The evolution of the Integrated Geobotanical and Historical Change Mapping (IGHCM) approach for documenting landscape change (1949-2010), Prudhoe Bay oil field, AK, USA

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In memory of Dr. Kaye Everett (1934-1994) who played a key role in developing these methods.

The oil fields near Prudhoe Bay, Alaska

- Total area enclosed by development is about 2,600 km² (about the size of Rhode Island or Luxembourg.
- Most of this development is composed of widely dispersed drilling pads and production facilities connected by roads and pipelines.
North Slope oil and gas production units

NIKAITCHUQ UNIT
OOOGURUK UNIT
COLVILLE UNIT
Harrison Bay
Nuiqsut
NPRA
Alpine Pipeline

MILNE POINT UNIT
NORTHSTAR UNIT

KUPARUK RIVER UNIT
PRUDHOE BAY UNIT

Map 32

Deadhorse

NPRA

Prudhoe Bay

TAPS

Badami Pipeline

Badami UNIT

Duck Island UNIT

Foggy Island Bay

Deadhorse

Harrison Bay

Nuiqsut

NPRA

Alpine Pipeline

Deadhorse

Foggy Island Bay

Map 32

North Slope oil and gas production units

Courtesy of BP Alaska and Aerometric Geospatial Solutions
Introduction

• Monitoring changes related to resource development is a key for future planning and sustainable management of Arctic natural resources.

• The Integrated Geobotanical and Historical Change Mapping (IGHCM) approach evolved between 1970 to the present to document land-cover and land-use changes associated with the Prudhoe Bay oil field, AK.

• The maps use the aerial photographic record to portray changes since 1949.
Key points of the talk

• The IGHCM approach evolved during 40 years of mapping at Prudhoe Bay starting with the International Biological Programme in 1972. The involved:
  o The oil industry’s regular updates of aerial imagery, topography and infrastructure maps, and analysis of their GIS database.
  o Development of the geobotanical mapping methods.
  o Incorporation of historical changes to terrain and infrastructure to make the IGHCMs.

• The GIS database for Map 32, made in the 1980s was recently updated with three years of imagery from 1990, 2001, 2010.

• Results:
  o Most of the direct oilfield infrastructure impacts occurred within about 15 years of the initial oil discovery at Prudhoe Bay.
  o Indirect impacts such as flooding and permafrost degradation continued to expand nonlinearly over the next 27 years.
  o Thermokarst of ice-wedges in areas non-adjacent to roads expanded dramatically between 1990 and 2001.
Aerial image history of development

1949: U.S. Navy, B&W, 1:24,000
1968: ARCO, color, 1:12,000
1970: USGS, B&W, 1:68,000
1972: Air Photo Tech, U.S. Tundra Biome, B&W, 1:3000 & 1:24,000
1973-2011: Prudhoe Bay Unit, Color, 1:18,000 scale.
1974, 1977, 1982: NASA, CIR, 1:120,000, 1:60,000

Regular color photographs at 1:18,000 scale and maps of infrastructure and topography by the oil industry since 1973.
Aerial photos used in the first vegetation and soil mapping effort

• Aerial photos commissioned by CRREL and the oil industry in 1972, shortly after construction of the Spine Road and used in the first vegetation and soil maps in 1975.
  • Two scales of photos are represented.
    – 1:12,000 scale covering the whole field.
    – 1:3000 scale (black lines) flown along the road network.
Current Aerometric Aircraft & Sensors

LiDAR unit

Digital mapping camera (DMC)
The geobotanical mapping method


Kaye Everett
First Prudhoe Bay maps were of the IBP study area.
Separate maps were made for soils and vegetation/landforms (Everett 1975, Webber and Walker 1975).
1980: Geobotanical Atlas of the Prudhoe Bay Region, AK:

Master maps coded with soils, landforms & vegetation

Combining geobotany with historical change

Vegetation 1949

Historic anthropogenic changes

• USFWS cumulative landscape impacts in the Prudhoe Bay Bay Oil Field 1949-1983.
• Study included historical mapping at two scales
  – 1:24,000 map documented history of the main Prudhoe Bay oil field infrastructure.
  – 1:6000 Integrated Geobotanical and Historical Disturbance Maps (IGHDMs) of three areas.
**Key papers**

**IGHDM mapping method**

Use of Geobotanical Maps and Automated Mapping Techniques to Examine Cumulative Impacts in the Prudhoe Bay Oilfield, Alaska

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**Analysis of cumulative landscape effects at Prudhoe Bay**

**Articles**

**Cumulative Impacts of Oil Fields on Northern Alaskan Landscapes**

_D. A. Walker, P. J. Webber, E. F. Binnian, K. R. Everett, N. D. Lederer, E. A. Nordstrand, M. D. Walker_

Proposed further developments on Alaska's Arctic Coastal Plain raise questions about cumulative effects on arctic tundra ecosystems of development of multiple large oil fields. Maps of historical changes to the Prudhoe Bay Oil Field show indirect impacts that lag behind planned developments by many years and the total area eventually disturbed can greatly exceed the planned area of construction. For example, in the wettest parts of the oil field (flat thaw-lake plains), flooding and thermokarst covered more than twice the area directly affected by roads and other construction activities. Protecting critical wildlife habitat is the central issue for cumulative impact analysis in northern Alaska. Comprehensive landscape planning with the use of geographic information system technology and detailed geobotanical maps can help identify and protect areas of high wildlife use.


Areas of published geobotanical mapping at Prudhoe Bay

Brown (1975)
Tundra Biome

Walker et al. (1980)
Geobotanical Atlas

Map 22

Walker et al. (1987)
FWS cumulative effects analysis

Raynolds et al. (2012) update

History of infrastructure and roadside flooding was mapped at 1:24,000 scale for entire map area in Walker et al. (1987).
2003: National Research Council (NRC) Report

- Cumulative environmental effects of oil and gas activities on Alaska’s North Slope.
Aerometrics mapped the history of infrastructure for the entire oilfield for the NRC report up to 2001.

(NRC 2003, Appendix E, Ambrosius 2002)
The present study: Updating the IGHCM of Map 32 to 2010 for the MALS project

- NSF Maps and Locals (MALS) project
- Will use such maps to assess local people’s perceptions of the changes on the North Slope.
Raynolds et al. 2012 CRSS poster

60 Years of Landscape Change within an Arctic Oilfield, Prudhoe Bay, Alaska

1. Introduction

We present an update of the integrated geological and historical disturbance maps. Walker et al. (1986) for a 2100-hectare portion of Prudhoe Bay Oilfield, Alaska. 23% of the area has been affected by industrial development and an additional 14% of the area has shown surface effects of permanent deglaciation.

- We used imagery from 1940-2010 to quantify changes over time. Aerial photos from before development were used to map the geobotanical conditions, soils, landforms, surficial deposits, and water bodies (Walker et al. 1986).
- The geobotanical mapping was used to create derived maps, such as breeding bird density and oil well recovery potential (Walker et al. 1986).
- Changes, through 1983, were photointerpreted and mapped (Walker et al. 1977). Recent imagery was used to update the map, including oil field development and other changes (Sections 4 & 5).
- Future work will focus on quantifying surface effects of changes in permafrost (Section 6).

2. Geobotanical mapping of conditions in 1968, before industrial development

- Primary Vegetation
- Landform
- Soils
- Surficial Deposits
- Water Bodies
- Breeding Bird Density
- Oil Well Recovery Potential
- Ground Insect Density

3. Example maps derived from geobotanical mapping

- Oil field development
- Surface Form
- Extraction Activities
- Marine Activities
- Horizonal Drilling
- Major Findings
- Area of changes not directly related to oilfield, including mining of tailings
- Total lake shoreline for study area
- Area of lakes not directly related to oilfield, excluding mining of tailings

4. Oilfield Development 1972 to 2010

- Area of types of industrial disturbance
- Total lake shoreline for study area
- Area of lakes not directly related to oilfield, excluding mining of tailings

5. Other Changes

- Area of new industrial development
- Area of water bodies
- Area of changes not directly related to oilfield, including mining of tailings

6. Future research

- 1972
- 2010
- Lake shore erosion continues to increase non-linearly
- There was a large increase in the area showing surface effects of permanent deglaciation between 1990 and 2001, possibly due to increased development in the study area.
Trends in industry-related changes

- **Direct impacts (gravel mining, pads, roads)**
  - Most direct impact leveled off after about 1983.
  - Indirect effects have continued to increase.

- **Indirect effects (thermokarst, flooding, vehicle trails)**
Widespread thermokarst expansion well beyond road margins between 2001 and 2010

Digital CIR image overlaid on LiDAR image, Courtesy of Aerometric Inc.
Increase in thermokarst

1972

A: Thermokarst on most residual surfaces with massive ground ice.

B: No thermokarst in drained lakes and surfaces with low ground ice.

2010
VHR imagery documents extensive thermokarst at Nuiqsut.

2006 Quickbird image from Google Earth
Take home points

• The IGHCM approach developed because of the coincidence of:
  o Evolving interest by scientific community in the geobotany, permafrost and climate change of the Arctic, starting with the Tundra Biome research in the 1970s, and includes most recently the MALS research which is bringing the relevance of this information to the people who are developing and living in the Arctic.
  o The oil industry’s and the government agencies’ evolving need for near-annual inventory of its North Slope infrastructure, which resulted in the amazing historical sequence of aerial photos and the GIS database covering the entire history of development.
  o Evolving technology for acquiring, mapping, storing, and manipulating spatial data.
  o Many serendipitous events including the right people, such as Kaye Everett, pushing this forward and facilitating its evolution.

• This historical mapping is the best record in the Arctic documenting the long-term trends change related to industrial development and to climate change.

• VHR satellite imagery offers a means for extending the record into the future and mapping much larger areas.