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**Changes in the Vegetation of Ross Links
Since 1955 and their relation to management**

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EXECUTIVE SUMMARY

1. Three vegetation maps of a large dune system in Northumberland are compared to quantify and interpret vegetation change between 1955 and 1988. The different vegetation classifications of each map required harmonisation to produce a single set of vegetation types for use in comparison. Final vegetation types are related to the National Vegetation Classification.

2. Vegetation change at Ross Links is examined using transition matrices. These reveal slight change in the period covering the early 1950s to 1964, followed by massive change in the period up to the final map of 1986.

3. One dominant trend is the stabilisation of more mobile dunes by linear succession (relay floristics). Between 1964 and 1986 a very large area of semi-fixed dune was converted to fixed dune grassland.

4. The major force of change between 1964 and 1986 was agricultural improvement associated with intensive livestock husbandry. Winter feeding of large numbers of cattle and sheep has resulted in a massive importation of nutrients to the Ross Links dune system and the effects are readily traced in vegetation changes, apart from eutrophication of slacks. Large extents of semi-improved and improved grassland are created, mainly from losses of fixed dune grassland and bracken.

5. Recommendations are made on detecting the early stages of similar vegetation change at other sites, and on management prescriptions to assist site recovery from intensive livestock husbandry.

6. The usefulness of repeated vegetation mapping is discussed as a technique for environmental audit.

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The onerous task of counting squares to quantify transitions was completed by Alastair Dargie. North-east Region of English Nature kindly supplied maps, aerial photographs and reports. Overall project supervision was controlled by Dr G.P. Radley as Nominated Officer, providing much useful discussion. Sincere thanks are due to all for their support in this project.

1. Introduction

1.1 Background

Ross Links is a major component of the Lindisfarne, Ross Links and Budle Bay grade 1 NCR site (Ratcliffe 1977). It is located on the north Northumberland coast with Budle Bay to the south and the extensive sand and mud flats of Fenham Flats and Holy Island Sands to the north, all to the south of Lindisfarne (Figure 1). It is a large and still partially prograding sand dune system which was noted for a clear successional sequence from foredune through to dune heath, and for its species-rich dune slack vegetation. It includes a separate dune island named Old Law, lying to the north of mainland Ross Links. The area has been the subject of three detailed botanical surveys over a period of approximately 35 years: in the early 1950's (Robertson 1955), in 1972 (Dargie 1973), and in 1988 (Woolven & Radley 1989). Each of these surveys includes a vegetation map, thus providing information on the character and extent of vegetation types for the three map dates and the opportunity to record and interpret change.

Over this period of *c.* 35 years the management of Ross Links has changed drastically. At the time of the first survey the site was heavily grazed by rabbits, with only low-intensity stock grazing by sheep and cattle. During the 1960's and 1970's much of the dune area was divided into fenced enclosures. Most of the enclosed land distant from the main beach was converted to agriculturally-improved pasture, whilst the remaining enclosures were used for wintering large numbers of cattle and sheep (with great quantities of winter feed brought on to the site to feed stock). The effects of this form of land use were still in their early stages when the site was surveyed in 1972, but by the time of the 1988 survey it was clear that the degree of change was both widespread and deleterious in terms of the nature conservation interest.

The Nature Conservancy Council, and now North-East Region of English Nature, have long been seeking a management agreement with the landowner to contain and, if possible, reverse the damage caused by this form of management. A report documenting vegetation change and putting forward a strategy for recovery would greatly assist with the formulation of an agreed management policy for the site. It would also help regional staff to evaluate proposals introducing or continuing similar management at other sites, and to frame other Section 15 agreements under the Wildlife and Countryside Act 1981.

The existence of detailed baseline data covering a period in excess of 35 years means that this project provides an almost unique opportunity to bring all surveys into line with the National Vegetation Classification (NVC) (Rodwell 1991a, 1991b, in prep.) and then to test repeated vegetation mapping as a means of measuring environmental change and damage. This is the main focus of the study, with the results to be assessed as part of strategies for scientific audit in English Nature.

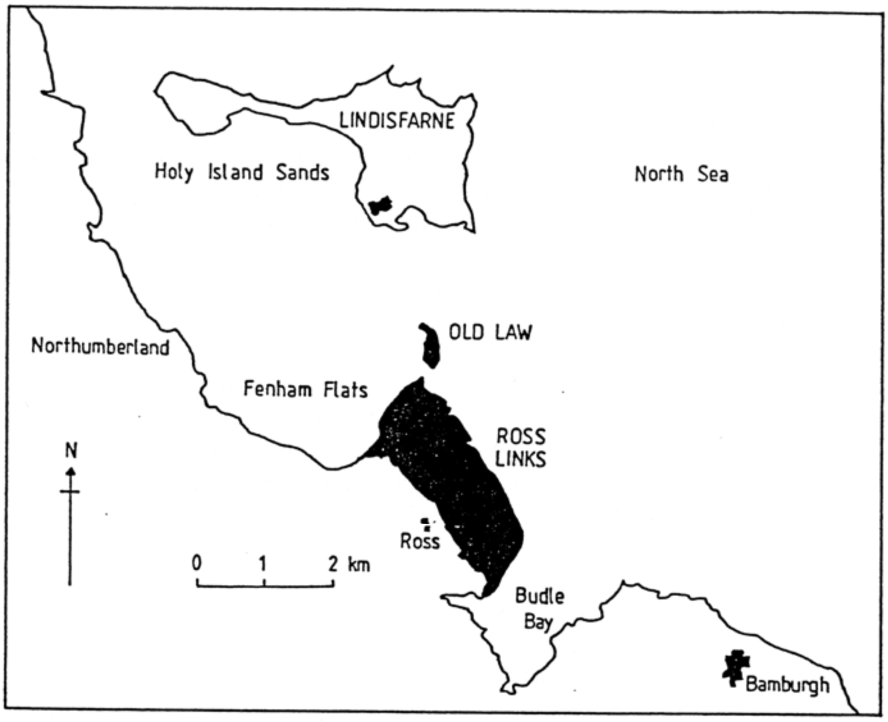

Figure 1 The location of Ross Links and Old Law in relation to the north Northumberland coast.

1.2 Project objectives

There are five specific objectives:

1. To measure the scale and nature of the changes that occurred in the vegetation of Ross Links between 1955 and 1988;
2. To relate these changes to the management of Ross Links over the same period, with particular reference to the effects of livestock husbandry;
3. To recommend ways of detecting the early stages of similar vegetation changes at other sites;
4. To recommend a practical management prescription to assist the recovery of this site and others similarly affected by livestock husbandry.
5. To provide a brief assessment of the usefulness of repeated vegetation mapping as a technique for environmental audit.

2. Vegetation change at Ross Links between 1955 and 1988

2.1 Methods

There were four main steps involved in determining vegetation change: harmonisation of classifications, redrawing and rescaling of vegetation maps, overlaying of maps and measurement of change, and production/interpretation of transition matrices. These are detailed below.

1. The three survey classifications (termed here 'Robertson', 'Dargie' and 'Woolven & Radley') were first harmonised by examining quadrat records and written descriptions, relating vegetation types to NVC units published in the final draft chapter for sand dune communities (and other NVC chapters). This was necessary even for the Woolven & Radley (1989) study based on NVC methods because that was based on a preliminary draft of the NVC sand dune chapter which was much changed and re-issued in late 1989. Harmonisation was achieved by a combination of experienced judgement (subjective examination of quadrat data), a TWINSPAN classification analysis (Hill 1979) combining quadrat data from Dargie (1973) and Woolven & Radley (1989), plus results produced by the MATCH program (Malloch 1990) for selected individual quadrats and quadrat sets. Data collected by Robertson (1955) used a different quadrat size and sampling basis, with mapped vegetation types not clearly related to types described in terms of quadrat data. It was thus not possible to integrate these data with later surveys and harmonisation here was the most subjective. Results were aggregated into a final summary table containing all classifications.

2. A common map scale of 1:5,000 was selected for comparison of vegetation maps. This was the scale adopted for the 1:5,000 vegetation map of Dargie (1973), based on photogrammetric mapping (using a Kern PG2L plotter) and field distances obtained by theodolite survey. The vegetation map of Robertson (1955) was in watercolour with pencil boundaries, without grid boundaries and with few identifiable fixed points for use in scaling. It was reported as derived from aerial photography but no detail is given of the photography (e.g. source, scale, date). For this project it was redrawn in permanent ink and enlarged to approximately 1:5,000 scale, though fit with the map of Dargie was difficult due to few fixed ground control points in common between maps. The island of Old Law (off the northeast corner of Ross Links) was not mapped by Robertson and a small dune area in the southwest corner of Ross Links was also omitted. The vegetation map of Woolven & Radley (1989) was produced at 1:10,000 and required enlarging to 1:5,000 scale. It included grid lines and many fixed ground control points to enable a fit with the 1:5,000 map of Dargie (1973). There were no missing areas of unmapped dune vegetation.

3. Each vegetation map was redrawn by hand as a set of A3-sized drawings on drafting film, incorporating the universal vegetation codes established by harmonising the three surveys. A grid of 1 mm squares was prepared on an A3-sized clear acetate sheet. The Robertson/Dargie map comparison was made by laying the Dargie map sector over the equivalent Robertson map sector, taking great care to achieve the best-possible fit using fixed ground control points (and not vegetation boundaries which could, of course, change over time). The 1 mm grid of squares was then fixed over both overlain maps. Each Robertson map polygon was then examined in terms of underlying Dargie map polygons, counting the number of 1 mm squares which remained the same or which changed to another vegetation type on the Dargie map. Particular care was taken of partial 1 mm squares on the boundary of a polygon, estimating these by eye in terms of complete 1 mm square equivalents. The 1 mm square count for each transition was then recorded in code by transition type (e.g. 6>6 53 = 53 square millimetres of type 6 on Robertson map remained as type 6 on Dargie map; 4>6 37 = 37 square millimetres of type 4 on Robertson map changed to type 6 on Dargie map). When the count for a Robertson map polygon was complete it was shaded in pencil to avoid double-counting at a later stage. When all of the overlain maps had been counted the transition data were tallied for each transition type. The same procedure was repeated for the Dargie/Woolven & Radley comparison, with the later survey as the top map. The Woolven & Radley map included a substantial number of mosaic and transitional polygons. Square totals for mosaics were divided between the vegetation types in the mosaic. Transitional polygon totals were retained unaltered, since such vegetational transition data could be of ecological interest.

4. Transition tallies were converted into hectares (by dividing 1 mm square totals by 400) and results assembled into two summary transition matrices covering the Robertson/Dargie and Dargie/Woolven & Radley comparisons. These were interpreted in terms of ecological or other change.

It is important to stress that square counting in step 3 was very time-consuming and required great concentration and care, despite being a very mundane procedure. Funds were not available to digitize each map and thus use a Geographical Information System (GIS) to generate transition details.

2.2 Results of harmonisation

The results of harmonisation are given in Table 1. The global code is used as a short annotation for rows/columns in transition matrices. The link with NVC types can only be made with certainty at the community level or, worse, combinations of NVC communities. There are several reasons for this disappointing result:

1. Several community types are only represented by few quadrats, sometimes only one quadrat, in the reports of Dargie (1973) and Woolven & Radley (1989). Accurate frequency data for species are thus not possible, preventing an accurate comparison with NVC diagnostic data via the MATCH program. Subjective, experienced judgement is probably the best guide in such circumstances. In one important case a single quadrat (18) was classified by Woolven & Radley as M23a *Juncus acutiflorus - Galium palustre* rush pasture, but was seen as aberrant in several respects (no *G. palustre*, high *Deschampsia cespitosa* cover, several SD17 species present). A site visit in December 1991 confirmed the *Juncus* as a large specimen of *J. articulatus*, with most stands representing rather species-poor and eutrophic forms of SD17 *Potentilla anserina - Carex nigra* slack. All mapped M23a was therefore converted to SD17 (type 9).

2. Mapping units in the Robertson (1955) survey are not clearly related to vegetation types which are thoroughly described in the thesis text. There are eight mapping units (bare sand, dune ridge vegetation, blow out vegetation, *Juncetum articulati*, pasture vegetation, *Nardetum*, *Pteridietum*, dune heath), in contrast to twentyfour vegetation types in the thesis text (NVC relations in brackets): *Ammophiletum* of mobile dunes (SD6d), stabilised dunes Type A (SD7d), stabilised dunes Type B (SD7a), fixed dunes (SD7b/SD12 transition), Long Bog marsh vegetation (SD12/SD17 transition?), *Juncetum articulati*(SD17d/MG11 transition), wet clay pasture (MG11), *Deschampsietum cespitosae*(MG9), *Salicetum repentis* (SD12/SD14 transition), Seral stage 1 (SD13?), Seral stage 2 (SD14a/c), *Salico - Ericetum tetralix* (M16), *Salico - Caricetum nigrae* (SD17d), meadowland (U4), dune pasture type A (SD12), dune pasture type B (SD12), sedge and grass heath (SD10?), grass heath (SD12), dune heath type A (H11a), dune heath type B (H11a), dune heath type C (H11a/M16 transition), *Juncetum articulati* of Glacial Sand Area (U4/U5 transition), *Nardetum* (U5), *Molinietum* (M25). It is unfortunate that the latter set of units was not mapped because affinities with NVC types are mainly clear, being based on detailed frequency information (for random 0.5 m quadrats).

3. The seven vegetation mapping units (apart from *Pteridietum*) of Robertson (1955) are aggregates of the twentyfour types described in the thesis and therefore each probably spans more than one NVC category. In particular, there is no mapped separation between calcareous and acidic pasture, nor between dry and wet heath. Areas of rank dune grassland equivalent to NVC type SD9 (*Ammophila arenaria - Arrhenatherum elatius* dune grassland) are not recognised at all, though *A. elatius* is not recorded in any of the species lists of Robertson (1955) and might be a more recent development. Slack types are also too broad to relate closely to NVC types.

4. The survey by Dargie (1973) fails to distinguish between calcareous and acidic dune pasture types, and between dry and wet heath. Slack categories are also too vague to relate closely to NVC types. Areas of rank dune grassland equivalent to NVC type SD9 (*Ammophila arenaria - Arrhenatherum elatius* dune grassland) are not recognised at all, though *A. elatius* is only recorded in one 1972 quadrat and might be rare at that time, in line with its absence from quadrat data in Robertson (1955). Faults in this survey are therefore close to those identified in Robertson (1955) and the lack of important detail in these two maps acts as a major constraint on harmonisation. Comparability between different mapping classifications has to be based on the level of the crudest (most wide-ranging) mapping category type in either system, and fails to use the sub-community detail of the NVC. Harmonisation is thus a compromise, forcing all classifications into a set of rules for cross-correlation which is determined by the crudest types (a 'lowest common denominator' approach). However, it is important to note the finer detail provided by the modern and national-type approach of the NVC, with obvious benefits if future surveys are based on this system.

The results of harmonisation are still of much ecological interest. A broad linear ecological succession (relay floristics) can be recognised in the following sequence (from Table 1): 1 > 2 > 3 > 4 > 5/10 (bare surface > mobile dune > semi-fixed dune > fixed dune > dune heath/bracken). Dune areas under the influence of the water table (8, SD14 *Salix repens - Campylium stellatum* slack; 9, SD17 *Potentilla anserina - Carex nigra* slack, 13 open water) are distinguished, as are vegetation/cover types showing agricultural impacts (6, improved grassland; 11, weedy stock feeding areas; 12, re-seeded/disturbed pasture; 14, shelterbelt). Changes in the balance between these dune types will thus reflect important habitat trends (natural and management-induced), despite being unable to interpret change at the finest level of community detail for all map dates.

Table 1 Harmonisation results relating three different map classification systems to the National Vegetation Classification (NVC). The global code is an abbreviation system used upon redrawn vegetation maps and in transition matrices.

GLOBAL CODE	NVC CODE	DESCRIPTION	ROBERTSON MAP	DARGIE MAP	WOOLVEN & RADLEY MAP
1	-	Bare sand/shingle	Bare sand	BS	BS
2	SD5, SD6	SD5 *Leymus arenarius* mobile dune SD6 *Ammophila arenaria* mobile dune	Dune ridge	4a Open *Ammophila*	SD6, SD7
3	SD7	SD7 *Ammophila arenaria - Festuca rubra* semi-fixed dune community	Dune ridge	4b Closed *Ammophila*	SD6, SD9
4	SD8, SD12	SD8 *Festuca rubra - Galium verum* fixed dune grassland SD12 *Carex arenaria - Festuca ovina - Agrostis capillaris* acidic dune grassland	Pasture type	6 Dune pasture	SD10, SD11
5	H11, M15, M16	H11 *Calluna vulgaris - Carex arenaria* dune heath M15 *Scirpus cespitosus - Erica tetralix* wet heath M16 *Erica tetralix - Sphagnum compactum* wet heath	Dune heath	7 Dune heath	H11, WH
6	MG6, MG7	Improved grassland MG6 *Lolium perenne - Cynosurus cristatus* pasture MG7 *Lolium perenne* leys	-	10 Improved fields	MG6, MG7, AI
7	SD9	SD9 *Ammophila arenaria - Arrhenatherum elatius* dune grassland	-	-	SD10/MG1, SD11/MG1
8	SD14	SD14 *Salix repens - Campylium stellatum* dune slack	Blowout	5a,c,d Slack communities	SD15
9	SD17	SD17 *Potentilla anserina - Carex nigra* dune slack	*Juncetum articulati*	5b Slack communities	SD16, M23a
10	U20	U20 *Pteridium aquilinum - Galium saxatile* bracken	*Pteridietum*	8 *Pteridium*	U20
11	-	Weedy stock feeding areas	-	-	Target notes
12	-	Disturbed (recently re-seeded)	-	Target note	-
13	-	Open water	-	OW	OW
14	-	Shelterbelt	-	Target note	Target note

2.3 Interpretation of evidence for change in Robertson/Dargie maps

The time period covered by the Robertson and Dargie maps is uncertain. The map of Robertson (1955) is based upon boundaries plotted from an aerial photograph, though the date and all other details of the photograph are not stated. An aerial photograph dated May 1947 is reproduced in Robertson (1955) but is probably different from the photograph used for mapping, for two reasons: first, a larger area in the southwest is not on the print compared to that missing from the vegetation map; second, large areas of bare sand on the photograph (close to a target railway) do not agree with areas of bare sand on the vegetation map. It seems likely that the vegetation map relates to an aerial photograph taken in the early 1950's. The map of Dargie (1973) is based upon 1:10,000 aerial photographs taken in 1964. Boundaries were taken from the photographs and very few were amended based on field survey in 1972. The map thus represents the vegetation in 1964. The time difference between vegetation maps is therefore 10-14 years.

The transition matrix for the Robertson/Dargie map comparison is given in Table 2. The cover types of the earlier map (Robertson early 1950s) are represented by columns, with the cover types of the later map (Dargie 1964) as rows. The right hand column contains Dargie 1964 row totals and the bottom row gives Robertson early 1950s column totals. The total area covered is 327.21 and excludes a small sector in the southwest of the Dargie map (not mapped by Robertson) and the island of Old Law (not mapped by Robertson).

Table 2 Transition matrix for vegetation change between the early 1950s and 1964 maps produced by Robertson (1955) and Dargie (1973). Area data in matrix cells in hectares. See Table 1 for definition of vegetation and other cover types.

		ROBERTSON (early 1950s)								
	COVER TYPES	1	2+3	4	5	8	9	10	14	TOTAL 1964
	1	0.60	1.60	1.40	0.05	0.70	0.90	0.80	-	6.05
	2	5.40	0.40	0.20	0.02	0.10	0.04	0.20	-	6.36
	3	8.60	78.70	11.70	1.10	8.20	0.50	5.20	-	114.00
	4	3.40	4.50	33.40	6.83	15.10	17.90	18.90	-	100.13
	5	0.01	0.30	2.40	1.50	0.70	0.50	0.70	-	6.11
DARGIE 1964	6	-	-	0.50	0.01	-	1.70	0.60	-	2.81
	8	1.80	4.70	3.10	0.90	11.40	0.30	1.60	-	23.80
	9	0.20	0.60	2.10	0.20	1.60	5.40	1.30	-	11.40
	10	1.90	3.60	8.90	1.90	1.40	1.30	22.00	-	41.00
	12	0.30	-	7.30	0.09	0.80	0.70	2.10	-	11.29
	13	-	-	0.01	-	-	0.01	0.01	0.03	0.06
	14	-	-	0.70	-	-	0.60	0.60	2.30	4.20
	TOTAL early 1950s	22.21	94.40	71.71	12.59	40.00	29.85	54.01	2.43	327.21

There are six major features of change in cover types on the two maps.

1. Increased dune stability

A fall in bare sand extent (22.2 ha to 6.1 ha) and a rise in mobile and semi-fixed dune (2+3, 94.4 ha to 120.4 ha) both suggest increased dune stability (most 1950s bare sand becoming colonised by mobile and semi-fixed dune by 1964). This result is consistent with normal dune succession and agrees with a marked reduction in extent of bare sand between the 1947 aerial photograph in Robertson (1955) and the 1964 aerial photographs used by Dargie (1973). Very little bare sand (1) remains the same in 1964, though much mobile and semi-fixed dune (2+3, 79.1 ha) is unchanged over this survey period - suggesting that virtually all areas of bare sand were involved in the stabilisation process. Changes to other cover types involving types early 1950s 1 and 2+3 are mainly small in total area and are only sizeable for 1>4 (3.4 ha), 2+3>4 (4.5 ha), 2+3>8 (4.7 ha) and 2+3>10 (3.6 ha). All are consistent with either more advanced succession (to 4, fixed dune grassland), blowout deflation to form dune slacks (8), or invasion by bracken (10).

2. Inadequate mapping of type 4 (fixed dune grassland)

Fixed dune grassland (4) increases substantially from 71.7 ha to 100.1 ha. Transition details suggest this is not largely due to succession from semi-fixed dune (2+3>4, 4.5 ha). Instead, there appears to be a confusion between categories in the two maps. Most serious, 33 ha of 1964 type 4 was mapped as slack (types 8 and 9) by Robertson and probably represents an exaggeration of slack extent at the expense of type 4 fixed dune in the early 1950s. Slack bottoms were easily traced using stereoviewing of the 1964 aerial photography but problems were found in areas of gentle slope transition to fixed grassland and hence there is also some confusion in the 1964 map. The possible slack error total (33 ha) approximates the difference in total slack area between the early 1950s (69.8 ha) and 1964 (35.2 ha). There is possibly a further error in type 4 on the Robertson map, with 11.7 ha mapped as type 3 in 1964, a reversal of the important successional trend noted above unless blown sand falling on to type 4 fixed dune was producing type 3 semi-fixed dune around blowout margins. Bare sand quantities in the early 1950s and 1964 seem too low to suggest that blowouts were sufficiently active, hence it is likely that some type 3 semi-fixed dune in the early 1950s was mapped as type 4 fixed dune. Overall, type 4 fixed dune seems poorly drawn on the early 1950s map and it might have exceeded the 1964 total extent, though there is also probably confusion here too.

3. Improbable reduction in extent of slacks

Discussion under 2 above suggests that a large area of type 4 fixed dune was mistakenly mapped as dune slack (types 8 and 9, 33 ha) by Robertson (1955). This probably explains the apparent fall in slack (8 + 9) extent from 69.8 ha in the early 1950s to 35.2 ha in 1964. In reality slack area might have been almost constant, though blowout change in the northern half of Ross Links might be responsible for a small amount of change.

4. Reduction in extent of heath

The extent of heath (type 5) is more than halved between the early 1950s (12.6 ha) and 1964 (6.1 ha) using map evidence. Very little early 1950s heath is still present as heath in 1964 (1.5 ha). Transition data strongly suggest that one reason for decline is conversion to type 4 fixed dune (5>4, 6.8 ha), possibly the result of an increase in grazing pressure. However, there are many other small transitions involving most cover types and these suggest that small 1964 type 5 polygons did not generally quite lie over the larger early 1950s patches, the result of planimetric error in overlay positioning. This fault is very likely, given the lack of ground control points on the early 1950s map and probable absence of any photographic rectification. It will affect most strongly those vegetation types distributed as small polygons (high edge to area ratio), with much less error associated with types forming large patches (low edge to area ratio). A further complication lies in the mapping of wet heath. Details in Robertson (1955) are insufficient to know if this vegetation was mapped as heath (5) or blowout (8). Slack quadrats in Dargie (1973) contain many wet heath samples and most wet heath was probably mapped as slack (8). Difference in treatment between authors could possibly account for the transition 5>8 (0.9 ha). Despite these reservations regarding interpretation problems, the size of the 5>4 transition is sufficiently large to suggest that conversion to fixed dune grassland was the primary reason for heath reduction.

5. Change resulting from agricultural improvements

Three main sets of change can be identified which relate directly to agricultural improvements, though all are on a comparatively small scale. No improved grassland was mapped in the early 1950s (and indicators such as perennial rye-grass *Lolium perenne*, cock's foot-grass *Dactylis glomerata* and crested dog's tail-grass *Cynosurus cristatus* are very rare or absent in the quadrat data of Robertson) but in 1964 2.8 ha of type 6 improved grassland was recorded, together with 11.3 ha of disturbed ground which was noted as reseeded in 1972 survey. The main habitat losses were fixed dune grassland (4, probably also including some erroneously mapped as 8 or 9 slack - *c.* 11 ha) and bracken (2.7 ha). Shelterbelt extent increased from 2.4 ha in the early 1950s to 4.2 ha in 1964, again involving loss of fixed dune and bracken.

6. Uncertain bracken decline

Bracken extent is reduced from 54.0 ha in the early 1950s to 41.0 ha in 1964, according to map evidence. Only 22.0 ha (10>10) remains as bracken on both maps. Loss to agricultural improvement is clear but only involves 3.3 ha. Conversion to fixed dune by increased stock grazing and trampling is a strong possibility (10>4, 18.9 ha). However, there might be some confusion between these types by Dargie (1973) because low bracken without complete canopy cover is not easily separated from type 3 semi-fixed dune (e.g. 10>3, 5.2 ha) and type 4 fixed dune on 1964 aerial photographs (e.g. 4>10, 8.9 ha). Transition data involve most cover types, usually as small areas - these results suggest that small bracken patches (common in the central sectors of Ross Links in 1964) are slightly misplaced by overlaying, generating planimetric error. Such errors make it impossible to separate real bracken invasion of heathland from spurious change.

2.4 Interpretation of evidence for change in Dargie/Woolven & Radley maps

The time period covered by these two maps is also a little uncertain. The Dargie map contains boundaries derived from 1964 panchromatic aerial photographs. The Woolven & Radley map is based on May 1986 colour aerial photographs, with most boundaries traced on to overlays placed on the prints. The most likely time interval is therefore 1964 - 1986, not that between the dates of survey (1972 and 1988). The northern sectors of Ross Links fitted well for the overlay of both maps, but it was poorer in southern sectors and rectification procedures by Woolven & Radley (1989) might not have been fully accurate. Some planimetric error is therefore likely in results.

The transition matrix for the Dargie/Woolven & Radley maps of Ross Links (excluding Old Law) is given in Table 3. This is separated from results for Old Law (Table 4) to enable comparison with Table 1 transitions and totals. The only slight difference in area between Table 1 and Table 2 is the addition of 0.9 ha to Table 2, representing a small area in the southwest of Ross Links missed from the early 1950s map. The slight increase in total area (2.4 ha, to 330.5 ha) in Table 2, over and above the 0.9 ha addition, may represent accretion between 1964 and 1986 (excluding strandline and low foredunes which were excluded in the redrawing of maps).

Table 3 Transition matrix for vegetation change at Ross Links (excluding Old Law) between the 1964 and 1986 maps produced by Dargie (1973) and Woolven & Radley (1989). Area data in matrix cells in hectares. See Table 1 for definition of vegetation and other cover types. Cover types separated by / are transitional types on Woolven & Radley map.

DARGIE 1964

WOOLVEN & RADLEY 1986	COVER TYPES	1	2	3	4	5	6	8	9	10	12	13	14	TOTAL 1986
	1	0.22	0.26	0.67	0.30	0.04	-	0.20	-	0.40	-	-	-	2.09
	1/2	-	0.07	-	-	-	-	-	-	-	-	-	-	0.07
	2	1.80	2.17	-	-	-	-	-	-	-	-	-	-	3.97
	3	1.91	2.04	4.60	-	-	-	0.04	-	0.01	-	-	-	8.60
	3/4	0.05	0.02	1.82	-	-	-	0.01	-	-	-	-	-	1.90
	4	0.60	1.18	71.15	21.80	1.60	0.06	6.30	1.10	3.10	0.40	-	-	107.29
	4/6	0.12	-	17.36	6.20	0.90	0.20	0.18	1.60	21.40	-	-	-	47.96
	4/5	-	-	0.10	0.50	1.0	-	-	-	0.03	-	-	-	1.63
	4/9	-	-	0.58	0.90	-	-	0.20	0.06	-	-	-	-	1.74
	5	0.09	-	0.67	1.46	0.80	0.20	1.60	0.96	0.39	-	-	-	6.17
	6	0.55	0.26	2.30	44.90	0.80	2.30	2.10	3.40	14.00	9.60	-	-	80.21
	7	-	-	7.38	0.50	-	-	-	-	-	-	-	-	7.88
	8	0.22	0.13	3.36	2.80	0.10	-	11.46	0.06	0.50	-	-	-	18.63
	8/9	0.05	-	0.29	-	-	-	0.40	-	0.08	-	-	-	0.82
	9	0.44	-	1.20	11.04	0.54	0.03	0.67	3.40	0.70	-	-	-	18.02
	10	0.01	0.26	0.67	0.99	0.10	-	0.50	-	1.00	-	-	-	3.53
	11	-	-	1.82	4.20	-	-	0.10	0.10	0.30	-	-	-	6.52
	13	-	-	0.03	-	-	-	-	-	-	-	0.06	-	0.09
	14	-	-	-	4.60	0.08	-	-	0.70	2.30	1.60	-	4.10	13.38
	TOTAL 1964	6.06	6.39	114.0	100.19	5.96	2.79	23.76	11.38	44.21	11.60	0.06	4.10	330.50

Table 4 Transition matrix for vegetation change on Old Law between the 1964 and 1986 maps prepared by Dargie (1973) and Woolven & Radley (1989). Area data in matrix cells in hectares. See Table 1 for definition of vegetation and other cover types. / = transitional vegetation type.

		DARGIE 1964				
	COVER TYPES	1	2	3	4	TOTAL 1986
WOOLVEN & RADLEY 1986	1	0.41	0.98	0.08	-	1.47
	2	1.25	3.92	0.30	-	5.47
	2/4	-	0.72	2.12	-	2.84
	3	0.03	0.91	0.69	-	1.63
	3/4	-	0.85	3.24	-	4.09
	4	3.18	1.57	7.94	-	12.69
	TOTAL 1964	4.87	8.95	14.37	-	28.19

There are six major features of change in cover types on the two maps.

1. Increased dune stability

There is a marked fall in bare sand (type 1) between 1964 (6.1 ha) and 1986 (2.1 ha), a first indicator of increased stabilisation on Ross Links. Mobile dune (type 2) extent falls from 6.4 ha in 1964 to 4.0 ha in 1986. The most dramatic change is in type 3 semi-fixed dune which collapses from 114 ha in 1964 to 8.6 ha in 1986. This is largely the result of change to fixed dune grassland (3 > 4, 71.1 ha), to fixed dune in transition to improved pasture (3 > 4/6, 17.4 ha), and the development of *Ammophila - Arrhenatherum* grassland (3 > 7, 7.4 ha). A very clear linear succession has thus occurred. Its further progress via fixed dune grassland and heath is difficult to distinguish due to management impacts on vegetation change. The same linear succession is found on Old Law (Table 4). Bare sand/shingle (type 1) is reduced from 4.9 ha (1964) to 1.5 ha (1986). Type 2 mobile dune remains approximately constant (1964, 8.9 ha; 1986, 8.3 ha) and this probably reflects the importance of blown sand from the beach zone in arresting stabilisation. Type 3 semi-fixed dune falls dramatically from 14.4 ha (1964) to 1.6 ha (1986), mainly the result of the transition to fixed dune (3 > 4, 7.9 ha; 3/4 > 4, 3.2 ha). These changes on Old Law match those on the outer part of Ross Links closely and point to an important natural linear succession producing dune stablity. This seems largely independent of agricultural management of the area (Old Law is not part of the Ross Links grazings), though the lack of more acidic grasslands on Old Law prevents analysis of any natural changes in later phases of the succession.

2. **Inadequate mapping of type 4 (fixed dune grassland)**

There is little overall change to fixed dune (type 4): 100.2 ha in 1964, 109.2 ha in 1986. However, only 21.8 ha of fixed dune in 1964 remained as such (4 > 4) in 1986. Of the remainder much was converted to improved grassland (4 > 6, 44.9 ha; 4 > 4/6, 6.2 ha). Confusion with slack types is suggested by two transitions: 4 > 9 (11.0 ha) and 8 > 4 (6.3 ha) and these might suggest the amount of error which was first identified in the Robertson/Dargie comparison (but it is not as severe as the equivalent Robertson confusions).

3. **Changes within slacks**

Overall slack extent (8 + 9) is roughly equal (1964, 35.2 ha; 1986, 37.4 ha) and probably reflects total slack extent fairly accurately. However, the balance between types differs over time. The SD14 type 8 is reduced from 23.8 ha in 1964 to 18.6 ha in 1986. The SD17 type 9 increases from 11.4 ha in 1964 to 18.8 ha in 1986. This change in balance may reflect poor definition of slacks in the 1972 survey of Dargie (1973) but, if not, an alternative hypothesis is that the SD17 type 9 is a more eutrophic type which has expanded. Many minor transitions are associated with both slack types, probably the result of planimetric error created by the small size of slack polygons and slight overlay misalignment.

4. **Reduction in heath extent**

A small heath (type 5) increase is suggested by transition totals (1964, 6.0 ha; 1986, 6.2 ha) but is probably misleading. The 1964 total excludes wet heath (probably mapped as type 8 slack), but 1986 type 5 includes wet heath vegetation which is extensive in the north of Ross Links. The transition 5 > 4/5 (1.0 ha) might represent heath changing to grassland under the influence of grazing pressure. Taken together, there has probably been a further reduction in heath extent, at least for dry variants (H11 *Calluna vulgaris - Carex arenaria* dune heath).

5. **Change resulting from agricultural improvement**

Improved pasture (type 6), disturbed/reseeded ground (type 12) and shelterbelts increased dramatically from 18.5 ha in 1964 to 100.1 ha in 1986 (including 6.5 ha of type 11 weedy stock feeding area). Fixed grassland in transition to improved pasture (4/6) was not mapped in 1964 but totalled 48.0 ha in 1986. The major expansions were type 6 improved grassland (to 80.2 ha in 1986) and fixed grassland in transition to improved pasture. The major habitat losses over this period were fixed dune grassland (4 > 6, 44.9 ha), semi-fixed grassland (3 > 4/6, 17.4 ha), and bracken (10 > 6, 14.0 ha; 10 > 4/6, 21.4 ha).

6. **Major bracken reduction**

The bracken loss to improved pasture (10 > 6, 10 > 4/6) totals 35.4 ha and is the major component in the fall of bracken from 44.2 ha in 1964 to 3.53 ha in 1986. The reduction might be slightly exaggerated because Woolven & Radley (1989) record several occurrences of scattered bracken in vegetation mosaics - these could not be quantified in terms of area. A large number of minor transitions are also involved and suggest that planimetric error is present, mainly the result of small bracken polygons and overlay slight mismatch.

2.5 General trends in dune vegetation

The major points to emerge from interpreting transition data are summarized in Table 5. These highlight the following trends:

1. increased stabilisation of the dunes, with the major reductions in bare sand (1), mobile dune (2) and semi-fixed dune (3) for both Ross Links and Old Law;
2. reduction in extent of dune heath;
3. reduction in extent of bracken;
4. major increases in the areas of semi-improved grassland, improved grassland, weedy stock feeding areas and shelterbelts, reflecting the agricultural development of Ross Links.

The trends are also illustrated graphically in Figure 2, with relatively slight change between the early 1950s and 1964, but with marked change in the balance of vegetation types by 1986 due to stabilisation and agricultural improvements.

Table 5 Summary changes in extents of vegetation types at Ross Links and brief interpretation of data and trends. Old Law data are presented in brackets (these are additional to Ross Links). All figures in hectares. ? = uncertain quantity or status.

Type code	Vegetation/cover type	early 1950s	1964	1986	Summary interpretation
1	Bare sand/shingle	22.2 (?)	6.1 (4.9)	2.1 (1.5)	Reduction in extent of bare sand as more mobile dune types stabilised by linear succession to fixed dune grassland.
2 +3	Mobile dune (2) and semi-fixed dune (3)	94.4 (?)	120.4 (23.3)	12.6 (7.1)	Increase in 1964 probably due to stabilisation of bare sand, falling to low 1986 total as fixed dune established. Area of 3 probably slightly exaggerated in 1964 map.
4, 2/4, 3/4	Fixed dune grassland, transitions from type 2 and type 3	71.7 (?)	107.3 (-)	100.2 (19.6)	Probably underestimated in early 1950s and 1964 map, especially the former. Total quantities in these two maps therefore uncertain. Much converted to improved grassland, with total stabilised by further fixed grassland derived from mobile and semi-fixed dunes.
5	Dune heath	12.6	6.0	6.2	Wet heath component uncertain apart from 1986 map. Uncommon at Ross Links and halved in extent, perhaps as result of stock grazing.
6, 4/6, 11, 12, 14	Agricultural improvements : improved grassland (6), semi-improved grassland (4/6), weedy stock feeding areas (11), reseeding (12), shelterbelt (14)	2.4	18.5	148.1	Major expansion to dominate vegetation/cover list in 1986. Inner central dune and northern areas are reseeded but change elsewhere resulting from high stock numbers and imported feed.
7	SD9 *Ammophila arenaria - Arrhenatherum elatius* rank dune grassland	?	?	7.9	Uncertain long-term status - may reflect stabilised dune grassland without stock grazing, inducing a rank sward.
8+9	Dune slacks	69.8	35.2	37.0	Extent probably exaggerated in early 1950s map. Balance might have shifted towards type 9 as result of eutrophication.
10	Bracken	54.0	44.2	3.5	In general decline and now rare, result of conversion to improved and semi-improved grassland, plus stock grazing and trampling.

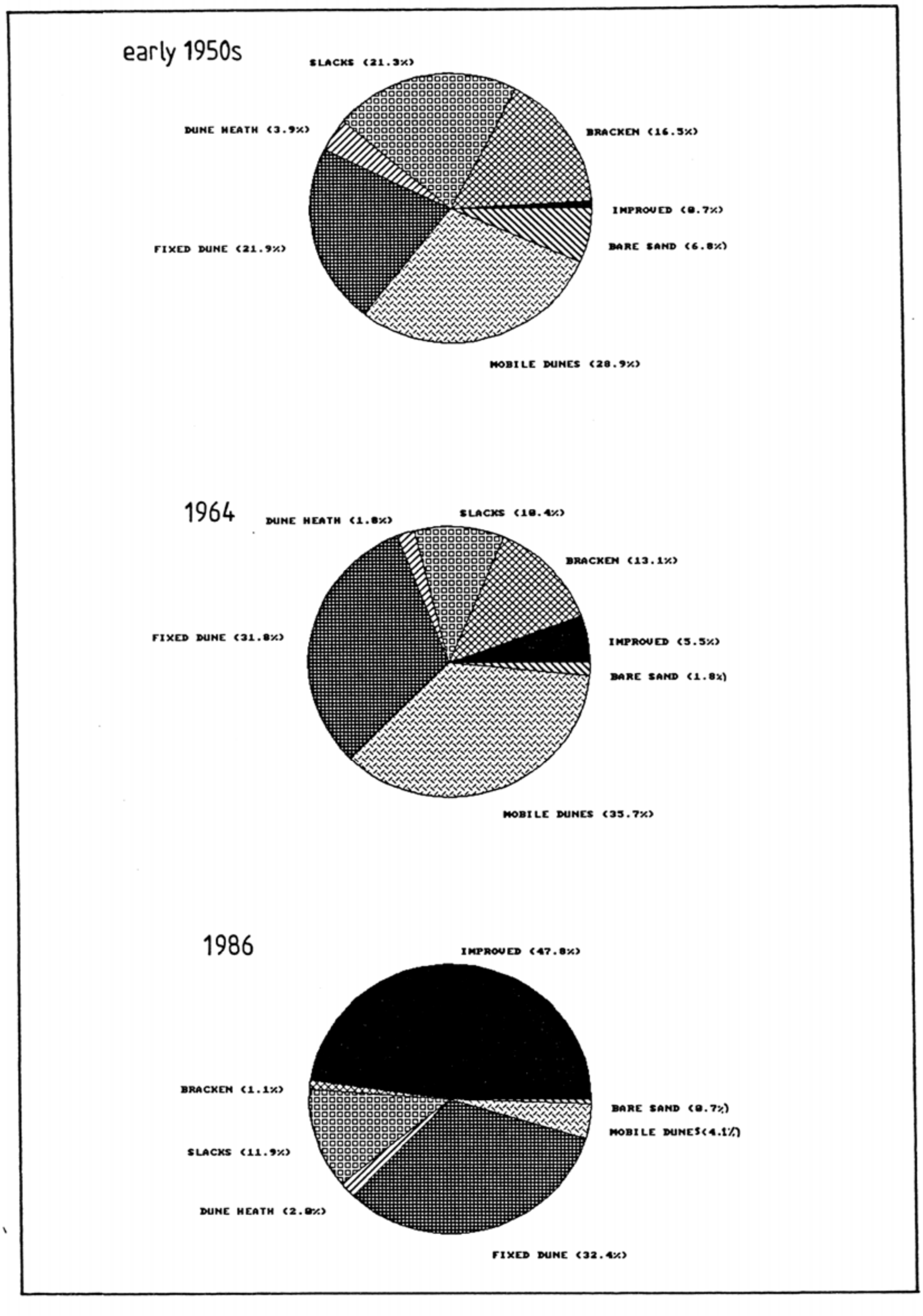

Figure 2 Percent vegetation composition of Ross Links for three map dates. Vegetation on Old Law is excluded. Data source: Table 5.

3. Vegetation change at Ross Links in relation to agricultural management

The changes observed from analysis of repeated vegetation mapping can be correlated with knowledge on changed agricultural management to help explain the fluxes and trends in vegetation cover. A recent thorough synthesis of management history is given by Woolven & Radley (1989) and the main points which relate to vegetation change are:

1. Ross Links has probably been used as pasture for extensive stock grazing for centuries, thus producing the extensive semi-natural and natural dune grasslands recorded by Robertson (1955);
2. disturbance by military training in the Second World War (mainly around a large target railway system) and high rabbit numbers up until a gassing campaign in 1953 both probably contributed to large extents of bare sand, mobile and semi-fixed dune upon the early 1950's map;
3. the 1953 reduction in rabbit numbers (and subsequent control by outbreaks of myxamotosis) plus the reversion to agricultural land use in the early 1950s combined to reduce important sources of disturbance and were perhaps important reasons for the strong evidence of stabilisation by linear succession observed in later maps. The extent of influence via removed disturbance is uncertain and other factors could also have been involved, given that stabilisation is also seen strongly on Old Law;
4. grazing levels remained low in the 1950s, with 200 black-faced sheep operating all year (*c.* 0.6 ewes/ha) and 50 bullocks in winter. No fencing constrained the grazers on the dune. The extensive character of management is reflected in the general similarity in vegetation composition between the early 1950s and 1964 maps (see Figure 2);
5. major agricultural improvements were put in place in the 1960s and 1970s, involving fenced enclosures, local drainage, fertiliser addition, local dune flattening, planting of shelterbelts, deliberate bracken eradication, and reseeding. The early shelterbelts and some reseeding are found on the 1964 map. A comparison of the early 1950s and 1964 maps (Figure 2) shows that bracken reduction was rapidly effective. The improvements were designed to intensify livestock management but the major effects upon vegetation are only found on the 1986 map;
6. winter stocking levels in the 1980s involved 400 cattle (1.3/ha) and 300 sheep (1/ha), levels far too high for the pasture available and thus very large winter feed quantities were brought on to the dunes. A relatively small number of feeding stations is supplied, leading to stock concentrations in these areas. Poor weather also leads large stock numbers to shelter in slacks (a feature first noted as a danger by Culwick (1977)). The trampling, dunging and urination effects have been profound and have led to large extents of improved grassland, semi-improved grassland and weedy vegetation in the locality of feeding stations (Figure 3). These effects are seen also in the 1986 vegetation map (Figure 2), though this may not reveal the full extent of impacts upon slacks (there is a hint in Table 3 of an increase in more eutrophic types in 1986);

7. in general there is a good correlation between agricultural management and observed vegetation change, particularly so in the case of identifying the role played by feeding stations in inducing deleterious change.

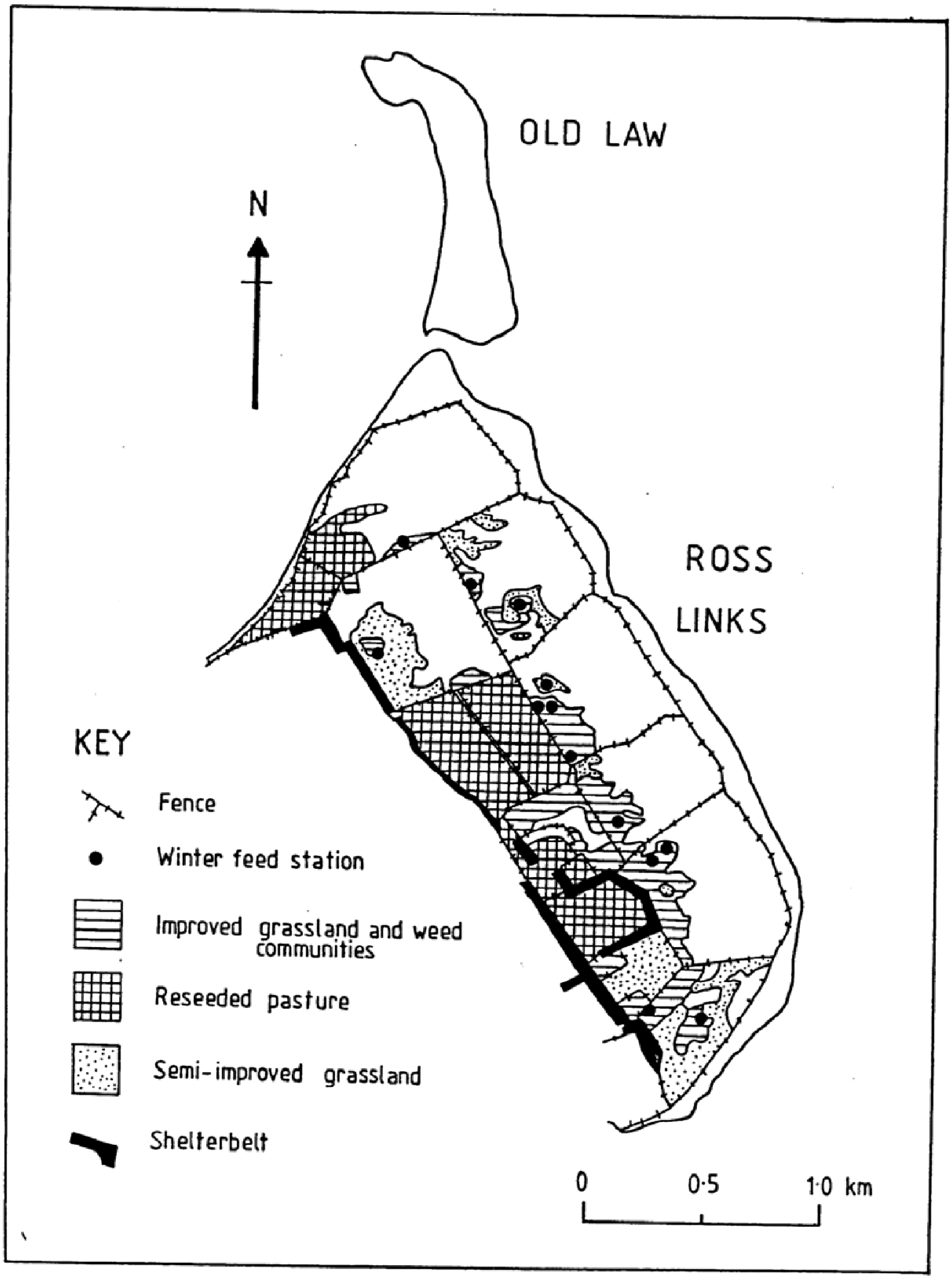

Figure 3 The location of major agricultural improvements at Ross Links in 1988. Source: Woolven & Radley (1989).

4. Detecting early stages of similar vegetation changes at other sites

Repeated vegetation mapping is most effective in portraying change over comparatively long time periods. It is not an efficient method of detecting the early stages of major vegetation change unless mapping is repeated at very frequent intervals. Alternative methods of detecting the early impacts of intensive stock grazing at other sites are as follows:

1. physical signs of intensive livestock management - fenced enclosures, reseeded dune grassland, presence of large numbers of animals, large winter feeding stations, major concentrations of dung, poaching in slacks, trampling erosion;

2. indicator species of grazing impacts, not normally found in nutrient-poor dune habitats with high cover or high frequency in the absence of intensive livestock grazing. Such species are more typical of mesotrophic, eutrophic and ruderal habitats - they thus reflect the increased nutrient inputs via imported livestock feed. At Ross Links these species include (in decreasing order of frequency):

   Fixed dune grassland
   Lolium perenne, Trifolium repens, Cirsium arvense, Stellaria media, Elymus repens, Cynosurus cristatus, Plantago major, Poa annua, Urtica dioica, Dactyis glomerata, Cirsium vulgare, Veronica arvensis, Ranunculus repens, Arctium minus, Chenopodium album, Rumex crispus, Urtica urens.

   Slacks
   Trifolium repens, Ranunculus repens, Poa pratensis, Stellaria media, Lolium perenne, Cirsium arvense, Trifolium pratense, Juncus articulatus, Juncus acutiflorus, Deschampsia cespitosa, Elymus repens, Plantago major, Cirsium vulgare, Cynosurus cristatus, Chenopodium album, Poa annua.

3. In the vicinity of winter feeding stations there is a further set of mesotrophic and eutrophic indicators, plus annual weeds. If these patches are extensive this should suggest high stock numbers. At Ross Links such species include (of equal frequency):

   Achillea millefolium, Arctium minus, Chenopodium album, Cirsium arvense, Cynosurus cristatus, Holcus lanatus, Lolium perenne, Senecio jacobaea, Stellaria media, Trifolium repens, Urtica urens.

4. On a longer timescale (five to ten years) annual monitoring of trends in sensitive variables (e.g. grassland height, with rank growth being reduced to a very low sward) or sensitive habitats (e.g. heathland being converted to grassland) would be sufficient evidence of increasing grazing for more detailed study to be initiated.

5. Management prescriptions to assist site recovery from intensive livestock husbandry

5.1 Problems in formulating management prescriptions

It is not possible to present detailed management prescriptions for site recovery for two reasons.

1. The most important reason is that there is little or no long-term experience of sand dune recovery from intensive livestock husbandry, matched with little current experimentation and monitoring. The essential scientific problem is the reduction of residual soil fertility to levels suitable for the re-establishment of nutrient-poor natural and semi-natural dune habitats. Leaching is known to be partially effective on sandy soils (Odum *et al.* 1984), though nitrogen is lost much more rapidly than phosphorus, especially if soil organic content is high and thus retains phosphorus on the organic exchange complex. Some research on allied problems in converting agricultural set-aside to species-rich grassland is underway (e.g. nutrient stripping methods based on removing nutrients assimilated in harvested barley) but results are only preliminary (Marrs *et al.* 1990; Gough & Marrs 1990). Much of this current work is probably not applicable to dune terrain.

2. Almost as important is the lack of a clear target for recovery. What is desired? - a return to the vegetation mosaic of earlier extensive husbandry such as that described by Robertson (1955), or to a mosaic which is typical of sand dunes in the northeast of England (e.g. NVC communities regarded as characteristic of Northumberland by Radley (1992)), or a non-ecological target decided by funding conditions? A return to the vegetation of the 1950s is heavily constrained by the large areas affected since by linear succession and thus might also require additional management prescriptions to re-initiate disturbance to dunes and slacks. A target of certain NVC communities is hampered by insufficient knowledge of the conditions needed to create them from present conditions. The character of foredunes, mobile dunes and semi-fixed dunes depend on sand supply, in turn dependent on the (unknown) sediment budget for Ross Links. Fixed dune vegetation would be largely dependent on rabbit numbers (variable at Lindisfarne, Garson (1985)), revised stocking levels for sheep and/or cattle (which could be varied) and large differences in soil nutrition levels (from fertilised reseeded grassland, via mesotrophic semi-improved swards to heath). Reliance on just leaching (i.e. abandon all stock grazing) would give bracken the opportunity to re-invade or for false oat-grass *Arrhenatherum elatius* to spread rapidly - both these species have affinities for richer soils, are of poor nature conservation value because they help create species-poor conditions, and the risks of their expansion and the costs to control it are uncertain.

5.2 General management prescriptions to assist site recovery

The following prescriptions are offered on the basis of very limited available science and the very uncertain time frame over which residual fertility could be reduced. All are based on rainfall leaching reducing soil fertility, with further uncertain effects once nutrients are transferred to the dune watertable. It is recommended that, if any of these are to be implemented, each is to be subject to initial experiment and rigorous monitoring to determine feasibility.

1. **Establishing semi-natural fixed dune grassland in areas of semi-improved grassland and all forms of improved grassland.**
   a. Cease all winter feeding of stock;
   b. revert gradually to extensive stock grazing levels (1 ewe/ha, 0.3 cattle/ha) to prevent build of dead organic material by undergrazed plants;
   c. monitor nutrient reduction (N,P) and when close to target levels vary grazing intensity in grassland mosaic (by use of fencing) to explore types of NVC vegetation produced upon more/less acidic sands and under different moisture conditions.

2. **Expanding dune heath in areas with fragmented heath patches**
   a. Cease all winter feeding of stock;
   b. Fence area within which heath is to be regenerated, excluding all stock;
   c. only permit grazing of heath in winter/spring period in years when rabbit populations are low (Leach 1985);
   d. monitor heath expansion, realising regeneration will take 5-10 years to be effective.

3. **Improving slack quality in areas of severe trampling and dunging**
   a. cease all winter feeding of stock;
   b. perform detailed slack survey to map slack quality on basis of species diversity and rare species distributions;
   c. revert gradually to extensive levels of stock grazing by sheep (1 sheep/ha);
   d. fence high-quality slacks to exclude cattle and monitor condition annually for 10 years;
   e. fence low-quality slacks to exclude cattle and design experiments to observe natural rate of recovery from cattle effects in winter, plus experiments on stripping nutrients by excavating humic topsoil (and thus re-initiating slack succession). Monitor slack quality for 5 to 10 years.

6. Usefulness of repeated vegetation mapping as a technique for environmental audit

6.1 Major uses

There are three important uses for repeat mapping in environmental audit:

1. identification and quantification of major successional trends; if regular mapping is employed then rates of change can be calculated and predictions can be made for future vegetation change;

2. identification and quantification of management effects can be made, allowing trends to be identified and correlations made with vegetation change;

3. data produced on trends could be used in formulating management policies at the site and regional scale, especially on sustainability issues (retention of certain habitats in sound condition for future generations).

6.2 Difficulties

There are two major difficulties to be overcome in using repeat vegetation mapping:

1. information loss will occur if vegetation maps are not based on the same classification system, since harmonisation will be required to compare maps. Adoption of the National Vegetation Classification as a mapping standard would be a useful measure, as will Phase 1 habitat survey for broader investigations of change (Dargie 1992);

2. vegetation maps need to be as accurate as possible in order to generate quality data on change. Resources must therefore be allocated to allow sufficient field time to trace vegetation boundaries and transitions with care and consistency, preferably using recent vertical aerial photography as the mapping base. This should then be followed by methods which position boundaries and transition zones accurately on the final map (e.g. photogrammetric techniques).

6.3 Further research requirements

Two aspects of repeat mapping deserve consideration for further methodological research:

1. In areas of complex topography such as dune terrain habitat relationships are such that a large classification system (such as the NVC) generates a complex vegetaion map with a high polygon density (e.g. the 1986 map of Woolven & Radley (1989)). Small polygons have a high edge/area ratio and thus more risk of error in area transition calculations due to slight misalignment of overlays. This is best overcome by ensuring an accurate positioning of boundaries in relation to standard points and lines used for overlays (e.g. National Grid lines). A photogrammetric map derived from aerial photographs would be the most accurate means to achieving this accuracy. If the 1986 map of Woolven & Radley (1989) was therefore redrawn by photogrammetric plotter, it could the be overlain on the original and transitions calculated. Any deviations from the main diagonal will be due to planimetric error and would thus allow an estimate of its importance - something which has not been quantified.

2. Calculating area transitions by square counting is very time-consuming and tedious, yet demands great concentration. Equivalent techniques exist within Geographical Information Systems (GIS) and a project exploring the application of GIS technology to repeat mapping statistics is probably needed, especially if photogrammetric plotters could replace data input by digitiser.

6.4 Skill requirements and resource support

The value of statistics and information generated by repeat vegetation mapping should be balanced against costs measured in the skills required of competent personnel and the backup resources which such personnel would need. A competent field ecologist is essential, with in-depth experience of the NVC and vegetation mapping using aerial photographs. A further ability to use a photogrammetric plotter and GIS software/hardware would then ensure rapid map production to a high standard. Such personnel are probably rare and the hardware requirements would be expensive. These factors probably make it impossible to use repeat mapping as a common method in environmental audit. Its main role would therefore be for critical sites or selected conservation ventures requiring detailed change information in relation to designing and costing management agreements, etc.

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