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Establishment and clonal spread of the alien shrub *Rosa rugosa* in coastal dunes—A method for reconstructing and predicting invasion patterns

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ABSTRACT

Little is known about the rates of establishment and clonal spread of invasive plants on a landscape scale. This knowledge is necessary for reconstructing and predicting invasions, for example of the alien shrub *Rosa rugosa*. A series of aerial photographs (1986, 1999, 2002, 2004, 2006) were used to map the species in coastal dunes of north-western Denmark (2354 ha), and all *R. rugosa* patches (1321) were recorded with GPS in 2004 and 2007. The 2004 records were used to digitize 82–161 distinct patches on the photographs. The increase in patch sizes from the older to the younger photographs was used to calculate a lateral clonal spread rate (0.42 m $year^{-1}$). Relative area increment by clonal spread was 16.4% per year, decreasing exponentially with patch size due to constant clonal lateral spread. Based on the lateral spread rate, recursive negative buffers were introduced to determine when each patch became established. Applying the clonal spread rate to current patches allowed to quantify future distribution patterns. *R. rugosa* invaded the study area after 1949, and most patches established after 1989. For 1986–2004, the establishment rate was estimated as 0.02 patches ha^{-1} $year^{-1}$. In 2004, the species had invaded 0.33% of the study area. If only clonal spread of existing patches is considered and assuming current environmental conditions and no management, the species will cover 3.9% by 2034. When including establishment of new patches, cover will increase to 9.5% in 2034. The advantages and limitations of the suggested extrapolation model are discussed.

1. Introduction

Invasive alien plants have become a challenge for conservation management and landscape planning (Ehrenfeld, 2008; Heckmann et al., 2008), because of their negative effects on biodiversity and ecosystem services (Nentwig, 2007). Management of invasive species requires decisions on the allocation of funds and manpower. Such decisions strongly depend on future range extension and population dynamics in endangered ecosystem types. However, most invasion studies are 'snapshots', and the invasion processes and associated impact on native biodiversity may strongly change over time (Strayer et al., 2006).

Historical invasions can be used to model future spread, but such analyses meet methodological problems. The invasion history of some species has been reconstructed on regional or continental scales, for example by using herbarium records (Mihulka and Pyšek, 2001; Fuentes et al., 2008), but there are few studies on long-term patterns of local spread (e.g. Foxcroft et al., 2004). Aerial photographs have been used for mapping local plant invasions, for example of *Rhododendron ponticum* (Fuller and Boorman, 1977), *Ammophila arenaria* (Buell et al., 1995), *Melaleuca quenervia* (McCormick, 1999), and *Pinus halepensis* (Rouget et al., 2001). The main limitations of such studies are (1) that reliable remote sensing and GPS-mapping data are only available for recent decades, (2) that few invasive plants can be identified as distinct patches on aerial photographs, e.g. flowering *Heracleum mantegazzianum* (Müllerová et al., 2005), and (3) that invasive species are mixed with and partly covered by taller vegetation. Moreover, local invasion can be a combination of seed dispersal and clonal spread of established individuals (e.g. Brown and Carter, 1998; Civille et al., 2005; Maheu-Giroux and de Blois, 2007), and these processes may respond differently to changes in land use. In clonal species, forecasts of population dynamics should consider that lateral growth rates may decrease in time, and clonal populations may be replaced in their centre by other species or die-back due to resource exploitation (Neira et al., 2007).

Coastal dunes are endangered in many countries (Martínez and Psuty, 2004), at least partly due to spread of invasive species (Avis, 1989; Acosta et al., 2008; Conser and Connor, 2009). In some

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regions alien species have been planted to stabilise dunes, and these plants have subsequently become invasive, e.g. *Pinus mugo* in north-western Europe, or *Ammophila arenaria* in California (Nordström and Lotstein, 1989; Buell et al., 1995; Wiedemann and Pickart, 1996). Coastal dunes are more susceptible to plant invasions under improved nutrient conditions and with locally reduced or increased disturbance regime (Rodgers and Parker, 2003; Campos et al., 2004; Kim, 2005).

In north-western Europe, the invasive shrub *Rosa rugosa* constitutes a considerable threat to dune landscapes, because it suppresses natural vegetation of high conservation value (Bruun, 2005; Isermann, 2008a). In Denmark, for example, it is the most common invasive alien plant (Thiele et al., 2009). The species is an introduced ornamental in gardens and parks, and it has been frequently used for planting hedgerows and other landscaping activities. As previous studies on *R. rugosa* have revealed negative impacts on coastal species diversity (Isermann, 2008b), information about the suggested future population growth could help directing management efforts.

This study presents a new approach for reconstructing and predicting establishment and clonal spread of invasive plant species. The method is a combination of GPS mapping, aerial photograph analysis and subsequent GIS modelling. Using the case of *R. rugosa* in coastal dunes of north-western Denmark, the objectives are:

1. to calculate the annual rate of lateral clonal spread of *R. rugosa* patches;
2. to test whether or not lateral clonal spread varied with patch size, habitat type or climatic factors;
3. to use clonal spread rates for reconstructing past establishment;
4. and to predict future rates of establishment and clonal spread of the species.

2. Study area and methods

2.1. Study area

The study area was coastal dunes of north-western Denmark (Fig. 1) where field research on *R. rugosa* had been done before (Frederiksen et al., 2006; Kollmann et al., 2007; Jørgensen and Kollmann, 2009). The northernmost point was located at 57°06′N, 8°35′E, south of the town of Hanstholm, and the area stretched over ca. 37 km in south-western direction, covering 2354 ha. Fourteen study sites along this coastal strip were chosen (13–517 ha), separated by villages and conifer plantations. The relief of the study area varied from flat in the northern parts to relatively steep in the central and southern parts with some dunes reaching 40 m a.s.l. The dune communities reflected a gradient of decreasing natural disturbance, from dynamic coastal white dunes to dune heath further inland (Frederiksen et al., 2006). Annual precipitation in the area was 795 mm, with highest values in October and lowest in April. Annual average temperature was 7.8 °C, ranging from 0.6 °C in January to 15.1 °C in July (Frich et al., 1997; Laursen et al., 1999).

The study area became part of the European NATURA 2000 network, and it was designated as the first Danish national park in 2007. Thus, the Danish Forest and Nature Agency is committed to protect the existing vegetation types against negative impacts, for example by invasive alien species. Most parts of the study area had been without human impact for several decades, except trampling and local management close to summer houses, parking places, roads and paths leading to the beach (Jørgensen and Kollmann, 2009).

2.2. Study species

R. rugosa Thunb. (Rosaceae) is a multi-stemmed deciduous shrub (1–2 m tall) forming dense stands (Bruun, 2005). Patches of *R. rugosa* expand laterally by suckers that develop from rhizomes or roots, and rhizome fragments are a potential mode of dispersal by water or (strong) wind. Scrub extension with a closed front is predominant, but single shoots interspersed with herbaceous vegetation are observed as well (Bruun, 2005). The fruits ('hips') are globose, 1.5–2.0 cm long and 2.0–2.5 cm wide, and a mean number of 62 (range 20–120) woody achenes per hip were found in wild populations in Denmark (Jessen, 1958). The achenes (6.6 mg; Bruun, 2005) are predated by finches and rodents which may contribute to local dispersal of the species (Snow and Snow, 1988). In addition to dispersal by frugivorous birds, fruits and seeds are effectively spread by water and by strong winds in late winter when most fruits are dried-up. The seed bank of the species is short-lived. However, quantitative information on reproduction, dispersal and clonal spread is scarce; for a review on the species see Bruun (2005).

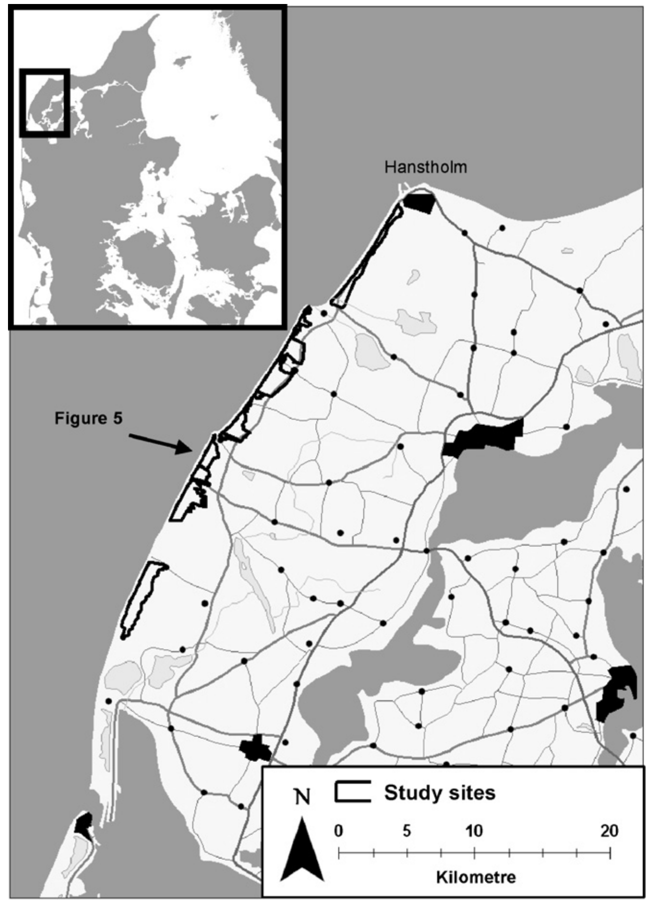

Fig. 1. The study area along the coast of north-western Denmark (2354 ha). The map shows the coastline, lakes and water courses (▒), towns (■), villages (●) and two categories of roads. ©Kort- og Matrikelstyrelsen, permission GX-04. The arrow indicates the location of Fig. 5.

R. rugosa was introduced to Europe from East Asia, probably via different routes and at several occasions between the late 19th century and mid 20th century. In the 1950s, it became a popular ornamental shrub around coastal summer houses, roads and parking places, due to its resistance to wind and its tolerance of poor soil conditions (Østergaard, 1953). More recently, the species has invaded species-rich coastal ecosystems in north-western Europe transforming them into monospecific scrub with reduced species richness (Isermann, 2008a,b).

Within the past decades, the distribution and local cover of *R. rugosa* have increased markedly along the Danish coast. Based on aerial photographs of a coastal heath in Denmark, Didriksen (1999) found that *R. rugosa* had spread from a few patches to a more or