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Trends, challenges and opportunities in the *in situ* conservation of cereal landraces in Scottish islands

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Abstract: Landraces are traditional crop varieties that often have special adaptations to the farming environment in which they have evolved and are therefore a valuable source of useful traits for plant breeders. In most agriculturally advanced countries, landraces of the main crops have generally been superseded by modern varieties. An exception to this in the United Kingdom is the cultivation on the Scottish archipelagos of Orkney, Shetland and the Outer Hebrides of three cereal landraces: bere, a 6-row barley (*Hordeum vulgare*), small oat (*Avena strigosa*) and Hebridean rye (*Secale cereale*). Our study focused on trends in their cultivation and use over the past 20 years. In the Outer Hebrides, a mixture of all three has continued to be grown on more than 200ha for feed because of its tolerance of nutrient-deficient sandy soils. Future cultivation is threatened, however, by damage from geese and deer, especially to fields used for seed production. In Orkney and Shetland, only bere and small oat are grown, and always as sole crops. The area of bere has increased in Orkney, from about 10ha in 2004 to almost 75ha in 2020 and has been driven by two supply chains producing bere for milling and malting. However, small oat in Orkney, and both small oat and, especially bere, in Shetland have been grown by very few farmers since 2018 and are at serious risk of being lost from cultivation. We discuss these results in the context of measures to support greater on-farm cultivation of these landraces.

Keywords: *In situ*, on farm, conservation, bere, small oat, Hebridean rye

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Introduction

Background

Food security is of growing global concern due to the rapidly increasing human population and the adverse impact of climate change on food production (Godfray *et al*, 2010; FAO, IFAD, UNICEF, WFP and WHO, 2017). Research into food security should focus on all aspects of the human food chain but logically should start with ensuring stable production of highly nutritious and diverse crops (Dhankher and Foyer, 2018). However, in recent years industrial agriculture has focused on the cultivation of fewer genetically homogeneous crop varieties leading to a reduction in crop diversity (FAO, 2012) caused by fewer crops in cultivation, fewer cultivars of each crop and reduced genetic diversity within each cultivar (Negri *et al*, 2009). There are about 31,128 plant species which currently have documented uses, of which 5,538 are associated with direct food production and a further 5,338 have potential for adaptive allele donation (RBG Kew, 2016). However, basic global human nutrition comes from just 30 species, and three major crops – rice (*Oryza sativa*), wheat (*Triticum aestivum*) and maize (*Zea mays*) – provide 50% of calories consumed globally. Food production is increasingly focused on these few crops while the bulk of semi-domesticated and wild edible species are underutilized (FAO, IFAD, UNICEF, WFP and WHO, 2017; Padulosi *et al*, 2013). Furthermore, industrial

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production and consumer demand are often focused on uniformity and achieving maximum production and consumer shelf appeal (Kilcast and Subramamiam, 2011). To achieve this, modern cultivars are genetically homogeneous, lacking the geographically localized infra-varietal diversity found in traditional varieties. These traditional varieties are produced via generational cycles of farmer seed selection, which results in adaptations to local environment and higher levels of genetic diversity than occur in modern varieties.

Cultivar uniformity increased production overall but the switch from traditional genetically variable crop landraces significantly depleted the gene pool of diversity available to breeders, which is required to sustain crop improvement in the future (Hawkes *et al*, 2000; Van De Wouw *et al*, 2009; Maxted *et al*, 2020). The price paid for crop uniformity is that these homogeneous cultivars are vulnerable to new strains of diseases or pests, or extreme changes in the growing environment (Committee on Managing Global Resources, 1993; FAO, IFAD, UNICEF, WFP and WHO, 2017). The threat to overall crop diversity by the replacement of landraces by higher-yielding but genetically uniform cultivars is well established at a global level (Negri *et al*, 2009; FAO, 2010). While modern varieties usually outperform landraces under optimal conditions, landraces may still be competitive in marginal environments where modern cultivars lose their advantage or where there is an associated niche market to sustain production (Yahiaoui *et al*, 2014; Marone *et al*, 2021). The intrinsic genetic diversity present in landraces means they will often produce some yield even in the face of new strains of diseases or pests, or sudden extreme changes in the growing environment. Conserving the maximum pool of diversity in landraces is a priority to sustain future agricultural production (FAO, 2012), and landraces grown in regions subject to very variable conditions are likely to have evolved traits that allow them to tolerate such changes. These traits are likely to be particularly valuable to breeders to mitigate the impact of conditions like climate change (Hawtin *et al*, 1997; Maxted *et al*, 2020).

Within the United Kingdom (UK), the agricultural regions where landrace cultivation and resulting diversity are greatest, are the Scottish archipelagos of Orkney and Shetland (the Northern Isles) and the Outer Hebrides (Kell *et al*, 2009) (Figure 1). The main landraces grown are three cereals: bere,[1] an ancient type of 6-row barley (*Hordeum vulgare* L.), small oat[2] (*Avena strigosa* Schreb.) and Hebridean rye[3] (*Secale cereale* L.). While bere and small oat are grown in all archipelagos, Hebridean rye is only grown in the Outer Hebrides. There are fundamental differences in the manner of cultivation of the landraces between the archipelagos. In the Outer Hebrides, the most common practice is to grow all three together as a mixture (Scholten *et al*, 2009) for animal forage. In contrast, in Orkney and Shetland, bere and small oat are grown as sole crops, with bere being used in Orkney for milling and malting. In Shetland, small oat is usually grown for straw used in basketry, making traditional straw-backed chairs or for thatching. In the Outer Hebrides and Shetland, and to a lesser extent in Orkney, cultivation of the cereal landraces is usually associated with crofting (see Supplemental Note 2), a small-scale, low-input traditional type of farming. Two other landraces that survive in Shetland are Shetland cabbage or kale (*Brassica oleracea* L.) and Shetland black potato (*Solanum tuberosum* L.). Livestock landraces have also been preserved in the Northern Isles, with the multipurpose Shetland cow in Shetland and seaweed-eating North Ronaldsay sheep in Orkney.

Locational and environmental context

Undoubtedly, the location and history of these archipelagos are important factors contributing to the survival of landraces in these areas. They are all peripheral areas, geographically isolated from mainland Scotland, which have always experienced difficulties, or high costs, in importing goods, resulting in a requirement for self-sufficiency. Climatically, they are hyper-oceanic with high rainfall, frequent gales and cropping seasons that are cooler and shorter than in other parts of Britain (Chappell *et al*, 2017). Other challenges for cropping include relatively poor soils and limited availability of machinery and equipment. The three archipelagos also have unique cultural identities and traditions. Although all were settled by Viking invaders during the 9^{th} century, Norse control of the Outer Hebrides ended earlier, in the 13^{th} century, and was superseded by a Gaelic culture which includes its own language still

[1] Under current terminology the name 'bere' is used to describe a distinct landrace population of lax-eared, 6-row, hulled spring barley that has been grown in Scotland and the north of Britain for over 1,000 years (Drosou *et al*, 2022). In the past, several synonyms appear to have been applied to bere including 'beare', 'bygg' or 'bigg' (Jarman, 1996; Wallace *et al*, 2019). In most cases, these names appear to refer to a similar type of barley to today's bere, but sometimes they were used to refer to any 6-row barley (Jarman, 1996). Phenotypically, bere from the different Scottish archipelagos as well as most of 35 accessions in a germplasm collection held by the James Hutton Institute, are similar although differences occur in some characteristics like days to heading and tolerance to manganese-deficient soils. Genotypically, these beres are also closely related to each other although cluster analysis has shown that the accessions separate into three distinct groups according to their archipelago of origin (Schmidt *et al*, 2019). In spite of these phenotypic and genotypic differences, different types of bere are not currently recognized by growers in Scotland although in the 19^{th} century named selections were available (Martin *et al*, 2009).

[2] We have used the name small oat for the Scottish *A. strigosa* landrace population which is the terminology used by SASA's (Science and Advice for Scottish Agriculture) Scottish Landrace Protection Scheme (Scottish Landrace Protection Scheme (SLPS) — SASA (Science & Advice for Scottish Agriculture)). On Orkney it is referred to as black oats and on Shetland as Shetland aets (Supplemental Table 1). Although there are phenotypic and genetic differences amongst accessions of small oat, growers in the island groups do not identify different types (Scholten, 2012).

[3] We again follow the terminology of the SLPS for the Scottish *S. cereale* landrace population. This is represented by relatively few accessions in the SLPS collection and has been much less studied than bere or small oat.

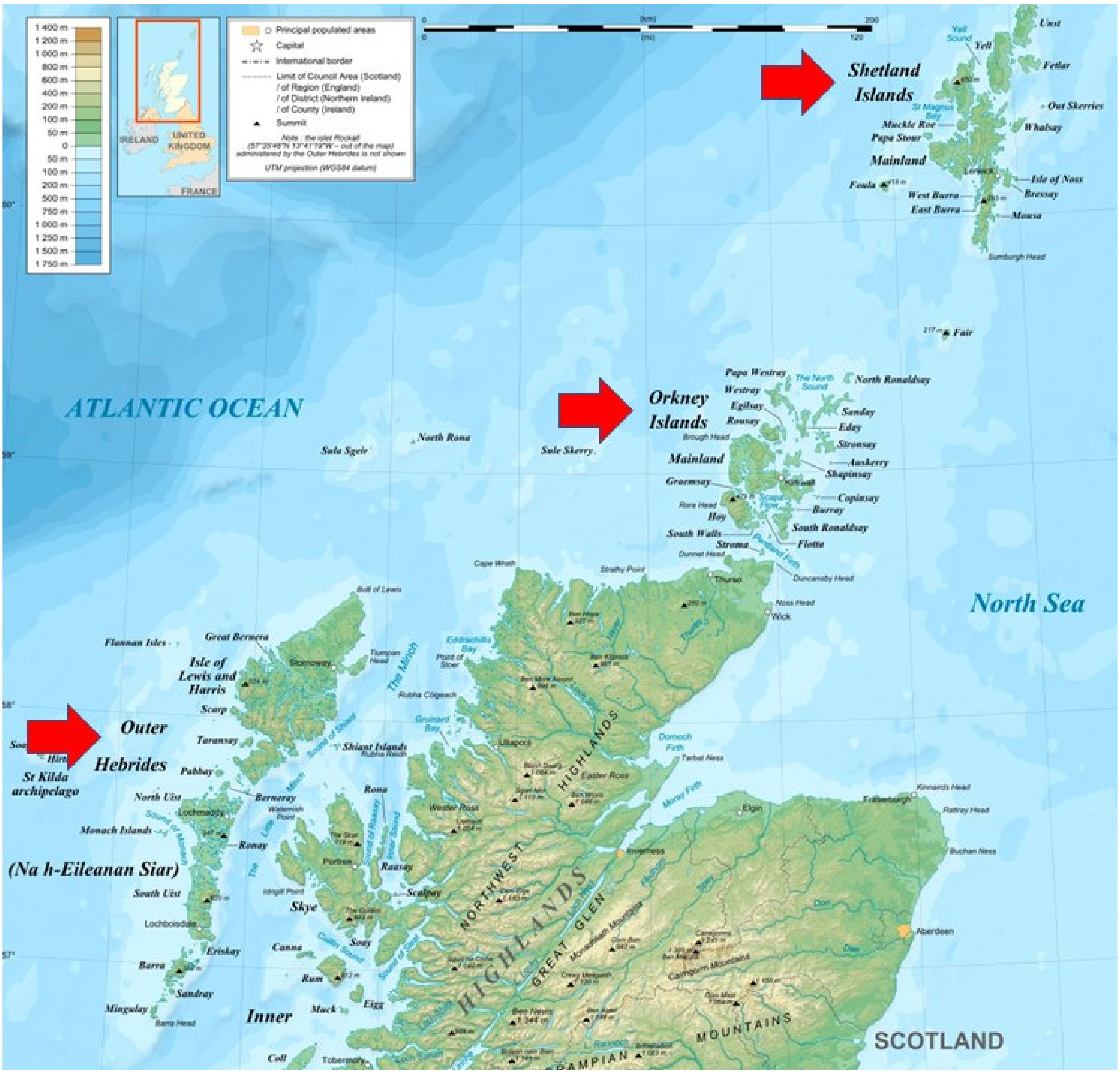

Figure 1. Map of northern Scotland with red arrows showing the location from north to south of the Shetland Isles, Orkney Isles and Outer Hebrides. The image was sourced from Scotland_topographic_map-en.jpg (2400×3450) (wikimedia.org) and originally produced by Eric Gaba; Supplemental Note 1 provides the complete attribution.

spoken by most islanders. Orkney and Shetland only became part of Scotland in the late 15^{th} century and many traditions and aspects of culture in the Northern Isles reflect the earlier Scandinavian links, especially in Shetland.

In all the archipelagos, but particularly the Outer Hebrides, a significant proportion of arable land is on sandy, coastal soils which have a high pH and low availability of trace elements, especially manganese and copper, forming a special habitat called 'machair' (Scottish Natural Heritage, 2003). Locally adapted types of bere have a remarkable ability to tolerate these deficient soils and produce reasonable grain yields while modern barley varieties lack this trait and yield very poorly or not at all (Schmidt *et al*, 2019). The Hebridean rye and small oat landraces are also tolerant of these soil conditions and this trait is likely to have been an important factor explaining the survival of all three landraces in cultivation down to current times. The machair is a particularly harsh agricultural environment because of its soil properties but also because of its exposure to gales, salt spray and periodic droughts; drifting of sand and soil erosion also occur (Scottish Natural Heritage, 2003). Over centuries, landraces have adapted to these conditions and on the Outer Hebrides the

bere, small oat and Hebridean rye mix is able to produce a reasonable yield with minimal inputs, apart from fertilizer, for which local stranded seaweed and animal manure are often used (Brown *et al*, 2020). Traditional cropping of the cereal landraces involves leaving land fallow as part of the rotation, resulting in the development of a unique coastal grassland with a rich and distinctive flora and fauna. Its importance is recognized by its inclusion in Annex 1 of the EU Habitats Directive (Walton and Mackenzie, 2009), and several machair areas are included amongst Natura 2000 sites (Scottish Natural Heritage, 2018). Continued low-input cultivation of these cereal landraces in combination with the application of organic fertilizers and fallow years is key to machair conservation (Scottish Natural Heritage, 2003), and so local biodiversity and cultural interests in this rare habitat both favour continued landrace use. In Orkney and Shetland, cropping of the machair is less formalized and, especially in Orkney, there are larger areas of better quality agricultural land for cropping. Some bere accessions collected from Orkney, which do not originate from machair areas, lack a marked ability to tolerate its manganese-deficient soils (Schmidt *et al*, 2019).

Although the three cereal landraces are well-adapted to the Scottish island environment, compared with modern varieties, they have several agronomic shortcomings (Martin *et al*, 2010), which limit their attraction to farmers. In particular, their grain yields are low and their straw is long, making crops very susceptible to lodging close to harvest. Lodging is aggravated on fertile land or with high levels of nitrogen and is sometimes accompanied by premature grain germination because the heads of lodged crops remain wet for long periods after rain. This is of concern where crops are grown for malting, milling or seed. Bere has relatively long awns and in some years these do not completely break off the grain during combine harvesting and this can result in time-consuming blockages in machinery.

Historical context

Bere was probably the earliest of the three cereal landraces to be introduced to Scotland, most likely during the Bronze Age or possibly in the Neolithic (Drosou *et al*, 2022). Small oat and Hebridean rye were probably more recent introductions, with oats first appearing at archaeological sites during the Iron Age (Bond, 1998) and rye during Viking times when there was an intensification of cereal production in the Scottish Isles (Smith, 2005). There may also have been more recent seed introductions of both Hebridean rye and small oat to the Outer Hebrides (Scholten *et al*, 2009).

Bere was widely grown throughout Scotland until the 19^{th} and 20^{th} centuries. It was mostly cultivated as a sole crop, even in the Outer Hebrides, and was important for in-kind and land rental payments and for milling into beremeal and making into malt, which was used for brewing and distilling. The latter allowed significant value to be added to the crop (Devine, 1994). Given the short cool growing season of all the archipelagos, a major advantage of bere was its ability to produce a crop of grain in a short time. Historically, this allowed bere to be sown after oats (both *A. sativa* L. and *A. strigosa*), which had a longer period to maturity, but to be still harvested before them in late August or September (Dodgshon, 2004), usually before the weather deteriorated and spoilt the crop or prevented harvesting. Consequently, bere was more likely to be harvested successfully than oats and was therefore important for food security. In all the islands, the importance of local cereals for food and malt declined as transportation links improved in the 19^{th} century, allowing the import of cheap wheat flour to the area and providing distilleries with access to barley with better malting characteristics than bere (Martin *et al*, 2009). The introduction of potatoes during the 18^{th} century and their widespread adoption for food also reduced the importance of cereal landraces as food staples. During the 20^{th} century, mechanization effectively lengthened the cropping season in the study area because it reduced the time required for cultivation and harvesting. This helped growers to adopt later-maturing, higher-yielding varieties than bere.

In Orkney, the conservation of bere during the latter part of the 20^{th} century can largely be attributed to the presence of a functioning water mill (Barony Mill) producing beremeal for local bakeries which provided a small market for locally grown bere. Since 1998, the mill has been run by Birsay Heritage Trust (BHT), which maintains its own line of bere and organizes its growing in the Birsay area with a local agricultural contractor, mostly leasing land from farmers. From 2004, the Agronomy Institute (AI) started to develop new brewing and distilling markets for bere and established its own supply chain with a small number of local growers (3-4 per year).

Cereal cultivation in Shetland has always been more difficult than in Orkney because of its more challenging climate and much smaller area of suitable arable land (Martin, 2015). During the 20^{th} century, the area of bere grown on Shetland declined from about 419ha in 1912 (Board of Agriculture for Scotland, 1913) to a few hectares by the end of the century and there were estimated to be only two to three growers of bere in 2002 (Shetland Organic Producers Group, 2003). Crucially, unlike Orkney, no large water mill survived in operation on Shetland into the 21^{st} century and there was therefore no milling market for bere.

It is not known when the practice of growing bere, small oat and Hebridean rye in a mixture started in the Outer Hebrides, but it may be relatively recent as historical accounts from the early 20^{th} century do not mention this practice (MacDonald, 1919). It likely became possible as the importance of local cereals for food and malt declined, as Hance (1952) reported that the decline in barley cultivation in the Uists from about 1,797ha in 1925 to about 335ha in 1946 had been

offset by an increase in rye and mixed grains. It has been suggested that a major advantage of the landrace mixture, apart from its tolerance to low levels of soil trace elements, is that it provides production resilience under the very variable soil moisture conditions of coastal, sandy soils (Smith, 1994). This can vary from drought to waterlogging depending on rainfall and the drainage characteristics and topography of individual fields. Within the mixture, Hebridean rye is the most drought-tolerant species while bere and small oat perform better on wetter land and bere is also valued for its nutritional contribution (Smith, 1994). Bere matures earlier than the other two species, however, and often starts to shed seed before harvest; the other two species, therefore, tend to dominate the mixture.

Study aims

An initial survey in 2003 of UK landraces (Scholten *et al*, 2011) identified the three Scottish island archipelagos as regions where the three cereal landraces as well as Shetland cabbage (Scholten *et al*, 2008) were still prized and maintained. The aim of the present paper is to update the results of the first assessment with more recent information on the landraces grown, grower numbers, area under cultivation and to identify interventions which could encourage wider growing of these landraces. These results are presented within the context of other factors which have affected the cultivation of the cereal landraces on these archipelagos. This update includes data collected during a survey undertaken in 2018 as part of the EC-funded Farmer's Pride project (Farmer's Pride, 2019), one element of which was to study the economic feasibility of landrace cultivation. Although the scope was inclusive, the main focus was on cereal landraces and the results reported are mainly for these.

Materials and methods

Area of study

The area of study included the three Scottish archipelagos of Orkney, Shetland and the southern part of the Outer Hebrides (the 'Uists') comprising North Uist, Benbecula, South Uist and Barra (Figure 1). The latitudinal range of these archipelagos is from approximately 57^{o}N to 61^{o}N.

Assessing area of landraces and grower numbers 2002–2020

For Orkney and Shetland, the number of landrace growers and area grown was small and we provide estimates of this based on our knowledge and information from key informants (for example, Shetland Organic Producers Group, the Agronomy Institute (AI) at Orkney College UHI and Birsay Heritage Trust).

With the much larger number of growers in the Outer Hebrides, we can only provide an estimate of grower numbers and the area grown and consider this to be most reliably based upon Scottish Government annual census data from 2002 to 2019 for the area of crops grown by region. For most years, data for the Outer Hebrides (Na h-Eileanan Siar) include the area of oats and mixed grains grown on agricultural holdings. Several local key informants, as well as extensive field surveying in 2006 (Scholten *et al*, 2008) indicated that most oat fields were small oats, and the mixed grain crops were the mixture of landraces – mainly small oat and Hebridean rye, but often also included some bere. Another strong reason for assuming that the census data for these crops reflect landraces is that the arable areas are mostly on the machair, and landraces are much better suited to these soil conditions than modern varieties. In some years the census provides the same data for the barley crop and, for the same reasons, this is most likely to be bere. However, we stress that for crofting communities, where crofts are often extremely small and holdings can contain several crofts, the use of the census data is likely to underestimate the area and, especially, grower numbers. Given the uncertainties in the data, we provide both the agricultural census data and estimates derived from consulting key informants.

Design of the 2018 survey and questionnaire

In 2018, the Farmer's Pride project provided an opportunity to reassess the landrace situation in the Scottish islands. A landrace grower questionnaire (Supplemental Note 3) was developed to update and further our understanding of the diversity of landrace cultivation in the UK and continental Europe (Austria, Hungary and Turkey). The questionnaire was used in face-to-face interviews with current or former landrace growers on the three island archipelagos. Interviews started with an introduction to the Farmers Pride project and the reasons for the interview. During the interview, background information was requested on the farmer's household and land use (Sections A, B and F) and participation in agri-environmental schemes (Section D). Specific information on landraces was requested in the following Sections: Section B (landraces grown and the reasons for growing them or stopping this); Section C (the interviewee's intentions about future landrace cultivation); Section E (the interviewee's response to a hypothetical support scheme for growing landraces); Section G (the extent of interviewee's agreement/disagreement with various statements about the situation of landrace conservation and support measures).

Crofters and farmers cultivating landraces were interviewed in July and August 2018. Interviewees were each questioned face-to-face, and answers were recorded in a Microsoft Excel table directly by the interviewer.

Crofter and farmer selection in 2018

In each of the island groups, key informants were used to identify an initial target group of farmers known to have recently grown landraces. Additional farmers were

added to the survey based on the recommendations of interviewees. A short public awareness article was published in *The Crofter* (Maxted *et al*, 2018) and local radio interviews were undertaken in Orkney and Shetland to increase visibility among the target community. By the end of the 2-month surveying period, a total of 42 farmers and crofters had been interviewed.

Travelling was time-consuming in all the archipelagos in the study and it was not possible to reach the remoter islands. In the Outer Hebrides, the study focused on growers in the Uists. Due to the scale of cultivation on the Uists, data were also collected from local Scottish Government offices and local observers on North Uist who had been consulted during the first field survey in 2006.

Results

Landrace diversity, area grown and grower numbers

Except for bere on Shetland, the 2018 landrace survey suggested relative stability in crop diversity (the number of landrace species cultivated) and also in their uses compared with the 2003 study (Table 1).

On Shetland from 2004 to 2006, an attempt was made to revive the growing of bere and small oat by Shetland Organic Producers Group. Although this resulted in a brief increase in growers (Table 2) to about ten of bere and five of small oat (3.3ha of bere and 0.7ha of small oat in 2004), several growers only planted extremely small areas and most failed to maintain their own supply of seed. Crucially, no new markets were developed for either crop. We estimate that from at least 2018, there has only been one grower of bere and just a few growers of small oat on Shetland.

Between 2003 and 2006 on Orkney, the area of bere grown by the AI and BHT supply chains was about 9–12ha and most of the growers included in the 2003 desktop survey were associated with these supply chains (Table 2). Subsequently, BHT successfully expanded the market for beremeal, exporting it to other parts of Scotland, and there was a considerable increase in interest in bere for both brewing and distilling following the release in 2012 of single malt whiskies made with bere (Martin and Wishart, 2015). As a result, the combined area of bere grown by the AI and BHT supply chains increased to about 51ha in 2018 and 69ha in 2020 when about 200t of bere grain were supplied for producing specialist whiskies.

For the Outer Hebrides, Scottish Government census data indicate a very slight decline in the area of oats and mixed grains grown between 2005 and 2018 (Table 2) and a more marked decline in the number of holdings growing these crops. It is possible that this reflects a consolidation of growing on the larger holdings. Census data for the Outer Hebrides only include barley from 2002 to 2008 and over this period the average area was 28ha on eight holdings; it is likely that most of this was bere. A later study (Scholten *et al*, 2009) estimated about 12 growers of sole crop bere on the Uists in 2008.

Landrace cultivation by growers in the 2018 survey

In 2018, amongst the 42 landrace growers interviewed, 29 were still growing at least one landrace (Table 3). The number of interviewees growing landraces in each archipelago (Table 3) broadly reflected the estimated grower numbers (Table 2) and was highest on the Uists (15), followed by Orkney (9) and Shetland (5). Amongst the growers of cereal landraces, most on the Uists (12 out of 14) were growing two or three species in mixtures while in Shetland there were only two growers of small oat and in Orkney, there were two growers of small oat and five of bere. Average arable land use per croft or farm varied between the island archipelagos (Table 3), with Orkney growers having the highest proportion of their land in arable cultivation (70% arable, compared with 30% pasture) and the highest average area of arable land per farm (49.7ha). Growers in the Uists had the second-highest average area of arable land per farm (13.5ha), but this was only 8% of their land, with 92% being pasture. Shetland had the lowest average area of arable land per farm (1.2ha). These figures broadly reflect more comprehensive agricultural census data for these areas (Supplemental Note 2).

Reasons for growing, or ceasing to grow, landraces

Growers were asked their reasons for growing landraces and given the option of multiple responses (Table 4). The most consistent replies came from Uist growers who unanimously listed the adaptation of the landraces to local soil conditions as the main reason for growing them (15 out of 15), followed by tradition (12) and low management requirements (9), with market demand figuring quite low (3). Tradition was also the most common reason given by respondents in Shetland (5 out of 5) and Orkney (5 out of 9).

The number of interviewees who had ceased growing landraces was largest on Orkney (7 out of 16) and the reasons mentioned included: lodging, weak straw, inability to apply fertilizer, lack of a market for bere, problems during combine harvesting, disease, loss of traditional knowledge, unfavourable weather and a high workload. On Shetland, 3 out of 8 respondents had stopped, and the reasons provided were: damage from sparrows, low yield, difficult to grow and problems with machinery. On the Outer Hebrides, 3 out of 18 had stopped and mentioned damage from geese, machinery problems and costs and adverse weather as the main reasons.

Participation in financial support schemes

Although several growers, especially on the Uists, preferred not to say what percentage of annual household income was derived from their croft/farm,

Table 1. Landrace species and their uses documented between 2003 and 2020 in the different Scottish archipelagos.

Archipelago	Landrace	2003 (Scholten *et al*, 2011)	2018 (Source: Farmer's Pride survey)	2019-2020 (Sources: Agronomy Institute; CDP! Project[1])
Shetland	Cabbage	Winter fodder	Winter fodder	Winter fodder
	Bere	Potential food and drink	None grown	Maintaining a local seed supply
	Small oat	Animal feed; straw for basketry, chairs and thatch	Animal feed; straw for basketry, chairs and thatch	Animal feed; straw for basketry, chairs and thatch
Orkney	Bere	Food and drink	Food, drink and animal feed	Food, drink and animal feed
	Small oat	Heritage crafts	Heritage crafts	Heritage crafts
Uists	Small oat mixtures with Hebridean rye and /or bere	Winter animal feed	Winter animal feed	Winter animal feed; exploring use of bere and rye for whisky

[1]CDP! Project (Crofters' Diversity Pays!, 2020)

Table 2. Approximate area of landraces grown and estimated grower numbers in the Scottish archipelagos.

Archipelago	Landrace	2002–2005	2018 Survey	2018–2020
Shetland[1]	Shetland cabbage	Data not available	Data not available	Data not available
	Bere	4ha; 10 growers	None grown	< 0.1ha; 1 grower
	Small oat	1–2ha; 5 growers	3ha; 2–5 growers	1–2 ha; 2–5 growers
Orkney[1]	Bere	9–12ha; 3–7 growers	59ha; 5–8 growers	73ha; 5–8 growers
	Small oat	1ha; 2 growers	< 1ha; 2 growers	< 1ha; 2 growers
Outer Hebrides[2]	Small oat mixtures with Hebridean rye and/or bere	i) 275–317ha of oats and mixed grains; 215–232 holdings; (Scottish Executive, 2005) ii) 300–600ha; 200–400 growers estimated by Scholten *et al* (2008)	i) 269 ha of oats and mixed grains; 147 holdings; (Scottish Government, 2018) ii) Key informants estimated the areas to be similar to those given by Scholten *et al* (2008)	i) 260ha of oats and mixed grains; 139 holdings; (Scottish Government, 2020) ii) Key informants estimated the areas to be similar to those given by Scholten *et al* (2008)

[1] The areas and numbers of growers of landraces in Orkney and Shetland are based upon our own knowledge and information provided by key informants (for example, Shetland Organic Producers Group, the Agronomy Institute (AI) at Orkney College UHI and Birsay Heritage Trust)
[2] Two estimates are provided for the areas and numbers of holdings of small oat and small oat mixtures in the Outer Hebrides: i) derived from the areas for oats and mixed grains given in Scottish Government census data and ii) derived from local key informants.

Table 3. Summary of respondent characteristics in the 2018 survey by Scottish Isle archipelago.

Archipelago	Number of interviewees; number growing landraces in brackets	Range of arable area (ha); averages in brackets	Number of landrace growers in agri-environment schemes	Number of landrace growers with more than 50% of income from croft/farm; number of responses in brackets
Shetland	8 (5)	0–3 (1.2)	4	1 (5)
Orkney	16 (9)	1–324 (49.7)	5	4 (8)
Uists	18 (15)	1–30 (13.5)	9	3 (4)

Table 4. Summary, by archipelago, of reasons for farmers growing landraces.

Archipelago	Number of respondents	Reasons for growing landraces (number of respondents who gave each answer in brackets)
Shetland	5	Tradition (5); not available elsewhere (2); market demand (3); adaptation to soils (3); disease resistance (2); quality of products (1); low management requirements (1)
Orkney	9	Low management requirements (5); tradition (5); market demand (3); adaptation to soils (3); disease resistance (2); quality of products (2)
Uists	15	Adaptation to soils (15); tradition (12); low management requirements (9); market demand (3); good feed for cows (2); yield (2); tolerance to extreme temperatures (1); quality of product (1).

this appeared to be greater on Orkney and the Uists than on Shetland with 50%, 75% and 20% of those replying to this question on Orkney, the Uists and Shetland, respectively, reporting that it contributed 50% or more of household income (Table 3). Half of those interviewed mentioned that they were currently, or had in recent years, taken part in an agri-environment scheme (Table 3). Amongst these, 67% were currently taking part in one, and 33% had done so previously. Accurate collection of data on scheme participation was not possible as not all growers had kept or had access to the relevant paperwork, and not all could recall which schemes they had taken part in or when. Amongst those who could recall, the following schemes were mentioned: the Agri-Environment Climate Scheme (9 growers), the Scottish Rural Development Programme (SRDP; 4), the Basic Payment Scheme (4), the Environmentally Sensitive Area Scheme (3), the Habitat Scheme (1), the Organic Maintenance Scheme (1), the Rural Stewardship Scheme (1).

Hypothetical bere barley support measures

None of the growers interviewed were currently involved in any specific support programme for bere. Nevertheless, 48% said that they would be interested in a support scheme which rewarded growers for each hectare of bere grown as a pure stand with the intention of saving seed each year. When asked how much monetary support they would require for this, responses ranged from £110 to £1,000 per ha with a mean of £338 per ha, which compares with previous support schemes such as SRDP payments which had a maximum of £500 per ha and the agri-environment scheme for machair soils of £230 per ha.

Planned croft or farm future

Growers were asked what they intended to do with the croft or farm once they stopped working it. The majority (61% of those asked) planned to hand them on to younger family members, while just over a quarter (27%) planned to sell them outside of the family. Those who were tenants (7%) would return the crofts to the owner upon retirement and the remaining 5% were not sure what they would do with the croft. On both Orkney and Shetland, the majority of growers planned to sell them outside the family. The Uists had the highest number of younger crofters and all of those interviewed intended the croft to continue to be worked upon retirement, with the majority planning to pass it on to a relative.

Discussion

Landrace maintenance in Orkney

Since 2002, there has been a very significant increase in the area of bere grown in Orkney from about 10 to 73ha, although this has not been matched by a large increase in growers (Table 2). This is explained by the role of BHT and the AI in managing and expanding supply chains for bere in which growing tends to be carried out by just a few growers and on leased land. To put the area of bere grown in Orkney into perspective, over the 20^{th} century this declined from about 1,600ha in 1912 (Board of Agriculture for Scotland, 1913) to about 5ha at the end of the century. Despite the recent increase in the area of bere, there are essentially only two maintainers of bere seed – the AI and BHT – and these organizations provide seed to their own growers.

The focus in Orkney on grain production for higher value off-farm use is facilitated by the larger arable area on Orkney farms (see Table 3 and Supplemental Table 2), a high level of mechanization and the availability of several batch grain dryers. In spite of the success of the AI and BHT supply chains, the 2018 survey showed that several farmers had stopped growing landraces (mostly bere) because of their agronomic shortcomings. These would be very obvious to Orkney farmers because of the large area (over 4,000ha) of modern 2-row barley grown on the island; this is higher yielding and less susceptible to lodging than bere. Nevertheless, other factors like tradition and bere's low management requirement are also important to some growers, as found by both the 2018 survey and an earlier study (Mahon *et al*, 2016). Here, management includes aspects like the use of inputs (fertilizer, herbicide, growth regulator and fungicide) and the quality of land required by the crop. Although not mentioned during the survey, straw is an important byproduct of bere grown for grain and is readily sold if farmers do not require it themselves. Since bere is usually harvested before the weather deteriorates too badly, the quality of its straw is normally very good and is used for feeding as well as bedding.

On Orkney, the main driver for continued growing of bere has been the demand for grain processed

locally into beremeal or sent to mainland Scotland for malting. These are then used to produce niche market, high-provenance food and drink products for both the local and export market and the tourism sector, including traditional bere bannocks (a type of flat bread), biscuits and bread made from beremeal and beers, whiskies and a craft vinegar made from bere malt. Long-term collaborations between the bere supply chains and distilleries have been important in building up a consistent market for bere, and several growers in the 2018 survey commented that they would be unlikely to continue cultivating bere without an assured buyer. Apart from being the only mill producing beremeal in Scotland, Barony Mill is also a visitor attraction which promotes bere, beremeal and other bere products. Although the conservation status of Orkney bere appears strong at present, it is dependent on demand from a relatively small number of end-users and would benefit from further market diversification and on-farm use. Increased interest in using bere for both brewing and distilling has resulted in small areas of the crop being grown for malting in parts of mainland Scotland and the north of England since about 2020. The success of bere has also encouraged farmers, craft maltsters and distilleries to start experimenting with other Scottish barley landraces like Scotch Common and Scotch Annat.

In contrast to bere, the growing of small oat in Orkney has virtually ceased. Its main potential value would likely be as a feed crop on Orkney's coastal sandy land where it was once commonly grown because of its tolerance to manganese deficiency. Its straw might also be of value for straw products and was once used for making traditional Orkney straw-back chairs. A major constraint on the wider growing of small oat in Orkney is a lack of seed. There is also a reluctance to grow it because of its ability to contaminate other crops and fields through volunteer plants or seed remaining in machinery.

Landrace maintenance in Shetland

The study showed that the situation of cereal landraces is most precarious in Shetland, both in terms of the number of growers and the areas of crops grown and the most cited constraint there was the lack of market demand for landrace products. By 2020 it is thought that there was only one grower of bere on Shetland who grew it on a very small scale in a net tunnel to protect it from damage by sparrows and about three growers of small oat who were growing this for straw. The difficulties of commercializing bere in Shetland have included a scarcity of machinery and equipment for growing the crop and drying grain on a larger scale, a lack of processing equipment for local milling or malting and high transportation costs, which make it expensive to ship elsewhere for processing.

Potentially, in Shetland, the growing of small oat for straw for basketry, straw-backed chair or thatching could be expanded, but these markets are very small. Additionally, farmers growing it for straw cannot use combines for harvesting as these crush the straw and they must either harvest using scythes or old reaper binders, which often have maintenance issues.

Landrace maintenance in the Uists

In the Uists, our study showed that the cereal landrace mixture is still a very valuable component of the machair crofting system and is economically important as a well-adapted, low-input crop for winter feed which allows growers to avoid the expense of importing feed (estimated to be £32–38 per tonne in 2018 (Jones, 2018)) and its associated carbon footprint. The continued use of seaweed and animal manure as a fertilizer for the mixture by some growers also contributes to its sustainability. A crucial trait underpinning the value of the mixture is the tolerance of all its component species to high-pH soils deficient in manganese and copper. This was reflected by replies in the 2018 survey where all respondents included the ability of the landrace mixture to grow on poor soil as a reason for growing the crop.

For continuity of cultivation, it is vital to attract a new generation of stakeholders to adopt and use landraces (Raggi *et al*, 2021). At the initial assessment in 2003 most of the Uist crofters were in their fifties or sixties, but during the 2018 field work it was apparent that there are now many younger crofters in North Uist involved in growing landraces and these showed a keen awareness of the uniqueness of these crops and, specifically, of the potential of bere. One example of this is the interest from a new distillery in the Baleshare crofting community, in sourcing both Hebridean rye (Blackley *et al*, 2022) and bere from local growers.

Local seed production is crucial for growing the landrace mixture and while some growers obtain seed from others, many maintain their own seed (Scholten *et al*, 2009). The composition of species and proportion of each is dynamic and varies with the grower and how weather and field conditions affect the crop. A major threat to the island seed system is damage from geese and deer. Data for greylag (*Anser anser* L.) and barnacle (*Branta leucopsis* Bechstein) geese numbers (Mitchell and Hall, 2020; WWT, 2022) indicate increases for the two species on the Uists from about 7,400 in 2003 to around 11,800 in 2018. At the time of the 2018 survey, there were at least four areas, one on North Uist and three on South Uist, where seed production had ceased because of the geese threat. This potentially threatens local landrace maintenance. Almost two out of three crofters in the survey mentioned geese as the main constraint on growing landraces, and this was included as a reason for stopping, or for not resuming, growing landraces. While some Government funding has been available for the management of geese numbers, local crofting stakeholders consider this inadequate for the scale of the problem (Scottish Crofting Federation, 2022). It has also been reported that some growers are

using farmer contacts in other parts of Scotland to grow the landrace mix to provide seed for them.

Tradition

Across all archipelagos, tradition was an important factor cited by many growers (22 out of 29) driving their current use of landraces. On Orkney, this may be due to the rise in demand for traditional products made from bere, but is not the case on the other archipelagos, indicating that growers enjoy the tradition for the connection that growing the crops provides with their heritage. Many commented to this effect during the survey and it was also identified as an important consideration in an earlier study (Mahon *et al*, 2016). Another possible explanation is that tradition is linked to the less intensive approach to agriculture which crofters and small farmers often adopt, including aspects like fewer inputs, small-scale production on more marginal land and use of less costly or technically advanced machinery and equipment. Despite the importance of tradition, crofters and farmers have not restricted themselves to traditional methods of cultivating them. Thus, over the last 40 years on the Uists, most crofts and farms have transitioned from harvesting the landrace mix with reaper binders and putting sheaves into stacks for later threshing, to using combine harvesters and, most recently, to harvesting the crop earlier and preserving it in wrapped bales. The latter, however, reduces the biodiversity value of the crop as it is harvested before wildflowers within it can set seed. As well as tradition, adaptation to local soils and low management requirements were also important reasons for continuing to grow landrace crops on all archipelagos. While all Uist crofters gave this reason, many also commented that if they could grow modern higher-yielding varieties, they would.

Grower satisfaction with current support measures

Half of the growers interviewed had taken part either currently or in the past in agri-environmental schemes (Table 3), of which seven different schemes were mentioned. This diverse range of grower support indicates an awareness that growers need support but also suggests that some rationalization could simplify the system for the growers and aid implementation. A major criticism of past schemes was that some, which were designed to protect wildlife (primarily birds), did not allow early harvesting of cereals. Consequently, harvesting was later than desirable and often resulted in crop lodging because of unfavourable weather. Another major complaint was that migrating geese arrived at harvest time and ate or damaged the crop before it could be harvested, compounding the problem of the specified harvesting date and adding to the uncertainty of a successful harvest. The consensus amongst crofters was that if there was more flexibility, they would be more likely to join agri-environment schemes. Most of those interviewed considered that resolving the problem of the geese outweighed the importance of financial support. Another issue raised was the lack of a market for landrace products, suggesting that stimulating this market would increase landrace conservation. Therefore, the solution is not simple and possibly a mix of financial support and appropriate policy actions would best support landrace maintenance long-term.

Recently a new post-Brexit UK Agriculture Bill has received royal assent. Part of the bill includes a clause allowing the Secretary of State to: “give financial assistance for or in connection with any one or more of the following purposes . . . (i) conserving plants grown or used in carrying on an agricultural, horticultural or forestry activity, their wild relatives or genetic resources relating to any such plant” (UK Parliament, 2020). Through the implementation of this clause, the Secretary of State can provide long-term funding for *in situ*/on-farm conservation of UK crop wild relatives and landrace genetic diversity conservation which could significantly support landrace maintenance and help underpin future UK food security. The practical application of this new law in England has yet to be formulated but such consideration as the flexibility of harvest time could be accommodated to ensure a desirable outcome for landrace maintenance. Within the UK, agriculture is a devolved policy area, however, and this clause has not yet been included in Scottish law.

Heightened profile of Scottish cereal landraces since 2002

The development and marketing of a diverse range of new commercial products from bere have helped considerably to raise its profile and that of other Scottish cereal landraces and have demonstrated the potential for realizing significant economic benefits from their conservation. Notable amongst bere products have been several single malt whiskies. The use of bere in such a high-value, iconic Scottish product has introduced a new clientele and audience to both the crop and discussions about the importance of landraces through the marketing and social media activities of distilleries with a global reach. This demonstrates the potential for commercialization to assist the promotion of landraces as well as add value to them (Raggi *et al*, 2021).

Commercialization of bere has also helped lever funds for scientific research on Scottish landraces which in turn has stimulated further interest in these crops. For example, research on bere has encompassed a diverse range of topics including: the nutritional properties of its grain and beremeal (Chappell *et al*, 2017; Theobald *et al*, 2006); agronomy (Martin *et al*, 2010; Brown *et al*, 2020); sustainability traits (Schmidt *et al*, 2019; Cope *et al*, 2021); and the origins of bere (Drosou *et al*, 2022; Wallace *et al*, 2019). Much of this research has been possible because of the collection of bere accessions that has been built up at the James Hutton Institute (JHI), and progress with genotyping the collection will allow genetic diversity to be taken into account as *in*

situ conservation strategies are developed. A spin-off of this research has been the multiplication of bere seed and the distribution of Scottish island landraces to the mainland by the JHI working with the Seed Sovereignty Programme in 2020 and 2021.

The need for an *in situ* on-farm conservation strategy

Given the threats to continued *in situ* growing of cereal landraces in the Scottish islands and the relatively good knowledge about their cultivation, utilization and genetic variation, it is an appropriate time to develop an *in situ* on-farm conservation strategy for them. Ideally, this would identify desirable conservation targets in terms of numbers of growers and seed maintainers and the area of crops required for this on each archipelago. It should also include measures for conserving both their genetic diversity and the underpinning traditional knowledge about these crops and support ways of passing this on to new, younger growers. Results from recent and ongoing genotyping and phenotyping (Schmidt *et al*, 2019; Scholten, 2012; Hagenblad *et al*, 2016) will be important for ensuring efficient conservation of genetic variation and providing these crops with the greatest possibility of being able to adapt to future changes in growing conditions. The strategy could be included in Scotland's evolving post-Brexit agricultural policy.

Conclusions

Implications for future *in situ* conservation of Scottish landraces

This study has shown that both the cereal landrace mix grown in the Outer Hebrides and bere grown in Orkney continue to contribute value to their respective farming communities and, for bere, there are considerable added value benefits to others in the food and drink value chains. While the conservation status of these crops in these locations seems promising, and for bere in Orkney, is much better than it was in 2003, there are still causes for concern. In particular, seed production of the landrace mix is threatened by geese in the Outer Hebrides and, with most Orkney bere being grown for distilling, it is vulnerable to changes in market trends. Also, there are only two organizations maintaining bere seed in Orkney and they both grow very similar lines which probably do not include the range of genetic variation found amongst Orkney bere within germplasm collections (Schmidt *et al*, 2019). Therefore, a review of the regeneration strategy to ensure a broader coverage of the diversity that exists would be beneficial.

There are now very few growers of small oat and, particularly, bere in Shetland and of small oat in Orkney and these crops are under serious threat of being abandoned and lost in these locations. It is important that accessions of this material continue to be incorporated into *ex situ* collections at the JHI and SASA's Scottish Landrace Protection Scheme (Green *et al*, 2009) to provide a foundation for any potential future rejuvenation schemes. The situation demonstrates the difficulty of *in situ* conservation of crops when they do not generate value (not necessarily financial) for growers. In both Orkney and Shetland, there is potential for wider use of both small oat and bere, alone or in mixtures, for animal feed on coastal, sandy soils as they are used in the Outer Hebrides. A key requirement for this, however, would be the availability of seed and this could become a commercialization opportunity for a grower or group of growers.

The food and drink value chains developed for Orkney bere might be replicated in the Outer Hebrides and Shetland to promote greater growing of bere and Hebridean rye but this would require suitable processing facilities, collaboration between growers and commercial end-users and probably support to growers to acquire appropriate machinery. These value chains also provide successful examples of landrace maintenance of much wider, even global, relevance.

Within the UK, the development, post-Brexit, of new devolved agricultural policies provides the Scottish Government with an important opportunity to develop an *in situ* on-farm conservation strategy for cereal landraces on the Scottish islands.

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Author contributions

OS carried out the farmer survey with assistance from the other authors. All authors contributed to writing the manuscript, which was finalized by PM.

Conflict of interest statement

The authors declare that they have no financial or competing interests.

Supplemental data

- Supplemental Note 1. Figure 1
- Supplemental Note 2. Crofting
- Supplemental Table 1. Linguistic diversity in Scottish cereal landraces
- Supplemental Table 2. Main differences and similarities in cropping land use and crofting between the archipelagos in this study
- Supplemental Note 3. Survey questionnaire for landraces on Northern and Western Scottish islands 2018

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