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Paradise lost — transformation of the gully landscape in South-East Norway

Liv Norunn Hamre, Knut Rydgren, Christian Incerti, Ingrid Hjorth-Johansen and Kia Sandra Simonsen

Faculty of Engineering and Science, Western Norway University of Applied Sciences, Sogndal, Norway

ABSTRACT
In the last 50–60 years, agricultural intensification and later urban development have threatened the rare and valuable gully landscape formed on marine clay. We studied landscape changes in eastern Akershus county in south-east Norway, which has one of the world's largest concentrations of marine gullies. Interpretation of aerial photos showed that about 25% of the gully area has been lost. Only 39.5% of the remaining area is original gullies, and 60.5% of the area has been affected by landscape change. The largest loss of gully area was between 1955 and 1991, mainly through land levelling and transformation to intensively managed agricultural landscape. The most densely populated areas also lost gullies to residential areas and industry. Gullies support high plant and animal diversity, and future management should be based on landscape ecological principles. Gully fragments should also be preserved to maintain connectivity between the many different habitats belonging to the gullies.

KEYWORDS
Marine gully; land cover change; landscape ecology; aerial photos; GIS

Introduction

Since time immemorial, human societies have been altering landscapes (Ellis, 2015), and today these changes are more rapid than ever (Plieninger et al., 2016). The most common drivers of landscape change include agricultural intensification, land abandonment and urbanisation, which reflect the changing demands of society (Plieninger et al., 2016; van der Sluis et al., 2016). Agricultural intensification often leads to loss of landscape elements, typically reducing both landscape diversity and habitat quality (Cousins et al., 2015). After habitat loss, landscape fragmentation is considered to be one of the main threats to terrestrial ecosystems and biodiversity (Hobbs & Yates, 2003; Ibáñez et al., 2014). Fragmentation reduces landscape connectivity, but habitat configuration may mitigate the effects of fragmentation to some degree, particularly through the maintenance of functional connectivity (Öckinger et al., 2012; Villard & Metzger, 2014).

Apart from urbanisation, the main drivers of landscape change do not usually lead to irreversible change, although there are some functions of natural ecosystems that are not feasible to restore as a result of climate change or for ecological or economic reasons (Hobbs et al., 2009). This applies for example, to the vulnerable gullies in marine clay that form entire gully landscapes in some regions. Gully landscapes formed in areas where glacio-marine sediments were deposited on the seabed immediately after the last deglaciation in the early Holocene 10,000 to 11,000 years ago (Mangerud et al., 2011). These areas were lifted above sea level by postglacial rebound of the crust, and have since been exposed to erosion processes that formed a characteristic landscape with V-shaped valleys. Intact gullies are

CONTACT Liv Norunn Hamre liv.hamre@hvl.no

dynamic because erosional processes are continuous, and highly productive because of the high nutrient content and moisture-holding capacity of marine clay. Norway has one of the largest concentrations of these vulnerable marine gullies in the world (Bergqvist, 1990). They are mainly found in the lowlands of south-east and central Norway (Erikstad, 1992; Sønstegaard & Mangerud, 1977), in relatively flat areas of Akershus and Nord-Trøndelag counties where the marine limit was high at the end of the last Ice Age. For several decades, Norway's agricultural policy encouraged levelling of gullies, which led to their loss in some regions (Erikstad, 1992). Streams were also filled and channelled, destroying many gullies as active geomorphological systems. Gully landscapes would only be recreated in the event of a new ice age followed by deglaciation and postglacial rebound of former seabed. It is therefore important to know what proportion of the gullies we have lost, and how we should manage the remnants of this vulnerable landform.

These remaining gullies are of high conservation value (e.g. Berger & Bengtson, 1995; Blindheim et al., 2016; Erikstad, 1992; Jansson, 2014; Jansson & Laugsand, 2014; L. Økland, 1995). The landform 'gullies in marine clay' is included in the *Norwegian Red List for Ecosystems and Habitat Types* as VU-vulnerable (Artsdatabanken, 2018; Lindgaard & Henriksen, 2012), and our knowledge of the relationship between geological diversity and biodiversity in these systems is limited (Norwegian Environment Agency, 2015). Complete gullies comprise large variation in habitat types, including many red-listed forest types, such as rich swampy spruce forest (EN), and semi-natural grasslands (VU) (Artsdatabanken, 2018; Blindheim et al., 2018). The gullies support high plant and animal diversity, including red-listed species associated both with forests and with semi-natural grasslands (Blindheim et al., 2018; Jansson & Høitomt, 2013). The long branching gullies are also important as wildlife corridors (Blindheim & Abel, 2002). Its high productivity made the gully landscape attractive for farming, and traditionally, the gullies were widely used for grazing (Kielland-Lund, 1998). Generally, only small remnants of these pastures still exist today. Many former pastures have been replanted with forest or abandoned so that forest has regrown naturally (Jansson & Høitomt, 2013). In the traditional farming regime that prevailed up to World War II, flat areas between the gullies were used for crops while the steep gully slopes were used for grazing (Arnoldussen, 2011). The introduction of modern agrotechnology and new agricultural policies in the period 1945–1970 brought about large-scale changes in Western agriculture (Plieninger et al., 2016; Robinson & Sutherland, 2002). One result was the transformation of many areas of gully landscape. Levelling made former steep-sided gullies available as cropland and allowed the use of heavy machinery. In Norway, large-scale levelling ended in 1989, when regulations issued by the Ministry of Environment introduced restrictions on levelling of agricultural land (Ministry of Agriculture, 1989).

The gully landscapes are located in the best agricultural areas in Norway and are sandwiched between urban areas and more traditional agricultural land. The gullies are therefore still under enormous pressure, but now due to development of residential and industrial areas, road construction and measures to prevent clay slides (Norwegian Environment Agency, 2015). In order to manage the remnants of the gully landscape properly, we need to know what we had, what we have lost and to what, i.e. the types of land-use change. We also need information on the current distribution of these landscapes. We have therefore examined an area of 460 km^2 in south-east Norway, and analysed how the area of gullies has changed from the mid-1950s to the present. More specifically, we seek to answer the following questions:

1. What proportion of the area of gullies has been lost during the last 50–60 years?
2. Which types of land cover have replaced the gullies?
3. In which period did the largest land cover changes take place, and why has the rate of loss varied over time?
4. How should the remaining gully landscape be managed?

Material and methods

Study area

We studied gullies in Skedsmo, Rælingen, Lørenskog and Sørum municipalities, and in parts of Fet municipality, all in Akershus county (Figure 1) in south-east Norway (Figure 2). The total area of the five municipalities is 603 km^2. With the exception of Oslo, Akershus was the county with the highest population growth (17.0%) in Norway from 2007 to 2017, although it only covers 1.5% of the land area (Statistics Norway, 2018). The marine limit in the area is around 220 m above sea level, and below this, gullies are found in areas with marine clay (Arnoldussen, 2011). The area belongs to the southern boreal zone or the boreo-nemoral zone (Moen, 1999). The gullies are mainly located in

Figure 1. Transformation of a gully landscape in Nannestad, Akershus county. In 1949 (upper), the landscape was dominated by gullies. By 2018 (lower), most gullies had been levelled and only fragments were left. Photos: Wilhelm Skappel (upper) and Sverre Solberg (lower).

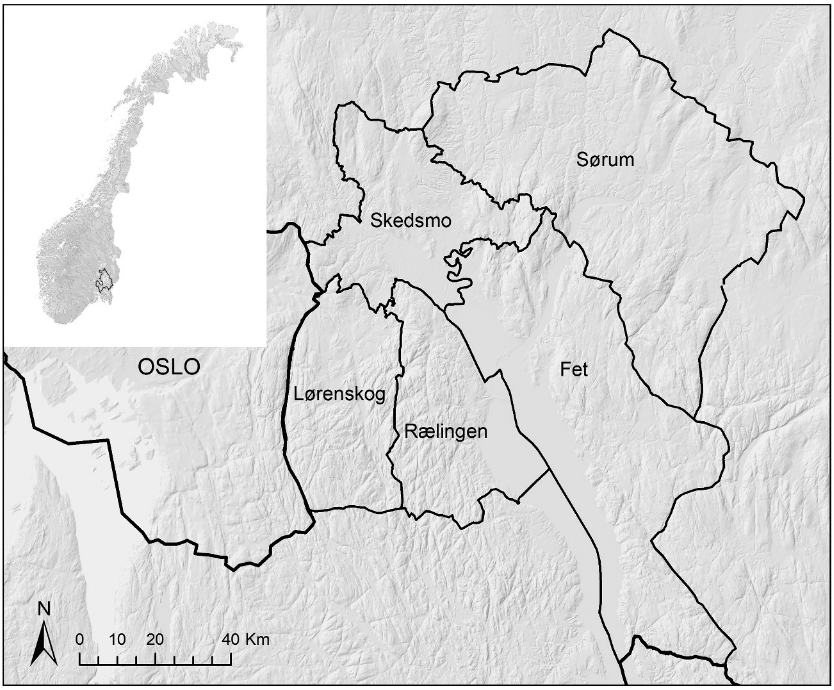

Figure 2. The study area is located in the five municipalities Sørum, Fet, Skedsmo, Rælingen and Lørenskog in Akershus county just east of Oslo, the capital city of Norway, in south-east Norway.

a matrix of intensively managed farmland, and none of them are protected as nature reserves or landscape protection areas at a national level.

Methods

Land cover changes were mapped by interpretation of recent digital orthophotos (2009 or 2013) and panchromatic black/white historical aerial photos (1955–1991) (Table 1), displayed in ArcGIS 10.3.1 (ESRI, 2015). The scale of the black/white historical aerial photos is ~1:5000. The availability of historical aerial photos in the municipality archives restricted and defined our study area. Total cover was not available for all municipalities for all years, so to obtain the best possible wall-to-wall cover, we defined three time periods; T1 (1955–1970), T2 (1985–1991) and T3 (2009–2013), and used aerial photos from all years in each period (Table 1). For Skedsmo, Lørenskog and Rælingen, all areas where gullies could exist were covered in each time period, but for Fet only 33.3 km^2 of 176 km^2 was covered. For Sørum and Fet we only had aerial photos from periods T1 and T3. The total study area was 460.3 km^2 (Table 1). All aerial photos were scanned and georeferenced using the recent digital orthophotos (2009 or 2013) as reference, using affine transformation in ArcGIS. Present land cover

Table 1. Aerial photography cover for each municipality in the different time periods.

Municipality	Time period 1 (T1)	Time period 2 (T2)	Time period 3 (T3)	km^2
Skedsmo	1967/68/69	1985/86	2009	77.0
Rælingen	1955	1985	2009	71.7
Lørenskog	1970	1989/90/91	2013	70.6
Sørum	1956		2013	206.6
Fet	1966/67		2013	33.3
Total study area				459.2

was mapped by interpretation of the 2009/2013 aerial photos, and controls were made in the field to minimise errors of interpretation. However, we were not able to use reference data to perform an accuracy assessment of the areas mapped from aerial photos as recommended by Olofsson et al. (2014). Our study goes back to the 1950s, and was based on all available reference data. We carried out a wall-to-wall mapping of gullies and four land cover types: agriculture, residential, industry and infrastructure. To minimise mapping errors, we ruled that all gullies must have a slope of at least 10°. To interpret slopes, we used 5 m contours from a digital topographic map at scale 1:1000. A slope of 10° between 5 m contour lines on a topographic map at scale 1:1000 corresponds to 2.8 cm on the map. In addition, we used a quaternary geological map (Norwegian Geological Survey, 2018) and earlier mapping of gullies to tune the search.

To identify land cover changes, we used a retrospective approach (Skånes & Bunce, 1997), comparing the present orthophotos with the older georeferenced aerial photos. As a starting point, the present land cover map was displayed on the georeferenced black/white aerial photos, and polygons were modified and reclassified where there was a change in land cover. We mapped the gullies and the other land cover types in all the three time periods (T1-T3; Table 1). We mapped all gullies and existing fragments of earlier complete gully systems, and did not differentiate between these in the analyses of changes in cover and landscape pattern. We defined gullies with the same area in period T1 and T3 as original gullies with a minimum history of 50–60 years without conversion. Some of these gullies may have been partly transformed before the first available aerial photos were taken in the mid-1950s, but probably only in exceptional cases.

Results

Land cover changes

During period T1, from the mid-1950s to 1970 (Table 1), gullies covered a total area of 33.07 km^2 in the study area (Table 2), and made up 7.2% of the total area investigated. In the 40–50 years between then and T3, 25.3% of the gully area was lost (Table 2 and Figure 3). The most important land cover change was from gully to agricultural land, and 20.2% of the gully area in period T1 was transformed to agriculture in period T3, while 2.3% became industry, 2.2% residential, and 0.7% infrastructure. The mean proportion of original gullies left in the study area in period T3 was 39.5% (Figure 4).

There were differences between the municipalities in patterns of land cover change from period T1 to period T3. The three smallest and most densely populated municipalities lost a larger proportion of their gully area, up to 33.6% (Lørenskog), as compared with around 23% in the two least densely populated municipalities (Sørum and Fet). The latter municipalities also had the largest proportion of original gullies left (Figure 4). Higher loss rates to residential and industrial areas explain most of the difference between the two groups of municipalities (Table 2).

For the three municipalities where data were available for all three time periods (T1, T2 and T3), there was a larger decline in gully area between the first two periods, i.e. between period T1 (1950s to 1970) and period T2 (mid-1980s to early 1990s), with a loss of 23.5% of the gully area (Table 2, Figure 3). Between periods T2 and T3 (2009 to 2013), only 6.4% of the area was lost. Between the first two periods, the dominant land cover change was from gully to agriculture, which accounted for a loss of 16.5% in gully area. Between T2 and T3, only 2.3% of the gully area was lost to agriculture, the same proportion as was lost to industry (Table 2).

Landscape patterns

The gullies varied a great deal in both shape and size (Figure 3), and the main pattern was a reduction of large gully fragments (Figure 5). Smaller gully fragments in the size class 10,000–50,000 m^2, were the most frequent both in period T1 and in period T3. In the three most densely populated municipalities, the smallest size classes of gully fragments increased in number from

Table 2. Land cover in time periods T1 and T3 for all municipalities, and for Skedsmo, Rælingen and Lørenskog for time period T2 in addition. T1 = mid-1950s to 1970, T2 = mid-1980s to early 1990s and T3 = 2009 or 2013. Sk/Ræ/Lø = Skedsmo, Rælingen and Lørenskog combined.

Municipality	Sørum		Fet		Skedsmo		Rælingen		Lørenskog		Sk/Ræ/Lø		Total	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Land cover Time period 1														
Gully	18.64	100	3.11	100	8.04	100	1.99	100	1.30	100	11.33	100	33.07	100
Land cover Time period 2														
Gully					6.20	77.1	1.55	77.9	0.89	68.5	8.64	76.3		
Agriculture					1.25	15.5	0.29	14.6	0.32	24.6	1.86	16.4		
Residential					0.29	3.6	0.07	3.6	0.03	2.3	0.39	3.5		
Industry					0.24	3.0	0.06	3.2	0.04	3.0	0.34	3.0		
Infrastructure					0.04	0.6	0.01	0.6	0.02	1.8	0.08	0.7		
Land cover Time period 3														
Gully	14.4	77.3	2.38	76.5	5.67	70.5	1.38	69.3	0.86	66.4	7.91	69.8	24.69	74.7
Agriculture	3.98	21.4	0.58	18.6	1.38	17.2	0.40	20.1	0.34	26.2	2.12	18.7	6.68	20.2
Residential	0.01	0.0	0.12	3.9	0.48	6.0	0.08	4.1	0.03	2.2	0.59	5.2	0.72	2.2
Industry	0.15	0.8	0.00	0.0	0.46	5.7	0.10	5.2	0.04	3.0	0.60	5.3	0.75	2.3
Infrastructure	0.10	0.5	0.03	1.1	0.05	0.6	0.02	1.1	0.03	2.2	0.10	0.9	0.23	0.7

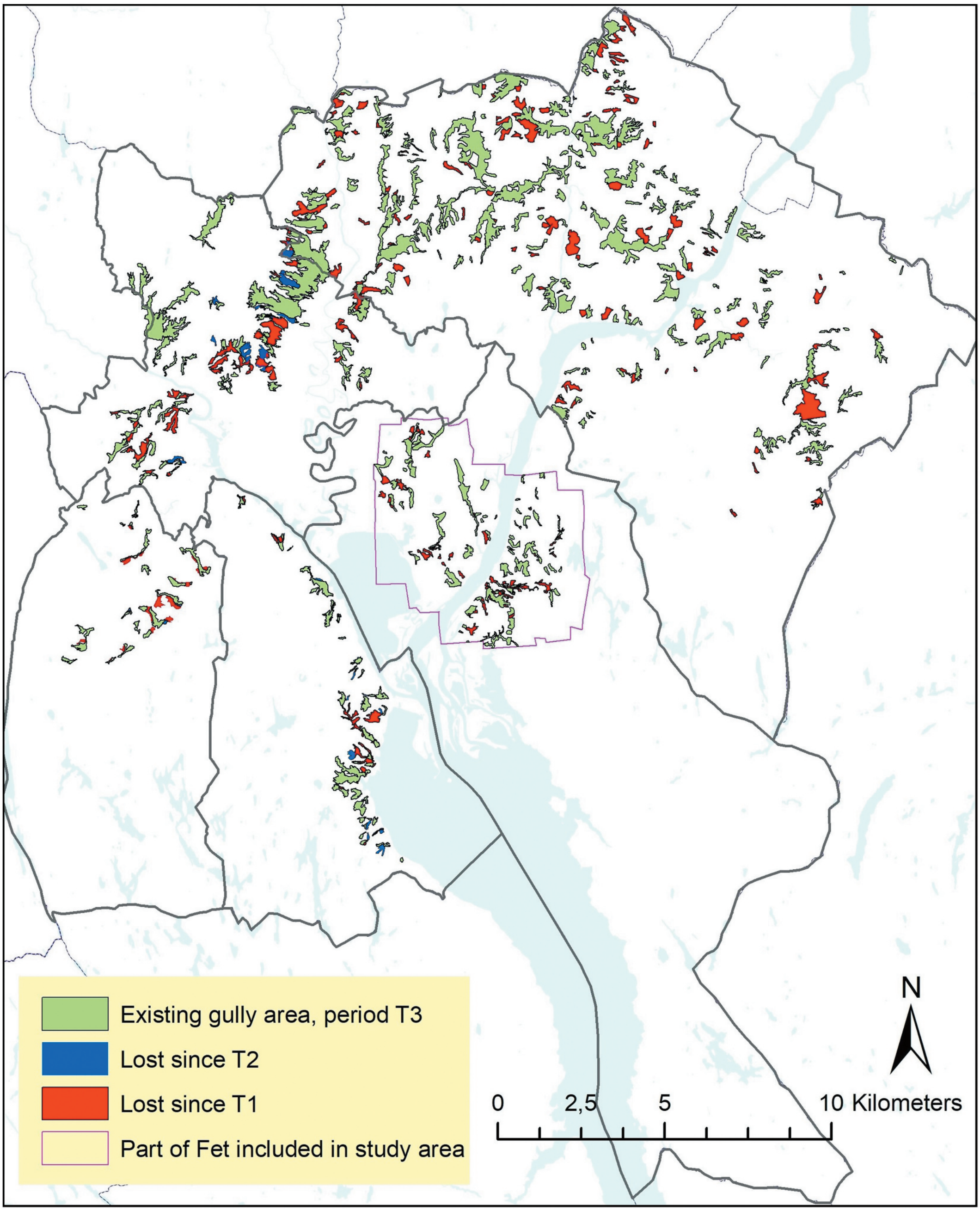

Figure 3. Changes in gully area during the last 50–60 years in five municipalities in Akershus county, south-east Norway, based on results for three (Skedsmo, Rælingen and Lørenskog) or two (Sørum and Fet) time periods. The periods were: T1 (1950s to 1970), T2 (mid 1980s to early 1990s), and T3 (2009 or 2013). Results for Sørum and Fet are for periods T1 and T3.

period T1 to T3 because the conversion of larger gullies (Figure 5). For the two less densely populated municipalities, the number of original gullies and fragments in all size classes decreased between period T1 and T3 (Figure 5).

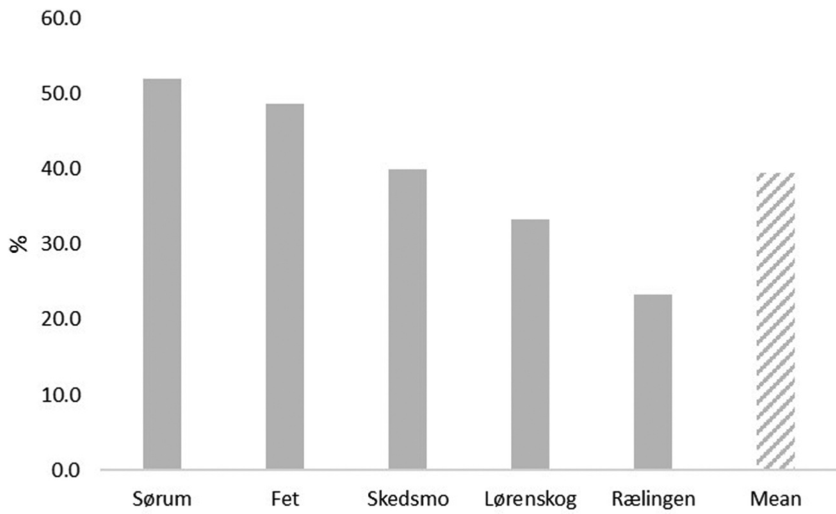

Figure 4. Proportion of original gullies remaining in period T3 (2009 or 2013).

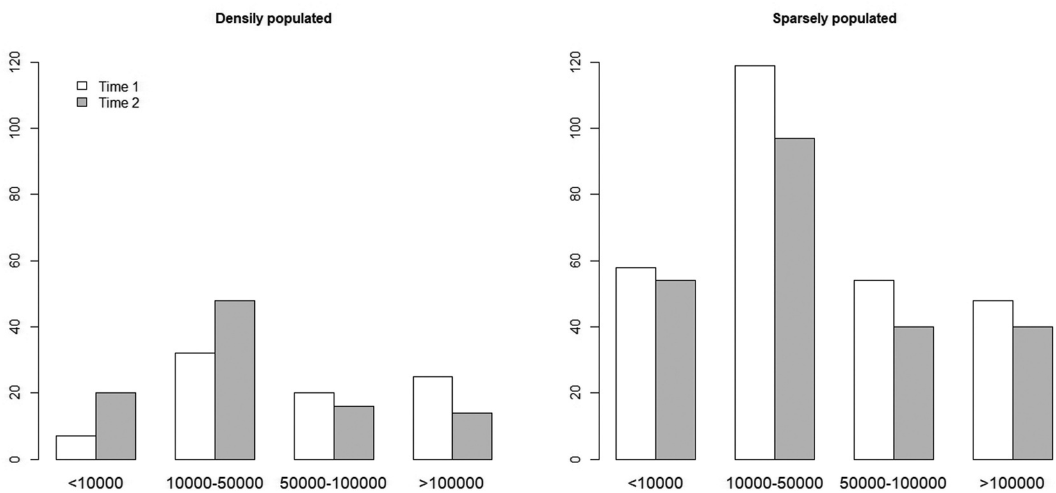

Figure 5. Distribution of gullies by size class in periods T1 and T3 for the densely populated municipalities (Skedsmo, Rælingen and Lørenskog) and sparsely populated municipalities (Sørum and Fet).

Discussion

Our results show that about 25% of the area of gully landscape has been lost in the study area during the last 50–60 years, and that only 39.5% is left of what we classified as original gullies. The largest losses took place in the 15 years between the periods T1 (1955–1970) and T2 (1985–1991), mainly through land levelling and transformation to intensively managed agricultural landscape. The loss is lower between the periods T2 and T3 (2009–2013), and the main reasons are a decrease in losses to agriculture, and the fact that many gullies had already been converted.

The loss of 25% of the gully area and conversion of 60.5% of the original gully area have caused fragmentation of the gullies, and thus reduced connectivity between habitats for many species. It is likely that an even larger proportion of gullies in the study area has been lost, as land levelling started before the time of the first available aerial photos in the mid-1950s. This large-scale eradication of gullies is not unique to the municipalities studied here. In the neighbouring county of Østfold, Erikstad (1992) showed a reduction of 60–80% in gully length at three study sites between the 1950s and 1987, and found that levelling had influenced almost all large gully systems. The high rate of loss to agriculture we found between 1955 and 1991 is in agreement with Erikstad's results. As was shown for the gully landscape in Østfold, this is mainly explained by the economic measures used in the 1970s and 1980s to encourage farmers to level gullies. Large areas were affected (Erikstad, 1992) as part of one of the largest landscape transformations by humans in Norway, which took place in parallel with general technological developments in agriculture throughout Europe in this period (Poschlod et al., 2005). The largest loss of gullies in our area was to intensively managed agricultural land, but the most densely populated municipalities lost a larger proportion of their gully area than the more sparsely populated ones. This difference is principally explained by the additional high loss to residential areas and to industry in the fringe between the urban areas closest to Norway's capital city Oslo and the surrounding agricultural landscapes. In areas with high population growth, the need for more infrastructure and more residential and industrial areas exerts constant development pressure even on valuable landscapes such as the gully landscape.

For the municipalities where we have data from three time periods, our results show that the driving force for gully transformation has changed in the intervening periods from agricultural intensification to population growth. This change is explained by the termination of the grant system for levelling gullies for agricultural purposes in 1987, due to pollution problems associated with run off of fertiliser and pesticides (Ministry of Agriculture, 1989). For the last 25 years, levelling of agricultural land has required a permit from the regional (county) authorities or, from 2001, the local (municipal) authorities (Norwegian Pollution Control Authority, 2001). The introduction of restrictions on levelling in 1989 (Ministry of Agriculture, 1989) is probably the most important factor behind the much lower loss of gullies from the late 1980s to the present. Another contributory factor may have been a growing awareness of the importance of maintaining valuable species and habitats among local authorities. A national programme to incorporate environmental issues into municipal planning was started in 1992 (Aall, 2002), and as a result many municipalities appointed ecologists and environmental coordinators. As a part of this process, some municipalities, including Skedsmo (L. Økland, 1995) and Rælingen (Berger & Bengtson, 1995), initiated mapping and inventories of gullies for use in land-use planning.

The large losses and fragmentation of gullies have also caused the loss and fragmentation of habitats for many species found in the gullies, and often reduced habitat quality (Blindheim et al., 2018). Even though many of the gully remnants are no longer active systems, many of them still have more or less natural vegetation (Blindheim et al., 2018; L. Økland, 1995), and stand out as species-rich islands in an otherwise intensively managed and species-poor agricultural landscape. They help to maintain biodiversity in the landscape, and studies of both agricultural landscapes and forests show that small habitat elements may function as refugia or act as stepping stones to increase functional connectivity between habitats, analogous to a meta-population (Fahrig et al., 2011; Halme et al., 2013; Herrera et al., 2017; Lindborg et al., 2014). Thus, maintaining gully fragments may mitigate biodiversity loss associated with loss of original gullies, at least for some species, as shown in a system of protected and non-protected wetlands (Uden et al., 2014). There is broad consensus that animal movement is facilitated by landscape connectivity, but understanding of the role of connectivity for plants is still limited (Uroy et al., 2019). In a survey of plants, fungi, mosses, lichens and some groups of insects in the gully landscape of Skedsmo municipality, many of the registered species occurred only once (Blindheim et al., 2018). The fact that each gully supports a unique assemblage of species may indicate that many species do not easily disperse between neighbouring gullies. A similar situation has been found in boreal swamp forests, which also forms islands of high biological biodiversity in a species-poor landscape (Ohlson et al., 1997; R. H. Økland et al., 2003). The wide variety of habitats in Norwegian gullies and the presence of many species with limited dispersal abilities, indicate that large numbers of gullies and gully fragments need to be protected to safeguard their biodiversity. Loss of the gully landscape also reduce the diversity of landscape types, and a precautionary approach should be taken to management of the remaining intact gullies (Anonymous, 2015). We know too little about relationship between the geological diversity and biodiversity, and the remaining intact gullies are important laboratories for such studies. Loss of landscape diversity is not consistent with Norway's commitments under the European Landscape Convention (Council of Europe, 2000). The continuing loss of gullies and other valuable habitat types in the landscape may be explained by the piecemeal nature of many planning decisions. One major reason for unsustainable land use is the challenge of scale (Leitaõ & Ahern, 2002; Theobald et al., 2005). Many land-use decisions are made at the individual scale, focusing on one particular project or property (Dramstad & Fjellstad, 2013). For gully systems, which cross both property and municipal borders, such local decisions prevent an overall management of the gully landscape. When planned changes are of an extent that requires planning permission, planning and management authorities should use a wider perspective to assess projects and whether they are compatible with longer-term plans for the local administrative unit. The European Landscape Convention calls for integration of protection planning and management of landscapes (Jones, 2007). The inclusion of the landform 'gully in marine clay' in the *Norwegian Red List for Ecosystems and Habitat Types* does not give any secure protection. The list is primarily designed to give decision makers a better knowledge base for their work on biodiversity and to increase their awareness of the impact of losing valuable areas such as gullies (Artsdatabanken, 2018; Lindgaard & Henriksen, 2012).

Conclusions

During the last 50–60 years, the gully landscape in the study area has undergone major transformation. Interpretation of aerial photos revealed that about 25% of the gully area has been lost, and only 39.5% remains as original gullies. In the 1970s and 1980s, farmers were encouraged through economic measures to level gullies to create flat areas that could be farmed more efficiently, but after 1987, urbanisation has been the biggest threat to the gullies. Even though they are now red-listed, gully landscapes have not been included in any of the many thematic nature conservation plans drawn up in Norway in recent decades, and only a few gully sites are protected under the Nature Diversity Act as nature reserves or protected landscapes. However, red-list status has resulted in growing awareness about this rare landscape type, and more municipalities have initiated mapping of gullies. Farmers are also being encouraged through economic measures administered by the Norwegian Agriculture Agency to manage the remaining gully landscape by keeping or introducing grazing animals (Lovdata Foundation, 2015). However, unsustainable land use is continuing, and it is important to avoid shifting baseline syndrome and its increasing tolerance for progressive environmental degradation (Soga & Gaston, 2018). Thus, Norway urgently needs a national conservation plan for this internationally rare landscape type, and needs to educate the public about its high biodiversity and the value of the landscape (see Solberg, 2019).

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Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Liv Norunn Hamre (PhD 2009 in vegetation ecology, University of Oslo) is an Associate professor at the Faculty of Engineering and Science at Western Norway University of Applied Science. Her research focuses on the analyses of land-use changes at different scales from populations to landscapes, mainly in the traditional cultural landscape. By combining field studies and GIS technology, her work addresses many aspects of the landscape at both spatial and temporal scales.

Knut Rydgren (PhD 1997 in biology – botany, University of Oslo) is a Professor at the Faculty of Engineering and Science at Western Norway University of Applied Science. His research focuses on restoration ecology, vegetation ecology, landscape ecology, and population biology (especially the bryophyte *Hylocomium splendens*). Recently, he has been particularly devoted to research on how to predict species compositional recovery following restoration.

Christian Incerti, Ingrid Hjort-Johansen and Kia Sandra Simonsen were bachelor students in Landscape Planning with Landscape Architecture at Western Norway University of Applied Science, working together with Liv Norunn Hamre and Knut Rydgren on the project.

ORCID

Liv Norunn Hamre http://orcid.org/0000-0002-9033-4260
Knut Rydgren http://orcid.org/0000-0001-8910-2465

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