullaig control site was subject to wave activity during the winter storms possibly leading to the loss of bags and germination rates were discounted here. The shallower site in Dunvullaig Bay had issues with coverage from loose algal matter. The conclusion was that neither of these areas would be ideal for restoration going forwards.

The Nursery area appears to be the most appropriate site for restoration due to the lack of competing algae and low wave action and germination was best in this area. Best germination rates were noted to be closest to the existing seagrass bed. It is possible that this is due to some protective effects from the proximity of the existing seagrass bed or that the existing bed favourably modifies the sediment chemical or microbiome composition. This is an area of ongoing scientific research that we will watch with interest. Based on the results from the 2021 germination monitoring, the restoration efforts in 2022 were focussed in the Nursery area.

Key learning - Pick and plant bags equalled or surpassed the germination rates of tank processed seeds.

Bag with germinating seed spring 2022

Key learning - The best germination rates were closest to the existing seagrass bed.

Growth and influx of species by summer 2022

Key learning - Unsecured hessian bags don't work well in areas with wave activity such as Dunvullaig Bay.

Do seeds harvested at an immature stage go on to ripen in the processing tanks and are these seeds viable?

There is a wide time period between when the first seeds appear on the seagrass spathes in May and when the majority of the seeds have ripened and been released naturally in mid September. Consequently there is a variability in the level of seed ripeness within the seagrass donor bed at any given time. In 2021 and 2022 we chose to harvest seeds from the second half of August to mid September to optimise the collection of ripe seeds. However, at the beginning of this period, some seed spathes appeared to be still at an early stage of ripening. We wanted to determine if these seeds would go on to ripen whilst held in the processing tanks, so a small scale study was undertaken. This study showed that the seeds, picked at ripeness stage 2, see *image 11*, at the end of August, all went on to ripeness stages 4, 5 or had completely released from the spathes by the end of October. This demonstrated that seeds picked at ripeness stage 2 appear to ripen when held in the processing tanks. The next key question was whether these seeds are viable.

Key learning - seeds picked at ripeness stage 2 appear to ripen when held in seagrass processing tanks.

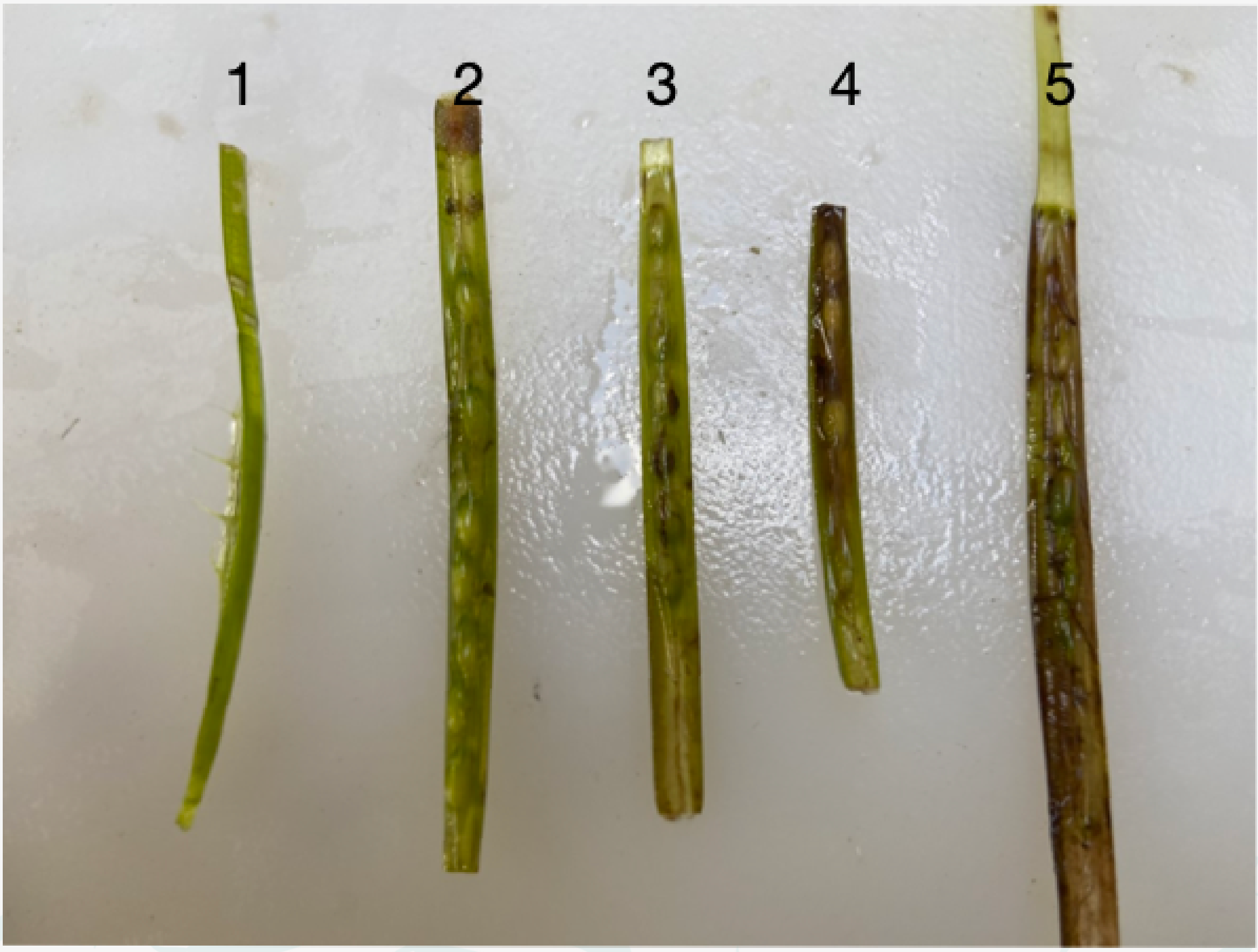


Image 11 Seed ripeness stages.

What is the viability of the seeds harvested at ripeness stage 2?

Z. marina seed viability can be determined by rate of sinking, with those that sink more rapidly having a higher germination rate, *ref 5*. The study carried out by Infantes, *ref 5*, showed a marked difference in seed viability between seeds which sank more quickly with those with a sinking velocity greater than 5cm/s having a greater than 90% viability. Those that had a sinking velocity less than 4cm/s, could be considered to have zero viability and would not be expected to germinate. Sinking velocity was measured for all of the seeds which had been part of the ripening study. Full details of the method are given in *appendix 4C*. Since Infantes noted a steep drop off in viability in the 0-99%, (or 4-5cm/s) category, seeds falling in this category were not deemed to be viable in this instance, *table 4*.

Out of the full sample of 200 seeds, 81 (40.5%) were found to be viable.

No of seeds with sinking speed 4-5 cm/s	No of seeds with sinking rate <4 cm/s	No of seeds with sinking speed >5 cm/s
0-99% viability	0% viability	100% viability
27	92	81

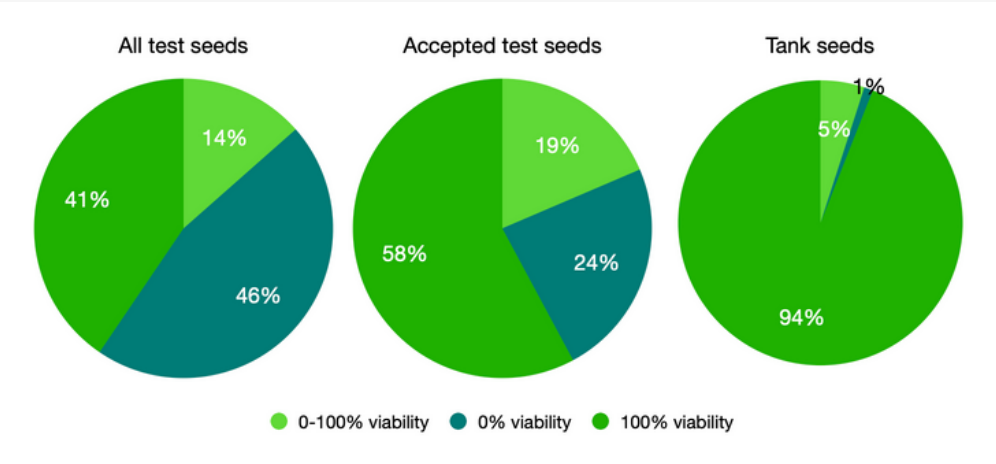
Table 4 - Viability of seeds picked early

The seeds from the ripening study were compared to a control sample of processed seeds which had been selected for sampling. The processed seeds showed a significantly higher viability of 96%.

Following time in the tanks, the seeds are subject to a 'gold panning' process which selects those that will be used for planting. During this process the more buoyant and thereby less viable seeds are rejected. This could account for the higher percentage of viable seeds in the tank sample.

The test sample of ripened seeds was subjected to the same gold panning process to control for this. Out of the initial 200 seeds, 140 seeds passed the gold-panning stage. 81 (57.8%) of these were found to be viable. Still significantly lower than the control from the project tanks which showed a 96% viability.

Key learning - 58% of seeds picked early were viable compared to 96% in the control sample.



What is the viability of the seeds harvested at ripeness stage 2?

Whilst subjected to the same treatment within the tanks and gold panning method for seed selection there appeared to be some inherent reduced viability within the sample of seeds picked early in the season. The differences between the sample seeds and the control seeds which were not accounted for in this preliminary study may hold some clues. The main differences were:

- Test seeds were picked earlier in the season, mid August, compared with the control seeds that were picked throughout the season but likely contained more seeds picked later.

- Test seeds were harvested from Dunvullaig Bay, compared with the control seeds which comprised of seeds collected across all donor sites but which likely contained more seeds from the Eileen Righ site.

It is possible that whilst seeds picked early appear to ripen and detach from the spathes, this could be the organic matter around them decaying rather than the seed ripening.

It is possible that seeds from Eileen Righ have a higher viability that those from Dunvullaig Bay.

Finally it may be that keeping seeds in the processing tanks for an extended period of time, in this case from the end of August until the end of October, adversely effects their viability.

Learning more about this will be one of the key goals for the 2023 monitoring season.

Key learning - Selection of donor bed, harvesting seeds too early or keeping them in the tanks too long are possible causes of reduced viability.

Image 12. Seed ripeness testing in progress.

Short-term questions - what have we learnt?

What is the current extent of seagrass beds in Loch Craignish? There were 5.25ha of *Z. Marina* and 0.25ha of *Z. noltii* in Loch Craignish in 2022.

How does this compare to potential historical extent? There may have been up to 92ha of seagrass in Loch Craignish. The current extent is just 6% of that.

What is the current extent of seagrass beds in connected local habitats surrounding Loch Craignish? There are currently 2 small seagrass beds in the waters adjacent to Loch Craignish providing weak habitat connectivity. There is an area of 31ha of *Z. marina* in nearby W. Loch Tarbert. There is a more extensive area of appropriate habitat currently without seagrass.

Is there a difference in the biodiversity within existing seagrass meadows compared with barren sediment? Seagrass beds host around twice the biodiversity of adjacent barren sediment sites. A total of 155 different species have been recorded in Loch Craignish, 106 of these were within the seagrass beds. Seagrass beds provide a home for 68% of the species in Loch Craignish despite only covering 0.4% of the seabed.

What was the germination success rate of seeds planted using the hessian bag method in 2021? On average germination rates across all of the sites were between 20-40%. Pick and plant bags equalled or exceeded the germination rates of tank processed seeds. Sheltered areas close to existing seagrass showed the best results.

Do seeds harvested at an immature stage go on to ripen in the processing tanks and what is the viability of these seeds? The seeds do appear to ripen however their viability is low.

What is the viability of seeds going into planting following the tank process? 94% of the seeds selected by the gold-panning method following tank processing were viable.

Current seagrass extent

5.5ha

Compared with

92ha

Potential historic extent

Seagrass beds make up 0.4% of the area of loch Craignish but host 68% the biodiversity.

94%

94% reduction in seagrass in Loch Craignish compared to potential historical extent

106

species recorded in seagrass beds

83%

Average seagrass bed density

31 ha

seagrass across

7

beds in West Loch Tarbert

300,000

Seagrass seeds planted

110 km

habitat surveyed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Long-term questions

Monitoring has also been undertaken to assist in answering longer-term questions about seagrass restoration. While the data gathered so far may provide some indicative results, we anticipate ongoing monitoring will be the key to understanding these themes:

- Ensuring no harm is being done to existing seagrass beds by restoration.
- Monitoring the germination, survival and expansion of restored seagrass.
- Evaluate different planting methods to determine which produce best germination rates in Loch Craignish.
- Assess the wider success of the project including socioeconomic factors.

Let's take a look at what we have learnt so far about these longer term themes.

Ensure no harm is being done to existing seagrass beds.

One of the most critical aims of the ongoing project monitoring is to monitor the health of the existing and restored seagrass beds, especially to ensure that no harm is being done to the seed donor beds by the restoration process. A number of factors were monitored in order to achieve this:

- Seagrass coverage
- Seagrass canopy height
- Seagrass bed extent
- Epiphyte cover
- Reproductive timing and effort
- Presence of INNS

The methods for monitoring each of these are given in *appendix 5*.

In total there are 10 seagrass beds in Loch Craignish. Five of these were chosen for monitoring due to their use as donor beds or as representative control beds. In 2021 baseline monitoring began to determine the health status of existing seagrass before restoration began. These beds were designated as either 'donor beds', those which seed was harvested from or 'control beds' those which seed was not harvested from. The site on which restoration was to take place was also monitored and was designated as the 'restoration site'. Finally, additional sites within the loch on which no restoration took place were designated as 'reference sites', see *image 13*.

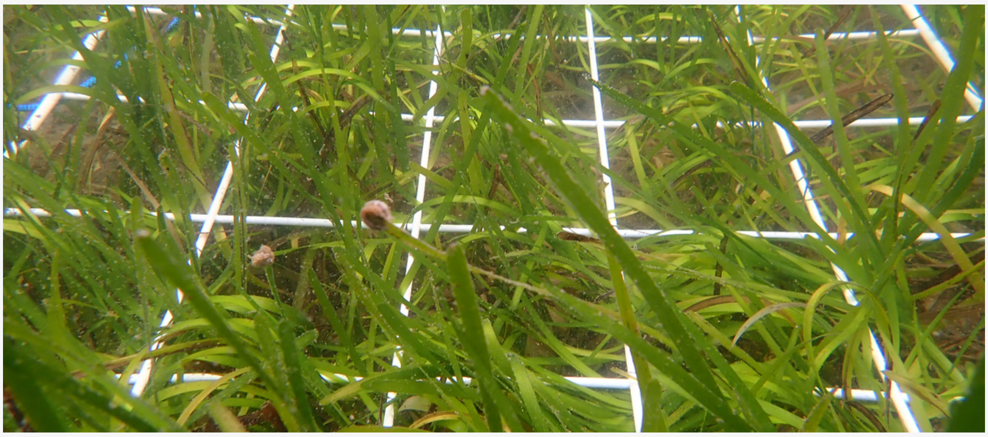
Image 13 map of southern Loch Craignish showing locations of donor and control seagrass beds and reference and restoration sites

Seagrass health - coverage

Seagrass beds within Loch Craignish have been found to be quite dense compared with other areas of seagrass in the local and wider area. Across five seagrass beds measured over 2 years, the average percentage cover of seagrass beds in Loch Craignish was 83%. This is equivalent to a rating of Superabundant on the SACFOR rating scale.

The beds in Dunvullaig Bay and Village Bay which were used as donor beds in the 2021 harvest season both showed an increase in percentage cover in 2022 compared to pre-harvest coverage in 2021. This would suggest that seed harvesting does not detrimentally effect the density of *Z. marina* beds one year following harvesting. This may be due to the natural infilling by the seagrass or a compensatory growth spurt or simply natural fluctuation. Continued monitoring will be undertaken to ensure there are no longer term detrimental effects caused by seed harvesting.

Key learning - Seagrass beds had a greater percentage cover the year following harvesting.



83%
Average seagrass bed density

Seagrass health - canopy height

Canopy heights differed across the five seagrass beds measured, with three of the beds, the Nursery, Village Bay and Eilean Buidhe having similar canopy heights in the range of 28-33cm. Dunvullaig Bay was on average taller with a canopy height of 45cm. The Eilean Righ bed was significantly taller at 70cm, see *image 14*.

The large difference in canopy height between the Eilean Righ bed and the rest of the seagrass beds in Loch Craignish may be due to it's location within the loch, which is geographically separated from the other beds in a more steeply shelving and tide washed area of the loch or the time of year surveyed. The Eilean Righ bed has also been noted to produce flowers and seeds later in the year than its counterparts within the loch. It is also possible that *Z. marina* in the Eilean Righ bed is a distinct ecotype. It is unknown at present whether any of these factors effect the viability or germination success of seed collected from Eilean Righ. This is a question that will be investigated in 2023.

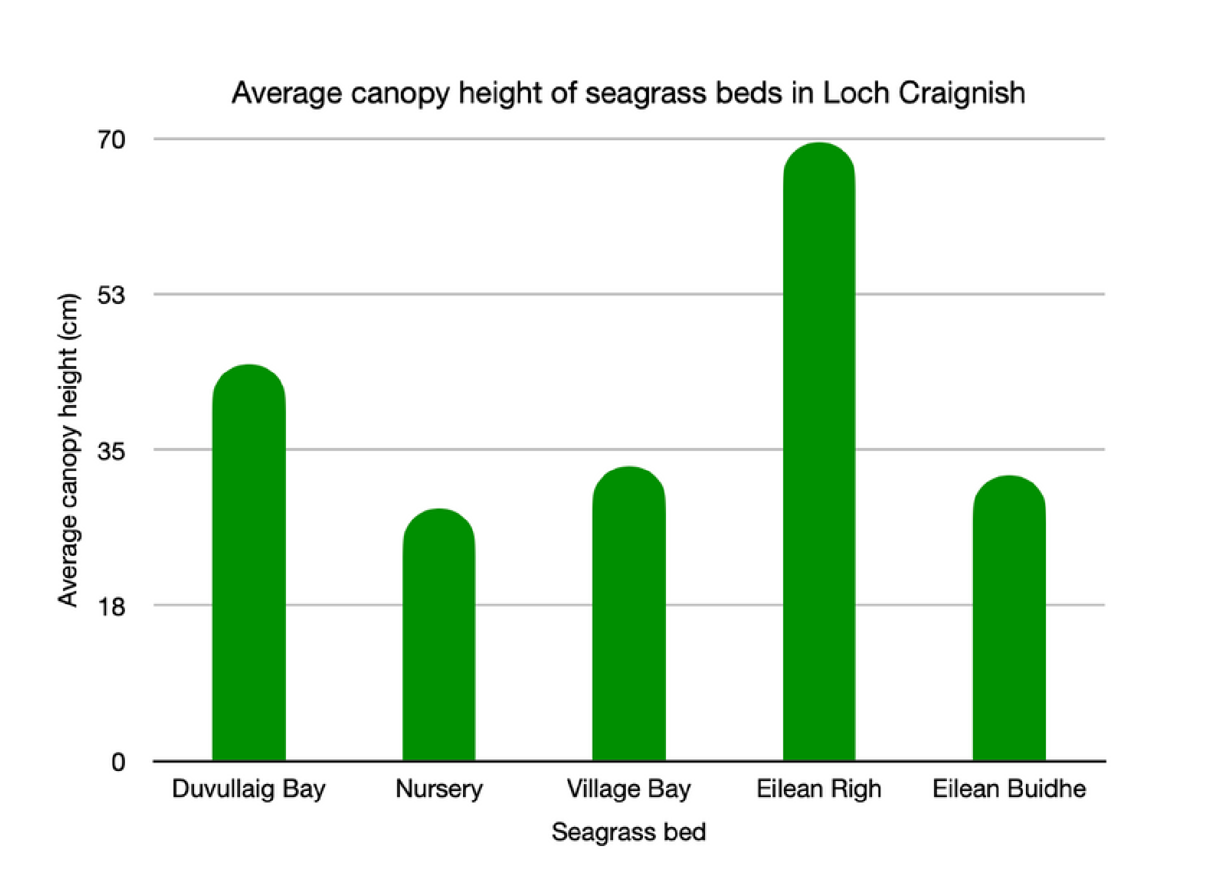


Image 14 Seagrass canopy height across four beds in the loch

Key learning - Eilean Righ seagrass may be a distinct ecotype. It is a possibility that this may influence the viability or germination success of seed collected from Eilean Righ.

Epiphytes, such as hydroids and algae, which grow on seagrass blades provide a valuable food source for many organisms. In excess their cover could reduce the amount of light that the plant receives and consequently detrimentally affect its growth, *ref 3*. Epiphyte cover was estimated from images taken during the biodiversity survey dives, using the same methodology as the 2021 surveys, detailed in *appendix 5*. These images were reviewed following the dive and the degree of epiphyte cover graded as low, medium or high according to the grading given in the Seagrass Restoration Handbook, *ref 3*. Epiphyte identification was not undertaken due to lack of published survey protocol and experience.

Seagrass bed	Epiphyte cover	
	2021	2022
Dunvullaig Bay	Low	Low
Nursery	Low	Low
Village Bay	Low	Low
Eilean Buidhe and Causeway	Low	Low
Eilean Righ		Medium

Table 5 - epiphyte cover across seagrass beds in Loch Craignish

Epiphyte cover was generally low across all of the surveys, see *table 5*. It was noticed during activities in the water around the seagrass beds that the appears to be a spike in brown algal cover appearing on the seagrass blades in early spring which disappears by the late spring. This pattern or epiphyte growth and reduction may correspond to the spring increase in plankton density followed by the subsequent production of polyphenol compounds by the seagrass which causes a reduction in the epiphytes in May/June, *ref 6*.

The Eilean Righ site was the only seagrass bed which showed a medium level of epiphyte cover. Here the epiphytes were predominantly bryozoans rather than the brown algal cover seen at other sites. The *image 15* shows examples of the epiphyte cover.

Key learning - Epiphyte cover was low across all of the seagrass beds.

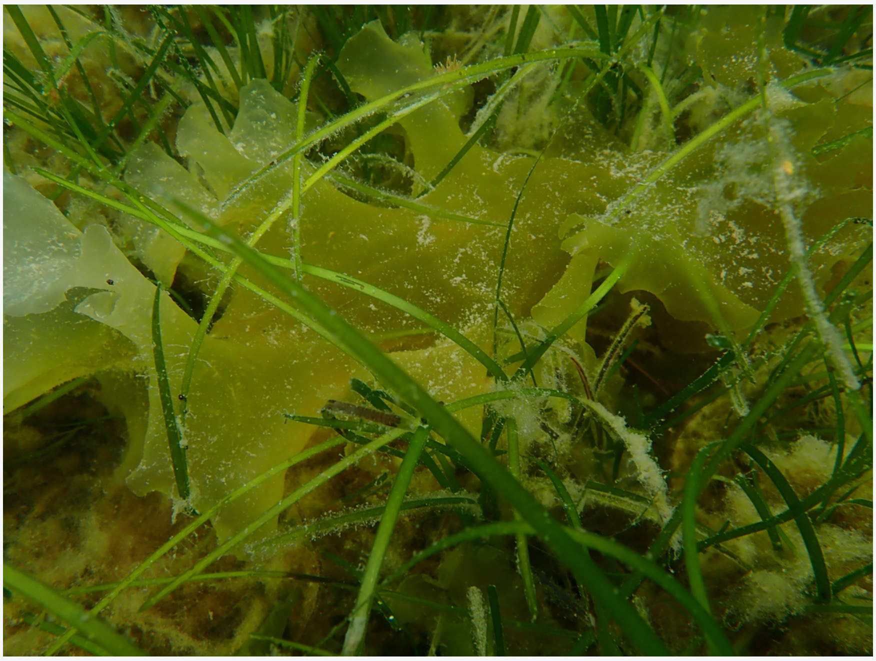
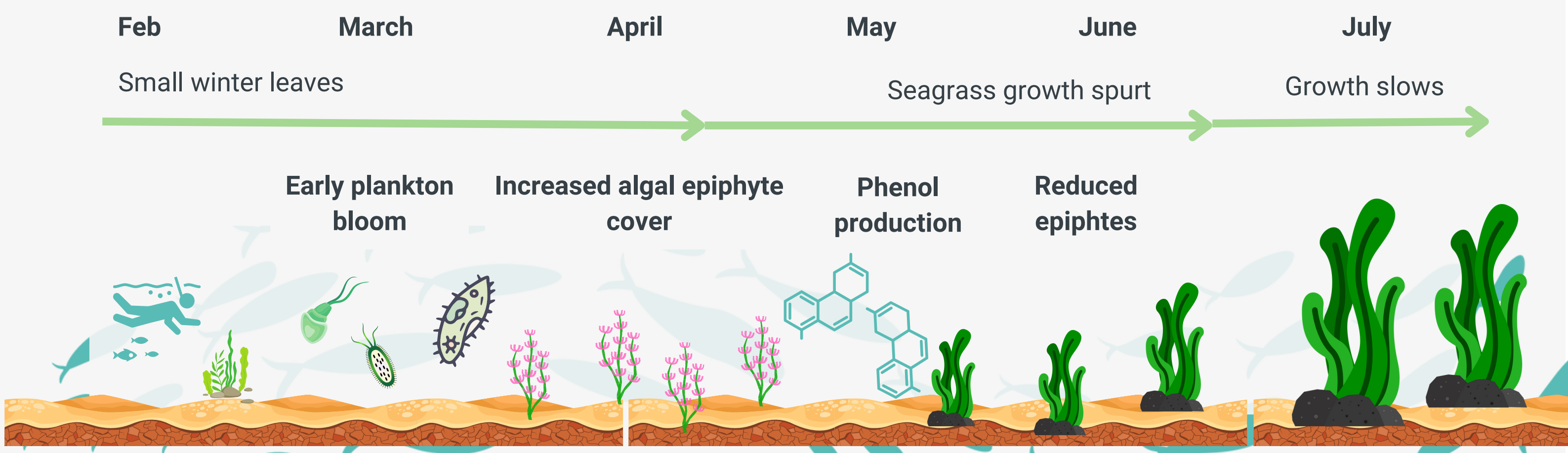


Image 15 examples of epiphyte cover

Key learning - There is a spike in brown algal cover in the early spring which disappears by the late spring.



Seagrass health - reproductive timing and effort

Reproductive timing and effort was measured across donor and control seagrass beds in order to:

- Provide a general measure of the health of the bed.
- Assess for any potential negative impacts from the 2021 seed harvest.
- Determine which beds would be appropriate to act as donor beds for 2022 seed harvesting.
- Determine the amount of seed which was appropriate to harvest.
- Investigate year to year variability in reproductive timing and effort.

Snorkel transect surveys were carried out across three of the seagrass beds used for seed harvesting and one which was not harvested. The same transect method as for the percentage cover and canopy height surveys was used. The number of reproductive shoots was recorded for each quadrat. Reproductive shoots were defined as those showing either flowers or seeds. From these surveys the average number of reproductive shoots was calculated per quadrat and hence per m2.

The average number of spathes with seeds per reproductive shoot was determined to be 8. Along with the average seeds per spathe of 6, see *table 6*. Multiplying these together gave an average of 48 seeds per reproductive shoot. This is similar to the results obtain by Project Seagrass's surveying of seagrass beds in the Solent which estimated 57 seeds per spathe, *ref 8*.

This allowed the average seeds per m2 to be calculated for the three beds. From this the potential total number of seeds on the beds was calculated. This was divided by 4 to indicate the total number of seeds which could be harvested from the bed following the 'Pick 1 leave 3' seed harvesting guidelines agreed with NatureScot.

Bed name	Village Bay	Duvullaig Bay	Eilean Buidhe	Nursery
Average reproductive shoots per m2	10	7	2	2
Potential number of seeds produced by bed	292,608	2,954,526	1,635,792	698,496
Seeds available to harvest using 'Pick 1, leave 3' method	73,152	738,632	408,948	174,624

Table 6 - Reproductive effort and seed availability

Key learning - These 4 beds produce over 5.5 million seeds.

Of the seagrass beds surveyed, the average number of reproductive shoots per m2 ranged between 2 and 7. Across just some of the beds in Loch Craignish to be used as seed donors beds, a potential 1,395,365 seeds were available after accounting for leaving 3 out of 4 spathes. This is far in excess of the 200,000 which were harvested.

There do not appear to have been any adverse effects on the health of the seagrass bed following harvesting in 2021 in terms of either cover or canopy height. The reproductive effort of just some of the seagrass beds in Loch Craignish produces 28 times more seeds than were harvested by the project.

Key learning - Seagrass beds produced 28 times more seeds than were harvested.

Image 16 Example of a reproductive shoot

Seagrass health - Invasive non-native species monitoring

Invasive non-native species (INNS) can cause serious problems for both restoration activities and the existing marine environment. All restoration activities have the potential to lead to the spread of INNS, *ref 2*. Whether by the introduction of biological material from different sites, such as the importing of seeds, or through the presence of project staff in the water who could spread INNS on their equipment. It is important that all restoration projects have a sound biosecurity plan as well as undertake surveying for INNS, *ref 2*. *Appendix 5* gives details of the methodology used for INNS monitoring. A table detailing the abundance using the SACFOR scale for all INNS across the survey sites for 2021 and 2022 surveys is also given in *appendix 5*.

In summary no INNS were found in any of the survey sites in 2021. In 2022 *Sargassum muticum* was found to be rare in the Dunvullaig Bay and Eilean Buidhe sites. *Sargassum muticum* was noted as present adjacent to surveys sites in this area in 2021. This result may indicate that the northward extension of range of *Sargassum muticum* is being realised in Loch Craignish. It is also possible that the exact selection of surveys sites each year led to the inclusion of existing *Sargassum muticum* in the 2022 survey but not the 2021 survey.

No other INNS were recorded in any of the survey sites in 2022.

Wire weed, *Sargassum muticum*, Leathery sea squirt, *Styela clava* and Pacific oyster, *Magallana gigas* were all observed outside the survey areas in 2021 and 2022.

Key learning - The abundance of INNS remain stable and rare within Loch Craignish.

Seagrass health - Seed predation

Shore crabs, *Carcinus maenus,* have been suggested to predate on seagrass seeds, *ref 4*, which may impact on the health of an existing or fledgling restoration seagrass beds. Consequently shore crab abundance was recorded from the video transects on all of the survey sites. The results for each site for 2021 and 2022 are given in *table 7* below.

Shore crabs, *Carcinus maenus* abundance using SACFOR scale across restoration areas										
Area	Dunvullaig Bay		Eilean Righ		Nursery		Eilean Buidhe		Village Bay	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
SACFOR rating	R	R	-	A	R	A	A	R	R	R

Table 7 - Abundance of Shore crab, Carcinus maenus R = Rare, A = Absent

Key learning - Shore crabs were rare or absent across the survey sites.

Boat mooring

Boat moorings are located within the loch at the north end with accompanying running moorings for small boats and tenders, managed by the Ardfern Yacht Centre. There is a second mooring field, with approx 60 moorings run by the Craignish Lagoon Moorings Association. As far as we are aware, all these moorings are of the standard block and chain type with no eco moorings available. It does not appear that either of the mooring fields are situated in areas with existing seagrass. Both mooring fields are in water of a depth of at least 7m and therefore are unlikely to conflict with seagrass habitat. The running moorings which are used for tenders and other small local boats are situated within the Village Bay seagrass bed. These moorings consist of either concrete blocks or boat anchors with two lines, one running at the surface and one along the seabed through the seagrass. The typical layout and extent of the effect of these moorings is shown in *image 17* below.

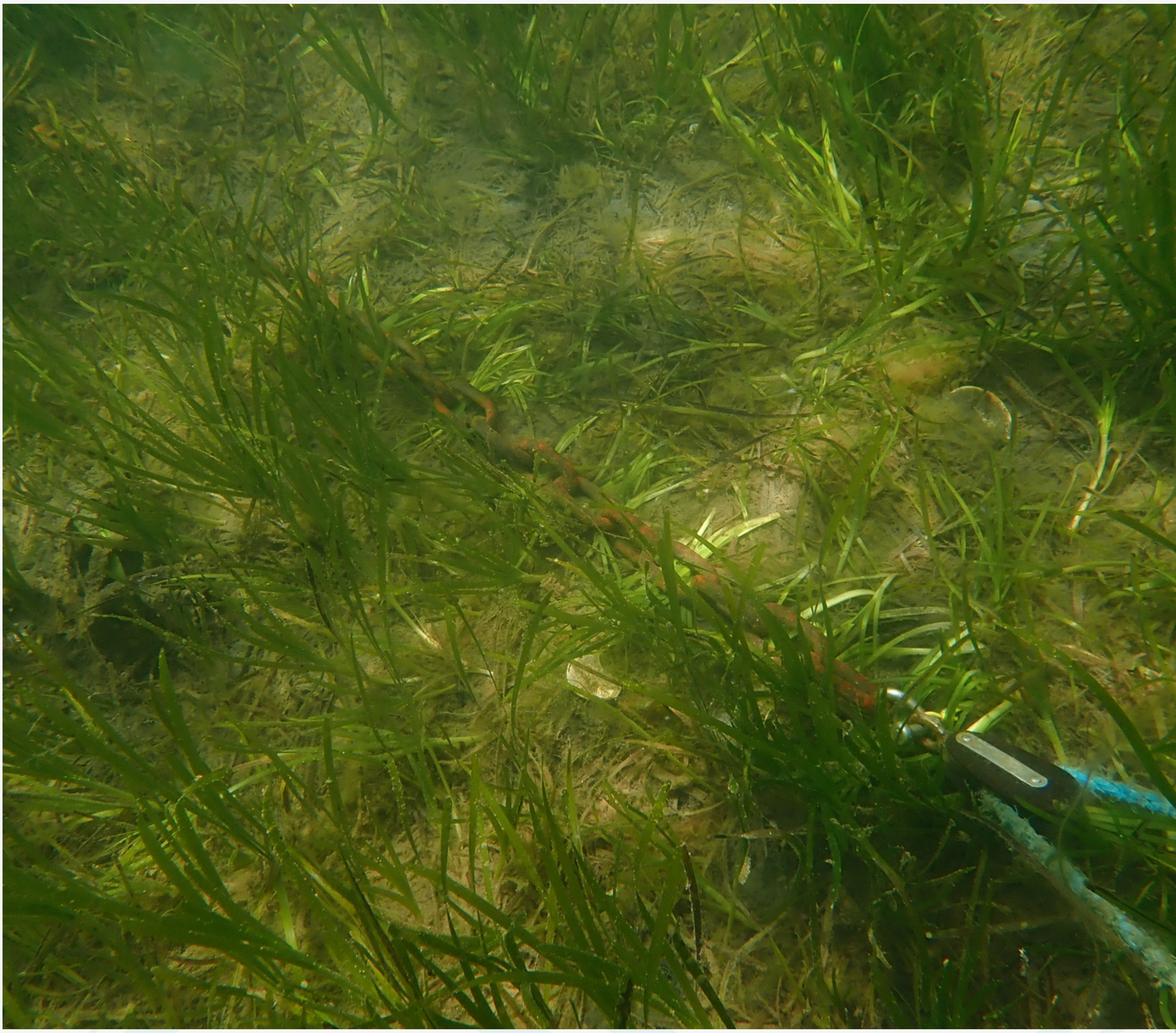


Image 17 A typical running mooring in the seagrass bed in Village bay

Boat anchoring

There is a popular anchorage for leisure vessels in the Dunvullaig Bay area, adjacent to the Dunvullaig bay seagrass bed, *image 18*. The area was used approx 20-40 times for anchoring during 2022. There is a concern that anchoring by leisure vessels could harm the seagrass in this area. A chart depicting the location of seagrass beds and providing education regarding anchoring has been produced and displayed at the Ardfern Yacht centre, *image 19*. The possibility of deploying buoys to mark a voluntary no anchoring zone on the seagrass bed has been considered for 2023.

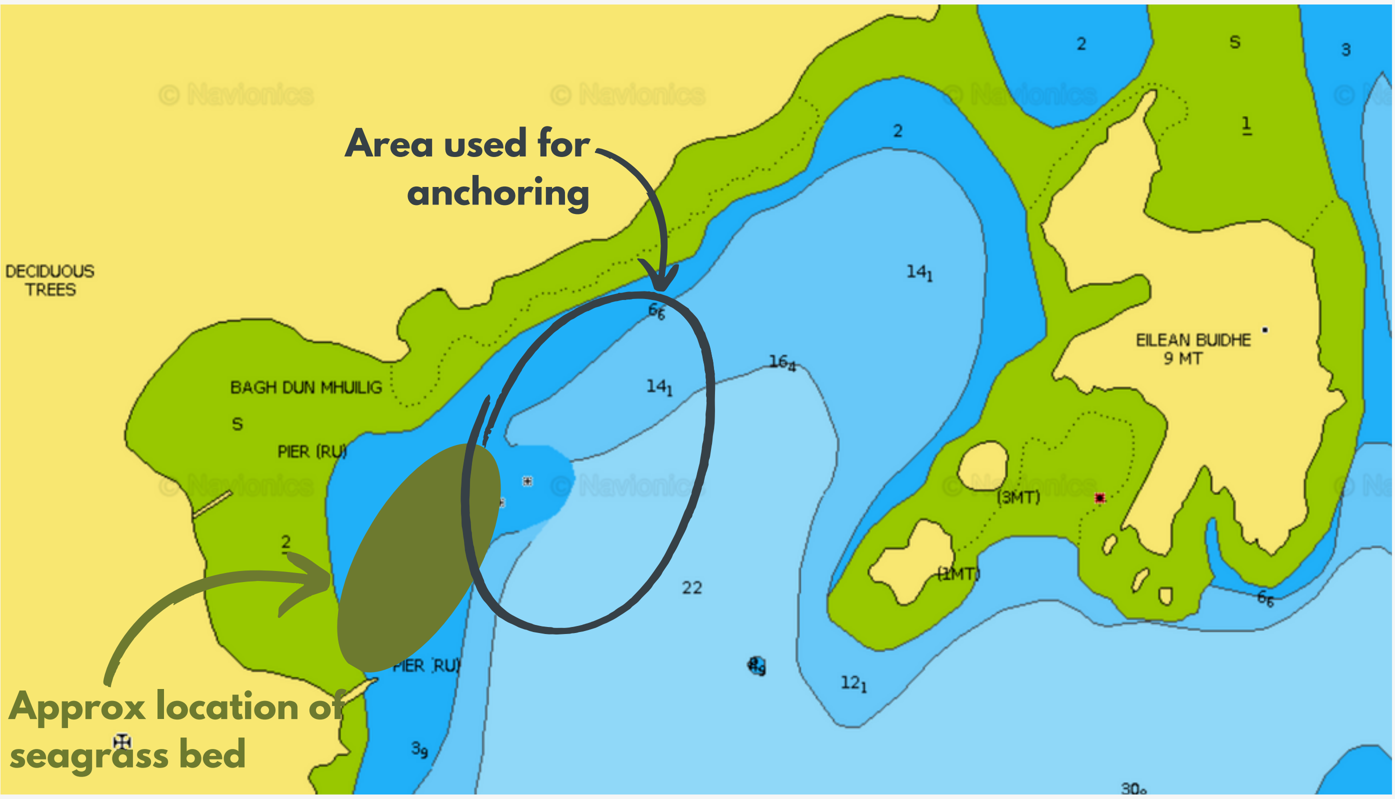


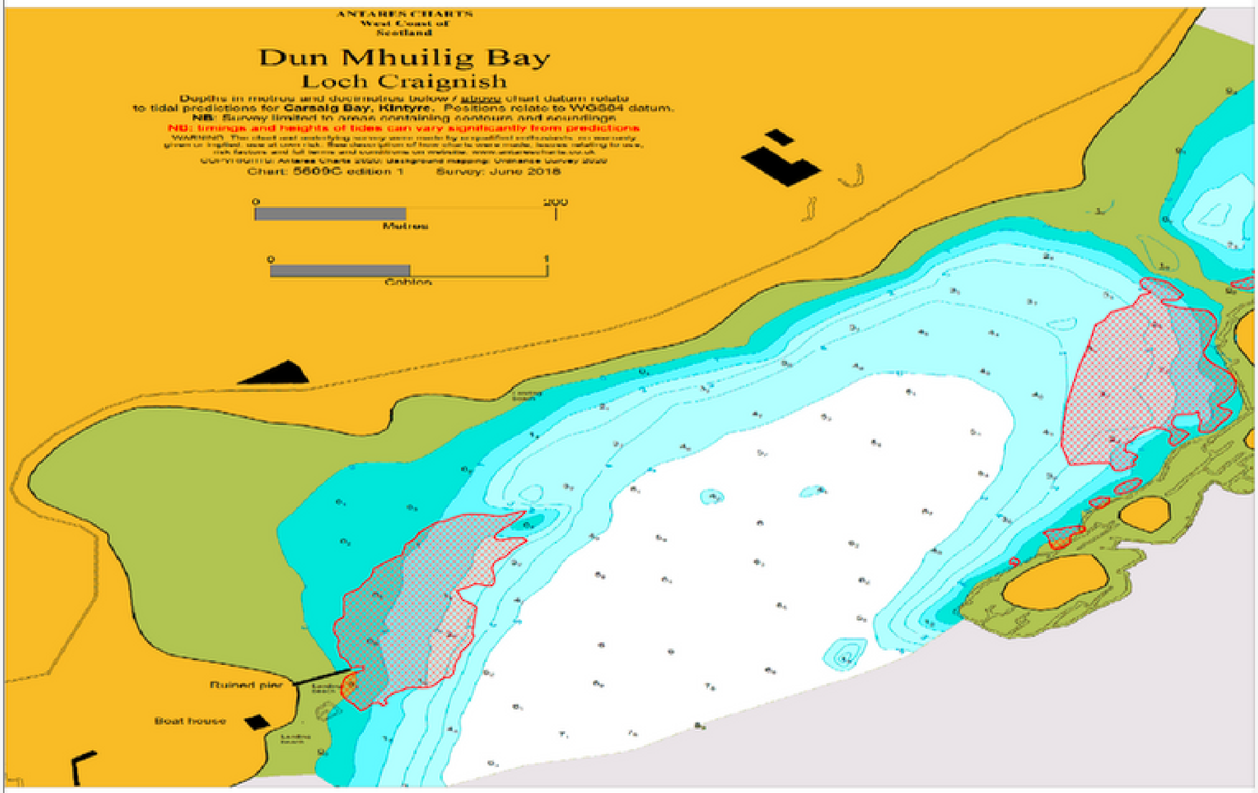
Image 18 - Location of seagrass and anchoring areas in Dunvullaig Bay

PLEASE DON'T ANCHOR ON THE SEAGRASS

Loch Craignish is home to about 5 hectares of seagrass. This is a rare and protected flowering plant which sequesters carbon and forms a vital habitat for spawning fish. Over 90% of seagrass meadows have disappeared around the UK owing to pollution, disease and bottom-trawling for scallops and prawns.

Here at Loch Craignish, our community-based charity, Seawilding, is restoring these meadows by harvesting and planting seed. You can help us by not anchoring on the seagrass meadows pictured here (you can anchor in deeper water on the sand/mud adjacent) and also by visiting www.seawilding.org and sponsoring our efforts to restore seagrass and native oysters to the Loch.

Thank you!



SEAWILDING
Community-led Marine Habitat Restoration

Image 19 - Poster produced to by Seawilding to provide education for local boat users

Evaluate different planting methods to determine which produce best germination rates in Loch Craignish.

Planting seeds using the hessian bag method was chosen for the first year of seagrass restoration as it had been used by our project partners, Project Seagrass, with some success in Wales, *ref 7*. As detailed in the short key questions section above, this method gave some success in Loch Craignish. This method was also used by restoration projects on the south coast of England with mixed success, where germination rates between 0 and 100% were documented, *ref 8*. At the same time other methods of seed planting have been implemented by other restoration groups including seed scattering and seed injection with good success. Additionally alternative methods of seagrass restoration including sod transplantation and rhizome transplantation have been found to be very successful for *Z. Marina* restoration. Germination of seedlings in an onshore nursery is being trialled across a number of international projects. So far, the survivability of seedlings grown in a nursery has not been demonstrated. Currently, there does not seem to be one 'magic bullet' method of seagrass restoration that works equally well in all locations. Different ecological niches seem to favour certain techniques and Seawilding aims to determine which are most successful in Loch Craignish.

It was decided that planting methodology trials would form a key part of the restoration planting in 2022. A section of the restoration area was allocated for planting trials and was laid out in a grid of 5m x 10m rectangles. Each of these rectangles was planted in September 2022 by snorkel divers using a different methodology. The remainder of the planting was undertaken immediately adjacent to this using the standard hessian bag technique. This acts as a control. The planting methods trialled are described in *table 8*, with pictures of the techniques in *image 20*.

Method	Description
Pick and plant sand	Spathes containing seeds were placed in the hessian bags immediately after harvest (rather than being processed in the tanks) and planted. Sterile sand was used as the substrate.
Pick and plant sediment	Spathes containing seeds were placed in the hessian bags immediately after harvest (rather than being processed in the tanks) and planted. Sediment collected from close to the existing seagrass bed was used as the substrate.
Pick and push	Spathes containing seeds were put into clumps of 5, these were wound into a clump and pushed directly into the sediment without hessian bags.
Seed injection	Seeds were processed in the tanks and then injected into the sediment using a caulking gun.
Scattering	Seeds were processed in the tanks and then scattered onto the seabed.
Shallow site	Seeds were planted using the standard hessian bag method on a shallow / intertidal site.
Spring planting	Seeds were processed in the tanks and held in a chiller until spring when they will be planted using the standard hessian bag method.
Autumn sod transplantation	A 25cm x 25cm sod was transplanted from the existing seagrass bed in September.
Spring sod transplantation	A 25cm x 25cm sod will be transplanted from the existing seagrass bed in Spring 2023.

Table 8 - Description of planting methodologies trialed in 2022

Key learning - 9 variations in planting methodology were trialled in 2022.

Image 20 trial planting methods in action: sod transplant, seed injection, scattering, hessian bags

Long term monitoring - what have we learnt?

Harvesting does not appear to have damaged the seagrass beds - All of the seagrass beds had a greater percentage cover the year following harvesting.

Epiphyte cover shows a seasonal increase in brown algal cover in the early spring which reduces by by late spring - This variation is natural and generally epiphyte cover was low across all of the seagrass beds.

Eilean Righ seagrass may be a distinct ecotype - This may influence viability or germination success of seed collected from Eilean Righ.

Seed production by the seagrass beds in Loch Craignish far exceeds the amount of seeds harvested - Over 5.5 million seeds, 28 times more seeds than were harvested were produced.

The abundance of INNS remain stable and rare within Loch Craignish.

Shore crabs were rare or absent across the survey sites - Demonstrating a limited potential for predation of seagrass by shore crabs locally.

9 variations on planting methodology were trialled in 2022 - Germination success will be analysed in the spring of 2023 and the learning gained applied to the methods selected for planting in 2023.

What goes into monitoring a project of this size?

432 quadrats

72 hrs of snorkel surveys

113 surveys across **21 sites**

2 km video transects

110 km habitat surveyed

New seagrass beds located

14 Z.marina

3 Z. noltii

165 hrs video analysed

31 ha seagrass across **7** beds in West Loch Tarbert

Looking to the future

The germination success of these methodologies will be assessed in summer 2023. At the time of writing, Seawilding was in the process of establishing a seagrass nursery with the aim of germinating seeds and growing them on to seedlings which can be planted out on the seabed. Learning more about this process in a Scottish context will form a key part of our learning in 2023. It is also hoped that permission will be gained for a 5 x 10m test plot for rhizome transplantation, a restoration method with an impressive success record internationally, in 2023.

Image 21 - Seawilding's seagrass nursery begins construction and a seagrass bed in British Columbia newly planted using the rhizome transplant technique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Outreach activities and volunteer engagement

The impacts of seagrass restoration reach beyond the purely ecological, *ref 9*. The Scottish Government highlights in its recently published Biodiversity Strategy, ref 10, that engaged communities thriving with green jobs is a key priority for biodiversity enhancement. As a community group, engaging with local people to improve their understanding, well-being and environment is core to what we do. In 2022 the following community and volunteer events were run as part of the project:

- **Wild Seas Weekend** - an open weekend hosted by Seawilding including a number of local marine conservation organisations where members of the public and Members of the Scottish Parliament took part in seagrass harvesting, experienced seagrass by paddle board and took part in seed preparation and planting.

- **Seagrass harvesting** - local volunteers took part in harvesting seagrass seeds by snorkel.

- **Seed planting** - local volunteers helped bag up the seagrass seeds and took part in planting seagrass seeds by snorkel.

- **Young people's training weekend** - young people interested in a career in marine conservation joined Seawilding to gain hands-on experience of surveying and restoration.

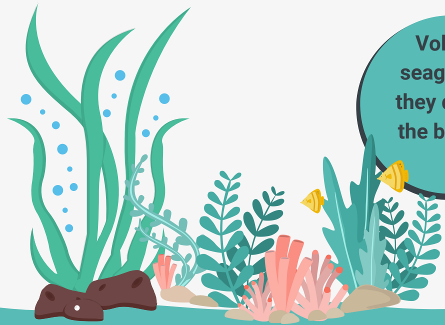
Image 22 - outreach activities in action

Wild Seas Weekend

A questionnaire was undertaken as part of the Wild Seas Weekend to understand the demographics and motivations of those attending and assess whether the event changed their attitudes to marine conservation. The results are summed up in the info graphic below.

VOLUNTEER SEAGRASS HARVESTING

Survey results



Volunteers understood seagrass facts before, but they didn't understand how the beauty of experiencing seagrass felt.

Demographics

- People of all age ranges from 18 to 65+ years old participated.
- 39% of people came from the local area.
- Volunteers came from as far as the Netherlands, Denmark and Australia.

Ocean connection

- For 21% of volunteers, this was their first experience of taking part in a conservation activity.
- 84% of volunteers regularly participated in some form of ocean based recreation.
- Access to ocean-based leisure activities is important to encourage action in ocean conservation.

Influence

- Knowledge of all aspects of seagrass ecosystem services was increased.
- 94% of volunteers reported that seagrass harvesting had influenced them to take positive action for ocean conservation.
- 24% were inspired to consider starting their own ocean conservation project.

Green jobs

- 38 volunteer hours were contributed.
- At least 14 overnight stays were booked in the local area as a result of the weekend.
- 18 local people were employed.
- 24% of volunteers were inspired to consider a career in conservation.

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Key message - Volunteers understood seagrass facts before, but they didn't understand how the beauty of experiencing seagrass felt.

The wordcloud below was generated from how the participants summed up their experience of the event.

Image 23 - the community in action at the Wild Seas Weekend

Young People's Weekend

A weekend event was run to provide young people interested in a career in marine conservation with hands on experience of the restoration project. They learnt about surveying, species ID, what running a project involves as well as taking part in hands on snorkel survey sessions. The feedback from the participants was extremely positive. Some of the participant quotes are given below.

Image 24 - young people's training weekend

Other engagement activities

In addition to this a number of other wide-reaching engagement and education projects were undertaken, including:

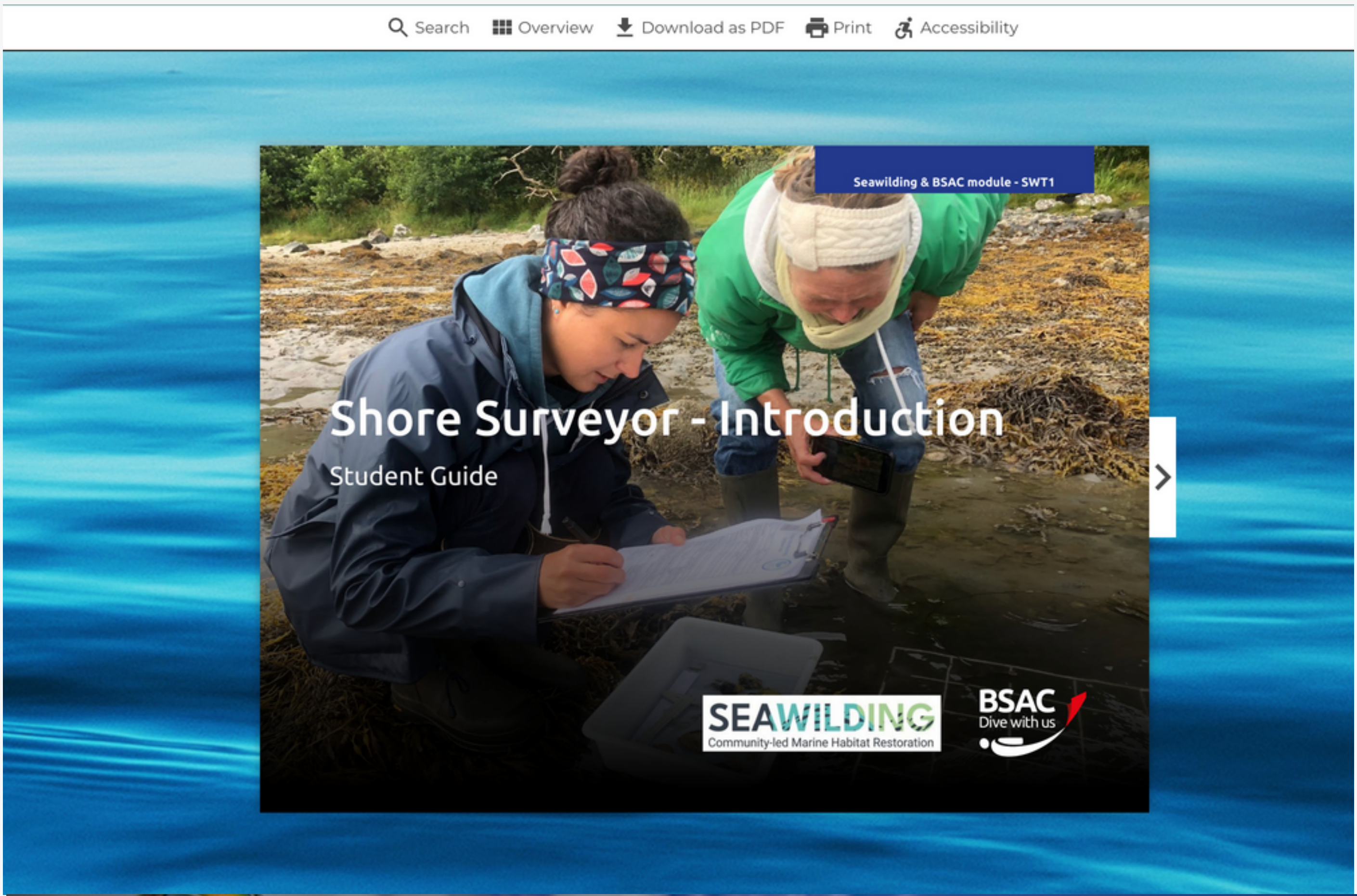
- Partnering with the Scottish Wildlife Trusts to produce a **Snorkel Trail for Argyll** and with the British Sub Aqua Club to produce a **Nationwide eLearning and citizen science platform**.

- Seawilding ran a **training weekend for other community groups** interested in beginning their own restoration project.

- A number of **films were produced featuring Seawilding** including one in partnership with the outdoor clothing manufacturer, Patagonia, showcasing the importance of seagrass to the marine ecosystem and the restoration work of the project.

- The project was also featured on **ITV's 'This Morning' program**, showcasing community-led seagrass restoration to a nationwide audience of millions.

Image 25 - Argyll Snorkel Trail Leaftlet



eLearning resource and citizen science project Shore Surveyor created in partnership with BSAC

Community groups training weekend

A weekend was run by Seawilding for other community groups interested in undertaking their own restoration projects. Twelve people attended from projects across Scotland to get on and in the water while the Seawilding team shared their experiences of restoration in practice.

The following is some of the feedback from participants:

"It was a good balance between practical work and talks"

"I really enjoyed the photography stuff. I feel like its quite often overlooked and this made me realise how important it is."

"Getting to know other projects was also really useful and where they are/what they are doing"

"Overall great weekend! Thoroughly enjoyed it and learnt a lot. 5 stars"

"Jam packed weekend full of valuable info, friendly and professional and knowledgeable staff. Thank you for supporting other orgs!"

"Dear Seawilding team, you scored 10/10 with this incredibly useful workshop! Perfect time management as well - respect!"

"Loved the course, great to get hands on with some of the aspects of the project."

"I found the tip of using Strava for mapping really useful"

"A great weekend, thank you!!! Very professionally organised and run. Allows you to appreciate the depth of info and knowledge needed and amassed since the beginning!"

"I thought the fund raising tips were useful in terms of bringing in some components of the more background project management aspects"

Image 27 - Community groups training in action

In total 488 people participating in outreach and education activities.

Volunteers contributed 164 hrs to the seagrass restoration project.

At least 123 overnight stays were booked by people participating in Seawilding activities and much use was made by visitors of the local cafe and pub.

Seawilding has been able to provide 6 full time jobs for members of the local community, three of these being supported by the seagrass restoration work. Additionally 12 other local people were provided with short term work as part of our activities.

Looking forward to 2023 and beyond

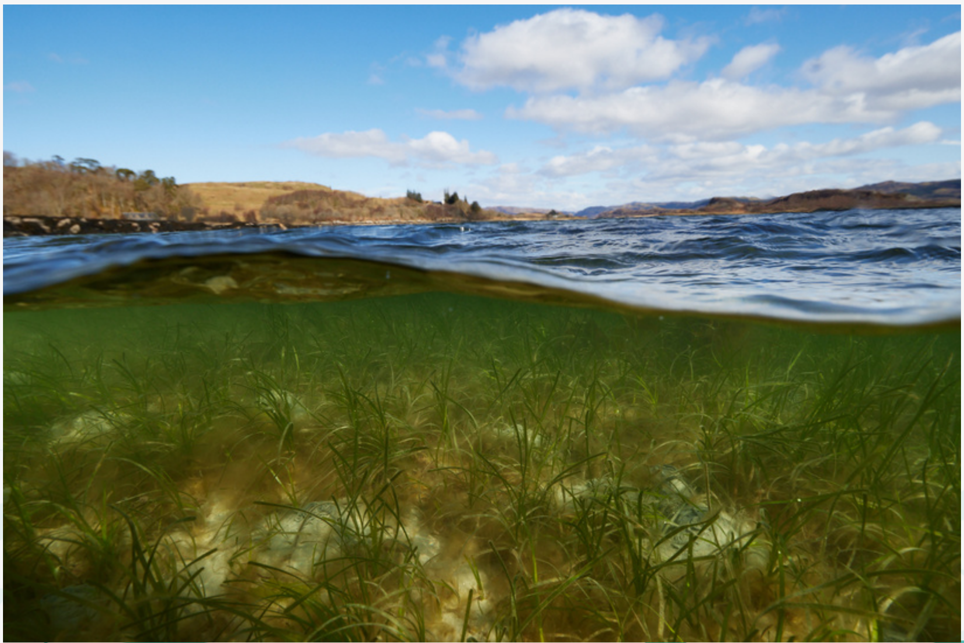
2023 should see the germination of our 2022 restoration and trial planting beds. The germination success of the methodologies will be assessed and should produce results in time to tweak the methodologies used for the 2023 harvesting and planting cycle.

The following priority questions and goals will be part of the 2023 project:

- Determine the spring germination success of hessian bag method.
- Determine the germination success of the other planting methodologies tested.
- Quantify the success of sod transplantation.
- Investigate the effect of sod transplantation on the donor site.
- Determine the 1yr survival of seeds planted in 2021.
- Test intertidal planting in Loch Craignish.
- Determine the ecotypes of seagrass in Loch Craignish - Does Eilean Righ produce super seeds?
- Set up the first seagrass nursery in Scotland.
- Gain permission for a rhizome transplantation test.
- Undertake phase 2 surveys for key areas of connected habitat.

Additionally our outreach and engagement work will continue, including:

- Wild Seas Weekend 2023
- Community Training weekend 2023
- 2 seagrass restoration Internship opportunities
- Launch of an international eLearning and citizen science project in association with BSAC. Titled ‘Underwater Surveyor' which will teach standardised survey techniques to snorkelers and SCUBA divers.
- Volunteer events for seagrass harvesting and planting.



Seawilding would like to thank all of our supporters and partners, who have made seagrass restoration in Loch Craignish possible

Financial supporters:

Brian D Newman Foundation | John Ellerman Foundation | The Craignish Trust

All the kind members of the public who has donated to Seawilding or sponsored a seagrass meadow.

Project partners:

Appendix

Appendix 1 - Key themes being investigated in Loch Craignish

	Question / hypothesis	Null hypothesis	Test / intervention	Variables	Who
1	Harvesting seagrass seeds does not effect the health of the seed donor bed.	There is no change in the health of seagrass beds following seed harvesting.	Seed harvesting. Pick one, leave 3 method	% cover SACFOR Shoot density Canopy height Reproductive effort	Seawilding
1A	Removal of a 0.25x0.25m sod does not effect the health of the donor bed.	There is no change in the health of seagrass beds following sod removal.	Collection of 2 x 0.25m2 sods	% cover SACFOR Shoot density Canopy height Wasting disease	Seawilding
2	Planting seagrass seeds increases cover of seagrass.	Planting seagrass seeds produces no difference in seagrass cover.	Seagrass seed planting using hessian bag method.	% cover SACFOR Shoot density Canopy height Wasting disease	Seawilding
2A	If when do restored seagrass beds produce seeds?	Restored seagrass beds do not demonstrate any reproductive effort.	Seagrass seed planting using hessian bag or other method.	Reproductive effort	Seawilding
2B	Is there a spill over in the propagation of seagrass into areas adjacent to restoration sites?	There is no propagation or germination of seagrass in areas adjacent to restoration sites	Seagrass seed planting using hessian bag or other method.	% cover SACFOR Shoot density	Seawilding
3	Planting seagrass beds improves biodiversity.	There is no difference in biodiversity between restored seagrass beds and unrestored sediment.	Seagrass restoration	Snorkel survey BRUV survey Species count Taxa number Nmax fish species Benthic sampling eDNA sampling	Seawilding
3A	Supplemental questions: Comparison between biodiversity in existing seagrass and sediment areas.	There is no difference in biodiversity between natural seagrass beds and bare sediment areas.	None	Snorkel survey BRUV survey Species count Taxa number Nmax fish species Benthic sampling eDNA sampling	Seawilding
3B	Is there a spill over effect in the increase in biodiversity in areas adjacent to restoration?	There is no difference in biodiversity between unrestored sediment and sediment adjacent to restoration areas.	Seagrass restoartion	Snorkel survey BRUV survey Species count Taxa number Nmax fish species Benthic sampling eDNA sampling	Seawilding
4	Comparison of germination success of seagrass planting methodologies	There is no difference in germination rate between seagrass planting methods.	Each planting method	Number of bags with shoots Number of shoots % cover SACFOR Shoot density Canopy height Wasting disease	Seawilding
4A	What is the success of the hessian bag method in Loch Craignish?		Hessian bag method	Number of bags with shoots Number of shoots % cover SACFOR Shoot density Canopy height Wasting disease	Seawilding

5	Whether seagrass restoration has any spill over effect in seagrass presence on wider habitats.	Null hypothesis: seagrass restoration has no effect on seagrass presence in wider habitats.	Seagrass restoration in Loch Craignish	Number of shoots % cover SACFOR Shoot density Canopy height Wasting disease	Seawilding
5A	Whether seagrass restoration has any spill over effect on the biodiversity in the wider body of water surrounding the restoration area.	Null hypothesis: seagrass restoration has no effect on the biodiversity in the wider body of water surrounding the restoration area.	Seagrass restoration in Loch Craignish	Biodiversity snorkel survey BRUV survey Species count Taxa number Nmax fish species % cover SACFOR Shoot density	Seawilding
6	Can seagrass seeds be germinated in a nursery and planted out successfully in the context of Scottish waters		Seed germination in nursery followed by seabed planting	Number of shoots % cover SACFOR Shoot density Canopy height Wasting disease	Seawilding
7	Quantification of carbon sequestration by seagrass			Sediment sampling Sediment analysis as part of a broader project Seabed carbon storage modelling	SAMS ReMEDIES SAMS
8	Is there a reliable method of using eDNA analysis to determine historic presence of seagrass?			Sediment sampling and eDNA analysis	SAMS

Appendix 2 - Summary of variables being monitored

Parameter	Method	2021	2022	Undertaken by
Seagrass mapping	Ariel survey (Dunvullaig Bay)	✓		Project Seagrass / SAMS
	GPS boundary mapping and ground truthing (10 beds)	✓		Seawilding
Mapping of potential restoration areas	Habitat assessment and GIS modelling	✓		Seawilding
	Echosounder survey	✓		Project Seagrass
	Habitat suitability modelling		✓	SAMS
Germination monitoring			✓	Seawilding
Seagrass health	Snorkel survey of shoot height and density		✓	Seawilding
	Epiphyte quantification	✓	✓	Seawilding
	Wasting disease assessment	✓	✓	Seawilding
	Assessment of reproductive state	✓	✓	Seawilding
Physical parameters	Light logger	✓	✓	Seawilding
	Water temperature	✓	✓	Seawilding
	Particle size assessment	✓	✓	SAMS
Biodiversity	Snorkel survey	✓	✓	Seawilding
	Video transect	✓	✓	Seawilding
	Predator count by video transect	✓	✓	Seawilding
	INNS assessment	✓	✓	Seawilding
	BRUV survey	✓	✓	Project Seagrass
	Benthic invertebrate survey	✓	✓	SAMS
eDNA	Sampling to determine historic presence of seagrass	✓	✓	SAMS
Blue carbon	Sediment core samples	✓	✓	SAMS

Appendix 3 - Research being undertaken by other organisations

Organisation	Research being undertaken
Scottish Association for Marine Science	Using eDNA analysis of sediment cores to determine historic presence of seagrass
Scottish Association for Marine Science	Carbon sequestration quantification.
University of Glasgow	BRUV analysis
SRUC Aberdeen	BRUV analysis
Cardiff University	Current restoration activities
University of St Andrews	Rewilding / restoration
National Oceanographic Institute	Carbon sequestration by seagrass
DEFRA	Uses of marine data
ReSOW	Socioeconomic barriers to restoration
University of Gloucester	Mapping restoration projects in the UK
University of Edinburgh	Understanding seagrass ecosystems

Appendix 4A - Biodiversity monitoring methodologies

Snorkel visual survey method

Biodiversity monitoring was undertaken by transect surveys and snorkeler, alongside video transect recordings. A methodology similar to that used by Seasearch and recommended by *NatureScot1*, was used for the visual surveying. The video transect methodology was based on that described in the *Community-led Marine Biodiversity Monitoring Handbook4*.

A snorkeler swam along a 25m reference transect marked by a weighted line. The snorkeler scanned an area 1m either side of the line as well as the water column, looking for macro algae and mobile and sessile fauna. The snorkeler took photographs of each individual species encountered using an Olympus Tough TG-5 underwater camera. The snorkeler also wore a chest mounted GoPro Hero9 camera which recorded a video transect of the survey.

BRUV method

BRUV surveys were carried out by the Seawilding team. A single GoPro camera was mounted on a fixed frame and placed on the edge of a seagrass bed. The BRUV ran for approx. 1 hour at each site and was baited with fish in a hessian bag.

Following retrieval the footage was reviewed by a member of the Seawilding team to identify and count the species present. These results were verified by another member of the Seawilding team. Where an identification to species level could not be made, genus was recorded. The maximum number of species in frame at any one time (Nmax) is a recommended metric to be used with BRUV analysis, and was calculated for all species.

Video transect method

A snorkeler swam along a 20m weighted transect line whilst wearing a chest cam mounted GoPro camera. Following the survey the footage was reviewed by a member of the Seawilding team to identify and attribute a SACFOR abundance rating for species present. These results were verified by another member of the Seawilding team. Where an identification to species level could not be made, genus was recorded.

Species list

Data was combined from the biodiversity surveys, BRUVs, video transects, biodiversity surveys carried out as part of the Native oyster restoration project, casual observations made during Seawilding's project work as well as BTO bird survey data collected in the Loch Craignish area. The aim being to provide a comprehensive list of macro flora and fauna within the waters and connected ecosystem of Loch Craignish.

Full species list

Species		Recored on seagrass site surveys		Recored on sediment surveys		Observed	
		2021	2022	2021	2022	2021	2022
Barnacles sp.	Cirripedia sp.	X					
Bladder wrack	Fucus vesiculosus	X	X				
Brown filamentous	Brown filamentous	X	X		X		
Channel wrack	Pelvetia canaliculata						
Cystoseira sp	Cystoseira sp	X		X			
Egg wrack	Ascophyllum nodosum	X	X	X	X		
Egg wrack epiphyte	Vertebrata lanosa	X			X		
False Irish moss	Mastocarpus stellatus					X	X
Fork weed	Furcellaria lumbricalis	X	X	X	X		
Gracilaria gracilis	Gracilaria gracilis	X	X	X	X		
Green filamentous		X		X			
Juicy whorl weed			X				
Mermaid's tresses	Chorda filum	X	X	X	X		
Pink encrusting algae	Pink encrusting algae			X	X		
Pom pom weed ?Harpoon weed	Pom pom weed ?Harpoon weed	X	X	X			
Oyster thief	Colpomenia peregrina		X				
Red seaweed	Asperagosis aramata	X					
Sand binder			X		X		

Sausage weed	Asperococcus bullosus		X		X		
Sea lettuce	Ulva Sp	X	X	X	X		
Sea Oak	Halidrys siliquosa	X	X	X	X		
Seagrass	Zostera marina	X	X	X	X		
Serrated wrack	Fucus serratus	X	X	X	X		
Spiral wrack	Fucus spiralis		X	X	X		
Sugar kelp	Laminaria saccharina	X	X	X	X		
Unidentified red seaweed	Unidentified red seaweed						
Wire weed	Sargassum muticum	X	X				
Artemis	Disonia sp.				X		
Ascidia mentula	Ascidia mentula	X	X	X			
Asparagopsisar m	Asparagopsisar m	X		X			
Atlantic cod	Gadus morhua	X					
American oyster drill	Urosalpinx cinerea						
Amphorina (nudi)	Amphorina sp.	X					
Banded chink shell	Lacuna vincta		X				
Beadlet anemone	Actinia equina			X			
Blue jellyfish	Cyanea lamarckii	X			X		
Blue mussel	Mytilus edulis					X	X
Boring sponge	Cliona celata						
Brittlestar	Ophiuroidea					X	
Brown shrimp	Crangon spp.	X	X	X	X		
Butterfish	Pholis gunnellus					X	X
Buzzard	Buteo buteo					X	A/W
Canada goose	Branta canadensis					X	A/W
Chiton sp.	Chiton sp.	X		X			
Sea squirt	Diplosoma listerianum	X					

Cling fish	Gobiesociforme s sp.		X				
Clytia hemispherica	Clytia hemispherica	X					
Cod	Gadus morhua		X				
Common cockle	Cerastoderma edule			X			
Common periwinkle	Littorina littorea	X			X		
Common prawn	Palaemon serratus	X	X				
Common sea urchin	Echinus esculents	X					
Common sandpiper	Actitis hypoleucos					X	A/W
Common starfish	Asterias Rubens	X	X	X	X		
Common wentletrap	Epitonium clathrus	X					
Common whelk	Buccinum undatum	X		X			
Corkwing	Symphodus melops	X	X				
Curlew	Numenius arquata					X	A/W
Dab	Limanda limanda	X			X		
Diplosoma sp	Diplosoma sp	X	X		X		
Dog whelk	Nucella lapillus						
Dragonette sp.	Callionymidae	X			X		
Edible crab	Cancer pagurus						
Eider	Somateria mollissima					X	A/W
Eurasian otter	Luttra luttra					X	X
European eel	Anguilla anguilla	X					X
European sting winkle	European sting winkle						
Facelina bostoniensis	Facelina bostoniensis	X		X			
Favourinus branchialis	Favourinus branchialis	X	X				
Feather star common	Antedon bifida		X				

Flat periwinkle	**Littorina obtusata**	X	X				
Flounder							X
Fluted sea squirt	**Ascidiella aspersa**	X	X	X	X		
Frosty sea mat	**Electra pilosa**						
Gannet	**Morus bassanus**						X
Goby sp	**Goby sp**	X	X		X		
Goldeneye	**Bucephala clangula**					X	A/W
Goldsinny	**Ctenolabrus rupestris**	X					
Great Northern Diver	**Gavia immer**					X	A/W
Green urchin	**Echinocyamus pusillus**	X					
Grey gurnard	**Eutrigla gurnardus**	X					
Grey heron	**Ardea cinerea**					X	A/W
Grey topshell	**Steromphala cineraria**	X	X				
Greylag goose	**Anser anser**					X	A/W
Gul Sp.						X	X
Harbour crab	**Liocarcinus depurator**	X	X	X	X		
Harbour seal	**Phoca vitulina**	X					X
Hayas sp	**Hayas sp**	X					
Hermit crab	**Paguridae**	X	X	X	X		
Hermit crab fur	**Hydtactinia ecinata**	X	X	X	X		
Herring Sp.	**Clupeiformes**	X					
Hooded crow	**Corvus cornix**					X	X
King scallop	**Pecten maximu s**						X
Keel worms	**Spirobranchus sp.**	X	X	X			
Kelp fur	**Obelia geniculata**	X	X	X			
Least chink shell	**Lacuna parva**		X				
Leathery sea squirt	**Styela lava**					X	X

Lightbulb seasquirt						X	
Limpets sp.	**Limpets sp.**					X	X
Little grebe	**Tachybaptus ruficollis**					X	A/W
Long legged spider crab	**Macropodia sp.**	X	X	X	X		
Long legged spider crab hydroid	**Long legged spider clad hydroid**		X				
Lugworm casts	**Arenicolidae**	X	X	X	X		
Maerl							X
Mallard	**Anas platyrhynchos**					X	A/W
Moon jellyfish	**Aurelia aurita**				X		
Mute swan	**Cygnus olor**						X
Native oyster	**Ostrea edulis**	X	X	X	X		
Needle whelk	**Bittium reticulatum**		X				
Nudibranch	**Jorunna tomentosa**	X					
Orange ball sponge			X				
Oyster catcher	**Haematopus ostralegus**					X	A/W
Pacific oyster	**Magdalena gigas**					X	X
Paddleworm eggs	**Phyllodocidae**	X	X	X	X		
Painted goby	**Pomatoschistus pictus**		X				
Painted topshell	**Calliostoma zizyphinum**	X	X				
Peacock worm	**Sabella pavonina**	X	X		X		
Pipefish sp.	**Pipefish sp.**	X	X				
Pollock	**Pollachius**	X	X		X		
Poor cod	**Trisopterus minutus**	X					
Pouting	**Trisopterus luscus**	X					
Punctured ball weed	**Leathesia marina**					X	X

Queen scallop	Aequipecten opercularis					X	X
Redshank	Tringa totanus					X	A/W
Red sponge	Hymeniacidon perleuis					X	
Red-breasted Merganser	Mergus serrator					X	A/W
Ringed plover	Charadrius hiaticula					X	A/W
Rissoria sp.	Rissoria sp.	X	X				
Saddle oyster	Anomia ephippium	X		X			
Sand goby	Pomatoschistus minutus	X	X		X		
Sand mason	Lanice conchilega	X	X	X	X		
Scale worm species	Polynoidae	X		X			
Sea gooseberry	Pleurobrachia pileus	X	X	X			
Seagrass bryozoa	Flustrellida hipidia		X				
Sea hare	Anaspidea sp.		X				
Seagrass hydroid	Laamedea angulata	X	X				
Seagrass hydroid	Scrupocellaria sp.		X				
Sea mat	Membranipora membranacea		X				
Sea pen							X
Serrated wrack hydroid			X				
Shag	Gulosus aristotelis					X	A/W
Shellduck	Tadorna tadorna					X	A/W
Shore crab	Carcinus maenas	X	X	X	X		
Shredded carrot sponge	Amphilectus fucorum		X				
Slavonian grebe	Podiceps auritus					X	A/W
Small-spotted catshark	Scyliorhinus canicula		X				X
Snakelocks anemone	Anemonia viridis	X	X	X	X		

Spiny starfish	**Marthasterias glacialis**	X					X
Spirobis sp.	**Spirobis sp.**	X	X				
Stalked jellyfish	**Calvadosia campanulata**		X				
Stickleback	**Spinachia spinachia**	X	X				
Strawberry worm	**Eupolymnia nebulosa**	X	X				
Teal	**Anas crecca**					X	A/W
Tower shell	**Turritellidae sp.**	X	X				
Turban topshell	**Gibbula magus**	X	X				
Two spot goby	**Gobiusculus flavescens**	X	X		X		
Velvet swimming crab	**Necora puber**		X				
White-tailed eagle	**Haliaeetus albicilla**						X
Whiting	**Merlangius merlangus**						
Wigeon	**Mareca**					X	A/W
Wrasse sp.	**Labridae sp.**		X				
Yellow ringed sea squirt	**Ciona intestinalis**		X				

Appendix 4B - Connected habitat mapping methodologies

The edge of the seagrass bed was identified from the surface by an observer on a paddle board. The boundary was mapped by a pair of paddle boarders, paddling the edge of the seagrass bed while recording the track on a GPS device. The methodology for the boundary mapping followed closely the Habitat Mapping methodology in the Community-led Marine Biodiversity Monitoring Handbook4 which is recommended for use in seagrass restoration projects by NatureScot1.

While locating the seagrass bed, the paddle boarders paddled abreast 2-4m apart depending on conditions to maximise coverage and minimise the risk of missing a sighting. Once a seagrass bed was discovered, the edge was located and mapping was begun. As a pair, the lead person became the scout and the trailing person became the GPS recorder. The scout went ahead to confirm the seagrass boundary, while the recorder activated the tracking function on the GPS device and followed. If the scout lost sight of the boundary, or needed to move off the boundary to examine/take photos, the recorder was notified and held station. It was not critical that the scout remained on the boundary, as long as the recorder remained on it. The scout took a selection of photos to aid ground truthing and verification. Once the scout was happy with the boundary location, the recorder returned to follow the scout. This two person method helped to maintain an accurate GPS track despite the edge of the seagrass bed sometimes being patchy or difficult to locate. When the mapping of the extent was completed by returning to the start point, the recorder stopped the track and saved the file.

The .gpx files were subsequently imported into QGIS where the areas of the seagrass were calculated and displayed visually as a layer on a satellite image.

Appendix 4C - Seed viability testing method

The clear plastic tube used for flow rate testing was filled with water. A point 50cm below the surface of the water was marked with tape. Seed passing this marked point in less than 10s would have a sinking velocity of more than 5cm/s and therefore high chance of viability.

Seeds were released at the surface in groups of 20 to allow progress of individual seeds to be tracked and to avoid seeds interfering with each other during sinking. A timer was started when the seeds were released. The 50cm mark was watched by an observer as well as filmed. The overseer counted how many seeds passed the 50cm mark before the 10s time limit expired.

The current project method for separating seeds involves a ‘gold panning method’ whereby floating seeds and slower sinking seeds (often light brown in colour and soft to the touch) are removed.

The test sample of 200 seeds was subjected to this panning method. Sixty (30%) of the seeds would have been rejected at this stage of the normal project seed collection process. One hundred and forty seeds went on to the sinking viability test.

Appendix 5 - Seagrass bed health monitoring methods

Seagrass coverage and canopy height method

Snorkel surveys were carried out in all of the designated donor and control seagrass beds. This allowed for a composite of data from multiple reference sites, which experience different environmental conditions to be collected, as recommended by NatureScot2. At each site, surveys were undertaken on both the seagrass bed and the adjacent sea bed (potential restoration area) for comparison. The snorkel survey was undertaken along a 25m weighted transect line, placing a quadrat every 2m to determine seagrass percentage coverage and canopy height, as recommended by NatureScot1.

The weighted end of transect line was placed at the edge of the reference seagrass bed.
A photo was taken above the water to record start position, this recorded a visual image and GPS reference for the start point on the camera.

The snorkeler then swam into the seagrass bed while unrolling the transect line, marked every 2m. The snorkeler stopped at every 2m as marked on line and a 50cm2 gridded quadrat was placed on the seabed. A photo was taken of this quadrat to record seagrass coverage.

The quadrat was then lifted vertically to measure canopy height, using the 10cm markings from quadrat grids, recording heights greater than height of quadrat as >50cm. This was repeated until the end of the 25m spool of line, and 12 quadrats of coverage and height had been recorded. A photo was taken above the water to record the end position using the GPS function on the camera. The snorkeler swam back to start position while rolling the line back onto the reel.

From the weighted start point, the snorkeler repeated the process, swimming away from the reference seagrass bed over adjacent sediment, again taking quadrat photos every 2m as marked on the transect line. This was repeated until the end of 25m spool, and 12 quadrats of coverage been recorded. A photo was taken above the water to record the end position using the GPS function on the camera. The snorkeler then swam back to start position while rolling line back onto reel and retrieved the end weight.

Seagrass bed extent method

Bed extent was mapped in 2021 and 2022. The edge of the seagrass bed was identified from the surface by an observer on a paddle board. The boundary was mapped by a pair of paddle boarders, paddling the edge of the seagrass bed while recording the track on a GPS device. The methodology for the boundary mapping followed closely the Habitat Mapping methodology in the Community-led Marine Biodiversity Monitoring Handbook4 which is recommended for use in seagrass restoration projects by NatureScot1.

While locating the seagrass bed, the paddle boarders paddled abreast 2-4m apart depending on conditions to maximise coverage and minimise the risk of missing a sighting. Once a seagrass bed was discovered, the edge was located and mapping was begun. As a pair, the lead person became the scout and the trailing person became the GPS recorder.

The scout went ahead to confirm the seagrass boundary, while the recorder activated the tracking function on the GPS device and followed. If the scout lost sight of the boundary, or needed to move off the boundary to examine/take photos, the recorder was notified and held station. It was not critical that the scout remained on the boundary, as long as the recorder remained on it. The scout took a selection of photos to aid ground truthing and verification. Once the scout was happy with the boundary location, the recorder returned to following the scout. This two person method helped to maintain an accurate GPS track despite the edge of the seagrass bed sometimes being patchy or difficult to locate. When the mapping of the extent was completed by returning to the start point, the recorder stoped the track and saved the file. The .gpx files were subsequently imported into QGIS where the areas of the seagrass were calculated and displayed visually as a layer on a satellite image.

Epiphyte cover method
Epiphytes such as hydroids and algae grow on seagrass, their cover can reduce the amount of light that the plant receives and consequently detrimentally affect it's growth. Epiphyte cover was estimated from images taken during the biodiversity survey dives, see methodology below. These images were reviewed following the dive and the degree of epiphyte cover graded as low, medium or high according to the grading given in the Seagrass Restoration Handbook2. Epiphyte identification was not undertaken due to lack of published survey protocol and experience.

Reproductive timing and effort method
It was important to determine which beds showed evidence of producing flowers and seeds as both a measure of the health and reproductive status of the bed5, as well as to determine which beds may be able to act as seed donor sites for the restoration project. Images of flowers or seeds were taken during the biodiversity surveys, see methodology below. These images were reviewed following the dive and reproductive status was recorded.

Presence of INNS method
The species data form the snorkel and video transect biodiversity surveys from both the reference beds and potential restoration sites were compared against the lists of INNS given above. All members of the project team were briefed on the identification of INNS and were encouraged to report any sightings which they made in Loch Craignish. These sightings were verified by other members of the team or external advice sought where identification was not certain. These casual observations are also noted.

The list of species considered as invasive were combined from the following lists. NatureScot lists the following INNS as those which could negatively affect the success of seagrass restoration: Japanese wire weed (Sargassum muticum), Common cordgrass (Spartina anglica), Slipper limpet (Crepidula fornicata), Harris mud crab (Rhithropanopeus harrisii), Asian shore crab (Hemigrapus takanoi), Wakame (Undaria pinnatifida)1.

NatureScot list the following as Invasive species which threaten Scotland6.

‘Marine invasive non-native species that are now widespread and well established in Scotland include:

- wireweed (Sargassum muticum)
- green sea-fingers (Codium fragile subsp. tomentosoides)
- common cordgrass (Spartina anglica)
- red alga (Heterosiphonia japonica)
- acorn barnacle (Austrominius modestus)
- Japanese skeleton shrimp (Caprella mutica)
- leathery sea squirt (Styela clava)

Invasive species found only in patchy locations within Scotland include:

- American lobster (Homarus americanus)
- carpet sea-squirt (Didemnum vexillum)
- Pacific oyster (Magallana gigas)

Species present in the British Isles but yet to reach Scotland include:

- slipper limpet (Crepidula fornicata)’6

INNS results

Present / Absent										
Area	Dunvullaig Bay		Nursery		Breakwater		Village Bay		Eilean Buidhe	
Year	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Japanese wire weed (Sargassum muticum),	A	R	A	A	A	A	A	A	A	R
Common cordgrass (Spartina anglica),	A	A	A	A	A	A	A	A	A	A
Slipper limpet (Crepidula fornicata),	A	A	A	A	A	A	A	A	A	A
Harris mud crab (Rhithropanopeus harrisii),	A	A	A	A	A	A	A	A	A	A
Asian shore crab (Hemigrapus takanoi),	A	A	A	A	A	A	A	A	A	A
Wakame (Undaria pinnatifida)	A	A	A	A	A	A	A	A	A	A

Present / Absent										
Area	**Dunvullaig Bay**		**Nursery**		**Breakwater**		**Village Bay**		**Eilean Buidhe**	
Year	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**
Green sea-fingers (Codium fragile subsp. tomentosoides)	A	A	A	A	A	A	A	A	A	A
Red alga (Heterosiphonia japonica)	A	A	A	A	A	A	A	A	A	A
Acorn barnacle (Austrominius modestus)	A	A	A	A	A	A	A	A	A	A
Japanese skeleton shrimp (Caprella mutica)	A	A	A	A	A	A	A	A	A	A
Leathery sea squirt (Styela clava)	A	A	A	A	A	A	A	A	A	A
American lobster (Homarus americanus)	A	A	A	A	A	A	A	A	A	A
Carpet sea-squirt (Didemnum vexillum)	A	A	A	A	A	A	A	A	A	A
Pacific oyster (Magallana gigas)	A	A	A	A	A	A	A	A	A	A
Chinese mitten crab (Eriocheir sinensis)	A	A	A	A	A	A	A	A	A	A
	Wire weed, *Sargassum muticum*, Leathery sea squirt, *Styela clava* and Pacific oyster, *Magallana gigas* were all observed outside the survey areas in 2021 and 2022.									

References

1 Establishing an environmental baseline prior to community driven restoration in Loch Craignish, Scotland. 2022 Alex Innes Thomson[1], Alasdair R O'Dell[1], Michael T Burrows[1]
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