Science of the Total Environment 568 (2016) 107–117

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Past and future of the EU-habitat directive species *Liparis loeselii* in relation to landscape and habitat dynamics in SW-Texel, the Netherlands

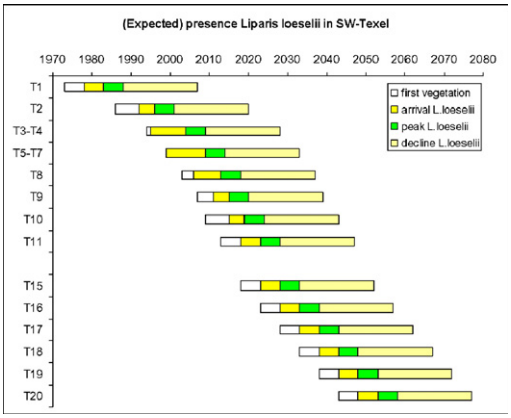
A.M. Kooijman [a,*], C.J.W. Bruin [b], A. van de Craats [a], A.P. Grootjans [c,d], J.G.B. Oostermeijer [a], R. Scholten [a], R. Sharudin [a,c,e]

[a] Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Science Park, PO box 94062, 1090 GB Amsterdam, The Netherlands
[b] State Forestry Service Texel, The Netherlands
[c] Centre for Energy and Environmental Studies (IVEM), University of Groningen, The Netherlands, 9747 AG Groningen, The Netherlands
[d] Institute for Wetland and Water research, Radboud University of Nijmegen, The Netherlands
[e] School of Marine and Environmental Sciences, University of Terengganu, Malaysia

HIGHLIGHTS

- Dune slack, soil and vegetation development over the past four decades
- Detailed time series of increase in soil C and decrease in pH
- Unsuitable habitat conditions *L. loeselii* in lime-poor dunes in 34 years
- Current formation of new dune slacks on SW-Texel every 4–5 years.
- Texel stronghold EU-habitat directive species *L. loeselii* for many years

GRAPHICAL ABSTRACT



Actual and expected presence of *L. liparis* in dune slacks of different age on SW-Texel. T1–T11 are existing dune slacks, with future presence based on present-day developments in vegetation and soil, and unsuitable habitat conditions 34 years after the start of succession. T15–T20 are expected future dune slacks, based on the current rate of new dune slack formation once every five years. Expected presence of *Liparis loeselii* in T15–T20 is based on present-day developments in vegetation and soil.

ARTICLE INFO

Article history:
Received 5 February 2016
Received in revised form 11 May 2016
Accepted 13 May 2016
Available online 9 June 2016

Editor: D. Barcelo

Keywords:
Carbon
Natural dynamics

ABSTRACT

Dune slacks are important habitats, with many endangered plant species. A series of eleven dune slacks of 1–42 years old was studied in SW-Texel, the Netherlands, with the EU-habitat directive species *Liparis loeselii* present in all except the youngest and oldest. Analysis of aerial photographs revealed that new slacks are currently formed every 4–5 years. In each slack, topsoil and vegetation data were collected in 2010 and 2014–2015. During succession, vegetation changed from brackish pioneer stages to dune slacks with *L. loeselii* and *Parnassia palustris* and ultimately grassland species. Differences between dune slacks and sampling periods were mostly significant. Herb cover and soil C increased with slack age, and over the five year study period, while bare sand, bulk density and pH decreased. The annual pH-decrease was 0.055 and 0.075 for pH-H_2O and pH-KCl respectively, and annual C-increase 0.16% and 35 g m^{-2}. *Liparis loeselii* was only present between pH_{H2O} 5.8–7.5 and pH_{KCl} 5.6–7.6, and only occurred at C-content below 4.3%. In lime-poor dunes, environmental conditions thus become unsuitable

* Corresponding author.
E-mail address: a.m.kooijman@uva.nl (A.M. Kooijman).

http://dx.doi.org/10.1016/j.scitotenv.2016.05.086

Nature conservation
Orchid
pH

approximately 34 years after the start of succession. In the dune slacks, *Liparis loeselii* established within 6 years, showed peak values after 11–16 years, and declined until conditions became unsuitable. Rejuvenation may occur after large storms with fresh sand deposits. However, even with further succession, the present populations are not endangered and probably last until 2040. With new dune slacks every 5 years, *L. loeselii* occurs in approximately eight different dune slacks at the same time, ensuring viable populations also in the future. This shows that adverse effects of succession can be counteracted by dynamics on local and landscape scale.

1. Introduction

Dune slacks belong to the priority habitats (H2190) of the European Habitat directive (European Union, 1992). Dune slacks are dynamic habitats, and once formed, undergo succession of vegetation and soil. Although habitat conditions and changes during succession in dune slacks are generally known (e.g., Lammerts and Grootjans, 1998; Shahrudin et al., 2014), integrated studies of actual dune slack formation, soil succession and the response of characteristic plant species are scarce. Such information is important, because adverse effects of succession on characteristic plant species may be counteracted by local and landscape dynamics.

One of the characteristic dune slack species is the orchid *Liparis loeselii* (L.) Rich., which has been listed as priority species in the EU-habitat directive (European Union, 1992). *Liparis loeselii* occurs in coastal dune slacks and calcareous peatlands (Jones and Etherington, 1992; Lammerts and Grootjans, 1998; Wheeler et al., 1998; McMaster, 2001; Pawlikowski, 2008; Naczk and Minasiewicz, 2010; Milanović, 2012; Oostermeijer and Hartman, 2014). The species has a wide distribution, ranging from the northeast of the United States and Canada, to northern and Central European countries and Russia, but populations of *L. loeselii* are in serious decline over most of its geographical range. In the European Union, it is now considered as an endangered species (Schnittler and Günther, 1999).

The relationship between survival of *L. loeselii* and successional stage in coastal dune slacks was first studied in Wales by Jones and Etherington (1992). They found that *L. loeselii* appeared between 12 and 15 years after initial vegetation establishment of the slacks. The orchid started to decline when the shrub, *Salix repens*, developed a dense vegetation cover, which occurred after around 40 years. In addition to vegetation development, abiotic factors such as pH and soil organic matter also affect the survival and population density of *L. loeselii* (e.g. Stuckey, 1967; Wheeler et al., 1998; Lammerts and Grootjans, 1998; Wotavová et al., 2004; Janečková et al., 2006; Oostermeijer and Hartman, 2014; Grootjans et al., 2016). Favourable conditions recorded for the species include a high pH (>6), combined with low availability of nutrients and low amounts of soil organic matter. A complicating factor is that *L. loeselii* has short-living populations with high rates of local extinction, and needs regular formation of new sites for survival (Eriksson, 1996; Oostermeijer and Hartman, 2014). The appearance of new plants is most prevalent in young dune slacks (Jones, 1998).

In the present study, we focus on a series of dune slacks on the southern tip of the isle of Texel, the Netherlands, which is a good model system to study the changes in habitat conditions during different successional stages. Texel is a dynamic, actively growing area, with dune formation since the 1300s (Sha, 1990; Ballarini et al., 2003). In the last century, a series of dune slacks has developed on a shoal attached to the island in 1908–1916, and dune (slack) formation is still an active process. The goal of this study is to analyze how fast development of new dune slacks has been over the past decades, how fast succession goes and how long it takes to reach unsuitable conditions for dune slack species such as *L. loeselii*. The ultimate question was whether development of suitable habitat occurs fast enough to maintain a viable population in the future.

2. Methods

2.1. Study area

The southern tip of Texel is one of the few places in Europe where natural formation of primary dunes still occurs (Fig. 1). The coast has been growing since the 13th century, due to accreting shoals in the ebb-tidal delta since the formation of the Marsdiep, the main connection between North Sea and Wadden Sea (Sha, 1990; Ballarini et al., 2003). The shoal the Hors became attached in 1749. The Onrust, the shoal on which the present dune formation takes place, became attached in 1908–1916. A new shoal is approaching: Razende Bol-Noorderhaaks, which has been above the low water line since 1925.

On the beach plains, new dune ridges and slacks have formed since the 13th century (Sha, 1990; Ballarini et al., 2003). In the present study, only dune slacks formed since the last century, south of the fore dune ridge of 1910, are taken into account. The series starts with dune slacks at the border of the western lake, formed after the final formation of a sand dike around 1964. The next large dune valley, Kreeftepolder, has also been created by sand dikes, and has been cut off from the sea since 1977 (Ballarini et al., 2003). In the area south of this sand dike, autonomous dune development has been allowed since 1984, which has resulted in the formation of many larger and smaller dune slacks, surrounded by relatively low sand dunes. All dune slacks were gradually colonized by *L. loeselii*. Since *L. loeselii* populations cannot survive when the habitat is overgrown by woody species (Jones and Etherington, 1992; McMaster, 2001; Bzdon and Ciosek, 2006), especially the older slacks are mown.

2.2. Development of dune slacks

For all dune slacks formed before 1986, the dates on the map of dune formation of Ballarini et al. (2003) were used, to determine when the foot of the surrounding dune ridge had been present. This date was used as the moment that slack formation had finished. For the dune slacks formed between 1986 and 2005, estimates of formation were based on aerial photographs. Aerial photographs of the area were available for 1986, 1996, 2000, 2003, 2005 and 2008. Because the photographs differed in quality, resolution and/or colour, interpretation in GIS was based on human observation and supervised classification, rather than digital unsupervised classifications. A dune slack was assumed to be formed when the influence of groundwater was visible on the aerial photographs, and when the surrounding dunes became higher and were growing together. For the period 2005–2014, high resolution (10 cm–1 m) infrared aerial photographs were available for every year except 2007. All of the aerial photographs, except 2008, were taken during ebb-time, and for most years both winter and summer recordings were available. For comparison with the earlier dataset, dune slack formation and vegetation development were analyzed with supervised classification, based on the criteria used above. The aerial photographs were also used to assess vegetation development in the sampling locations, together with vegetation maps of the area of 1988, 1994, 1996, 1999, 2004 and 2005. All materials were provided by State Forestry Service, the site manager, Rijkswaterstaat, responsible for coastal defence, and the Ministry of Defence, the actual owner of