Holocene dune reactivation along the northern Curonian Spit: geological, paleoecological, and archaeological implications

Ilya Buynevich
Temple University (USA)

Collaborators:

Albertas Bitinas
Donatas Pupienis
Aldona Damušytė

Coastal Research & Planning Institute
Vilnius University
Lithuanian Geological Survey
- Erosion
- Flooding
- Submergence

Chandeleur Islands, LA

Hurricane Katrina

Dauphin Island, AL

July 2001

Sep 2004 (post-Ivan)

Aug 2005

Photos by USGS Coastal and Marine Geology Program
Deposition (sand invasion)

Desert dunes, Mauritania

Ingleses, Brazil

Atalaia, N. Brazil

Baltic Sea coast
Coastal Dune Research

- Activity through Holocene
- Global distribution
- Sensitivity to environmental changes

Record of:
- wind patterns (GCM groundtruth)
- wind velocity
- sea-level change
- sediment supply
- precipitation/water table elevation
- vegetation dynamics
Basin-Scale Links

- NAO-sensitive regions

- Similar:
  - post-glacial SL history
  - sediment sourcing
  - prevailing winds
  - vegetation
Complementary Paleoenvironmental Records

Dunes

Intradunal Wetlands

- paleosol/peat
- aeolian sand

Landscape stability
Climate: warm/humid/storminess
Age control: AMS $^{14}$C

Dune activity
Climate: cold/dry/storminess
Age control: OSL
Chronology of European Dune Activity

European coastal dunes

Existing Chronology

Climate deterioration - abrupt cooling (Meese et al., 1994; Bond et al., 1997)

Medieval Warm Period

Little Ice Age

N. America

Cape Cod
N. Carolina

Curonian Spit

previous

Poland

Northern Ireland

N. Europe

Netherlands

NE England

SW Denmark

Short activity phases: large $^{14}$C dating errors?
Aeolian activity phases: number, timing, and triggers?

Outline

• High-resolution subsurface (GPR) imaging
• Paleosols: distribution and chronology
• Revised optical (OSL) chronology
• Lithological anomalies (geophysics, ichnology)
• Paleoecology: Holocene dune and lagoon faunas
• Geoarchaeology: human-landscape interaction
Highest coastal dunes in Northern Europe

**Study Area**

- Baltic Sea
- Lithuania
- Curonian Spit
- Russia
- Lagoon

**Massive Sand Transfer**

- Landward sand transfer
- Oversteepening and collapse

**Baltic Sea**

- Massive $(10^7-10^9 \text{ m}^3)$

**Location**

- GoogleEarth Image

**Direction**

- Dune migration

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GoogleEarth Image
Outcrop/core studies – limited information
Ground-Penetrating Radar (GPR)

Rapid, continuous, high-resolution subsurface imaging

SIR-2000 GSSI Inc. GPR

Layer 1

Layer 2

paleosol

control unit

survey wheel

200 MHz antenna

electromagnetic waves
Paleosols – Chronology of Landscape Stability

Naglių Nature Reserve
Lithuania
Russia

Baltic Sea

exposed paleosol P1
deflation surface (25 m above MSL)
deflation remnant
Paleosol P3
deflation surface

P1
P2
P3

33° dune slipfaces
dune migration
water table

Range: 300 ns
Vertical Resolution: 16-18 cm
Two-way travel time (ns)

Depth (m)
20 km

0 5 10 m
Paleosols – Chronology of Landscape Stability

Evolving dune morphology

3,355±115

deflation remnant (dr)

3,355 ± 115

deposition remnant (dr)

1,255 ± 85

5,690 ± 80

Little Ice Age begins

700 ± 40

Legend

P1 Paleosols: exposed
buried

P2

P3

P4

Baltic Sea (1700 m)

Curonian Lagoon (200 m)

vegetated dune

deflation remnant (dr)
Improved $^{14}$C Chronology of Dune Activity

Climate deterioration - abrupt cooling
(Meese et al., 1994; Bond et al., 1997)

Revised Chronology

European coastal dunes

Curonian Spit

N. America

Poland

N. Europe

NE England

SW Denmark

Northern Ireland

N. Carolina

Climate deterioration - abrupt cooling
(Meese et al., 1994; Bond et al., 1997)
Activity-Stability Phases

Phase 1: ~5,700 cal BP

Phases 2-4: 3,400-700 cal BP

Phase 5: post-700 cal BP (Little Ice Age)

Age of spit > 6 ka

with SL rise

deflation

burial

Similar evolution:
Łeba dunes, Poland (Borówka, 1975)
Cape Flattery dunes, Queensland, Australia (Pye, 1993)
Activity-Stability Phases

timing
(inception and duration)
of aeolian activity

P4
P3
P2
P1

burial
Coupled $^{14}$C and OSL Chronology (cal yBP)
Chronology of Dune Activity: Summary

- paleosol (stability)
- aeolian sand (activity)
- paleosol (stability)

bulk $^{14}$C

AMS $^{14}$C

2σ

2σ

bypassing (non-deposition)

OSL

AMS $^{14}$C

bulk $^{14}$C

2σ

2σ

2σ

2σ
Revised Chronology of Dune Activity

Climate deterioration - abrupt cooling
(Meese et al., 1994; Bond et al, 1997)

Revised Chronology
(red-OSL ages)

Calendar years BP

0 1000 2000 (AD 1950) 3000 4000 5000

Little Ice Age
Medieval Warm Period

N. America
Cape Cod
N. Carolina

Curonian Spit
new
previous

Poland

Northern Ireland

N. Europe

Netherlands

SW Denmark

NE England

Short episodes of large-scale dune migration

(Buynevich et al, 2007; Gaigalas and Pazdurs, 2008)
Reactivation of aeolian activity: Triggers

Storms, disease, deforestation

Fires (natural and man-made)

charcoal
Reactivation Surfaces (paleosols absent)
AD 1550-1800

18th century advance phase, Karvaičių

GoogleEarth Image

10 km

Baltic Sea
Lithuania

wind

Karvaičių
Reactivated Dunes
Equatorial Brazil

Atlantic Ocean

Dune migration

Buried forest

OSL ~1m 5m

30.09.2008 14:45
Heavy-Mineral Concentrations

HMCs: high-amplitude reflections

Texture: high-amplitude reflections

Gray Value

Distance (m)

Range: 300 ns
Vertical Resolution: 16-18 cm

paleosol 1
paleosol 2

HMC

0 1 2 3 4 5

Gray Value

0 100 200

Distance (m)

0 5 10 15

Gray Value

0 5 10 15

Gray Value

0 5 10 15

Gray Value

0 5 10 15

Gray Value

0 5 10 15

Gray Value
Paleo-Wind Intensity and Sand Transport

Impact threshold velocity (Bagnold, 1954):

$$u_{*t} = A \sqrt{\frac{\rho_s - \rho_{air}}{\rho_{air}}} gd$$

Quartz: 2.65

Garnet: 3.5-4.3

Magnetite: 5.18
MS as paleo-wind proxy

volume MS profile – ground exposure

surface trench

158.1 68.6 152.5 83.5 0.7

dune migration →

Medieval Warm Period

Little Ice Age

few HMCs (calm period?)

HMCs (intensified wind activity)

HMCs

magnetic susceptibility ($\kappa \times 10^{-5}$ SI)

1,255±85

Distance (m, upwind of P1)

700±40

Buynevich et al. (2007)