Grand Canyon Monitoring and Research Center

Results and Recommendations from the Remote Sensing Initiative

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Presentation Order

- **Brief History**
- **Objectives**
- **General Approach**
- **Approach & Results for Specific Monitoring Requirements**
- **Summary Recommendations**

Brief History

- **1997 – stakeholders request GCMRC investigate expanded use of remote-sensing technologies for data collection.**
- **1998 – GCMRC convenes remote-sensing PEP.**
- **1999-2003 – data collection, evaluation, and summary reports for specific requirements.**

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Initiative Objectives

- **Less intrusive, cost effective approaches that:**
  - **Provide acceptable accuracies**
  - **Increase capability and productivity**
  - **Expand spatial coverage**

General Approach

- **Review current monitoring requirements (parameters, accuracies) - interviews**
- **Literature review to determine most useful approaches/technologies**
- **Review characteristics of all existing (106) airborne and spaceborne sensors**

General Approach (*continued*)

- **Determine monitoring resources approachable by remote sensing**
- **Selection of viable sensors for testing**
- **Data collection**
- **Evaluation and report generation**

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Sensors Considered Inappropriate

- **All spaceborne – generally too low resolution, some 1 m resolution, but all sensors geosynchronous orbit with data collection at 9:45AM local producing serious shadows**

- **Airborne radar – aircraft too large to navigate canyon, too low resolution above canyon, and backscatter interference from canyon walls**

- **SHOALS LIDAR – restricted to very clear water and provides only 3-m point spacing**

Resources not Approachable

- **Very small or obscured features – individual plants, cave/adit deposits**
- **Chemical characteristics of water**
- **Faunal populations**
- **Fish foodbase**

Resources Approached

- **Archaeological structures**
- **Camping sites/beaches**
- **Physical characteristics of water**
- **Channel substrate**

Resources Approached (*continued*)

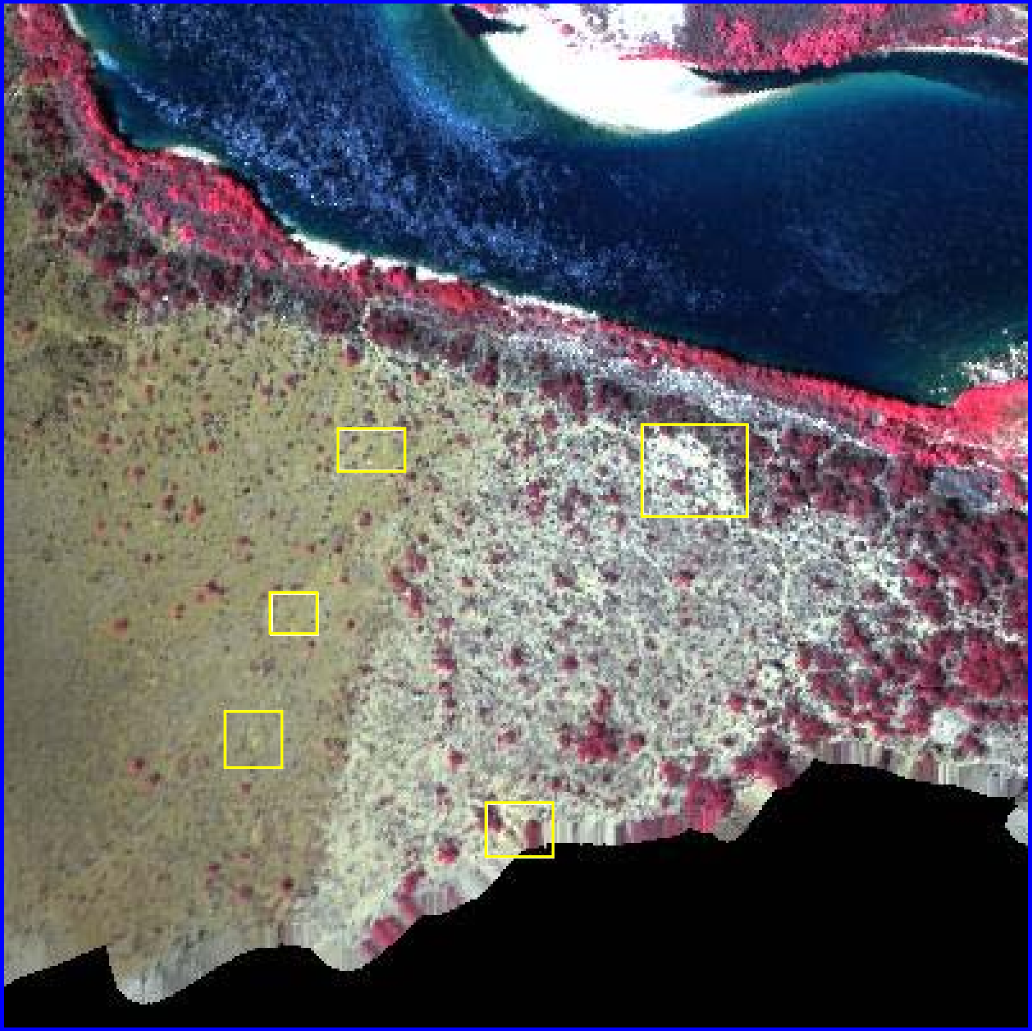
- **Terrestrial sediment deposits – geomorphology, topography**
- **Terrestrial vegetation mapping**
- **Terrestrial canopy volumes**

Archaeological Structures

- **Requirement: detect structures and monitor modifications**

- **Approach: 100-cm thermal-infrared imagery, different resolutions (11-100 cm) of visible/near-infrared image data, and high-resolution (3 cm) stereo photogrammetry**

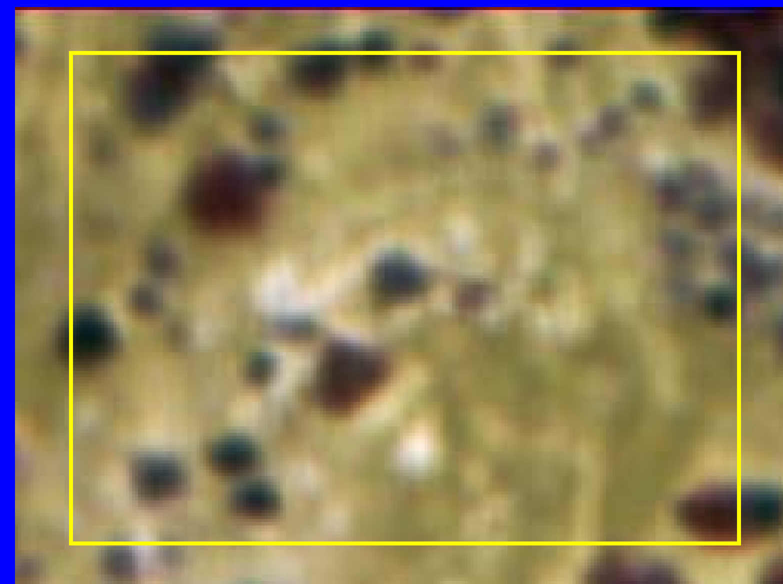
Detection Study Area – Unkar Delta



Detection - Results

11-cm CIR image

100-cm CIR image



- **Requires CIR with resolutions <11 cm res.**
- **Daytime TIR less effective than 100 cm CIR.**

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High-resolution Photogrammetry

- **Study area: Several selected archaeological sites**

- **Approach: Photogrammetric analysis of 3-cm-resolution stereo imagery (240-m AGL; $22,000), acquired pre- and post-monsoon season**

- **Results: Could not achieve the required 6 cm vertical accuracy to detect arroyo and structure modifications in post-monsoon data**

- **Possible Alternative: very high-resolution (30 cm) LIDAR (100-m AGL; $6,200)**

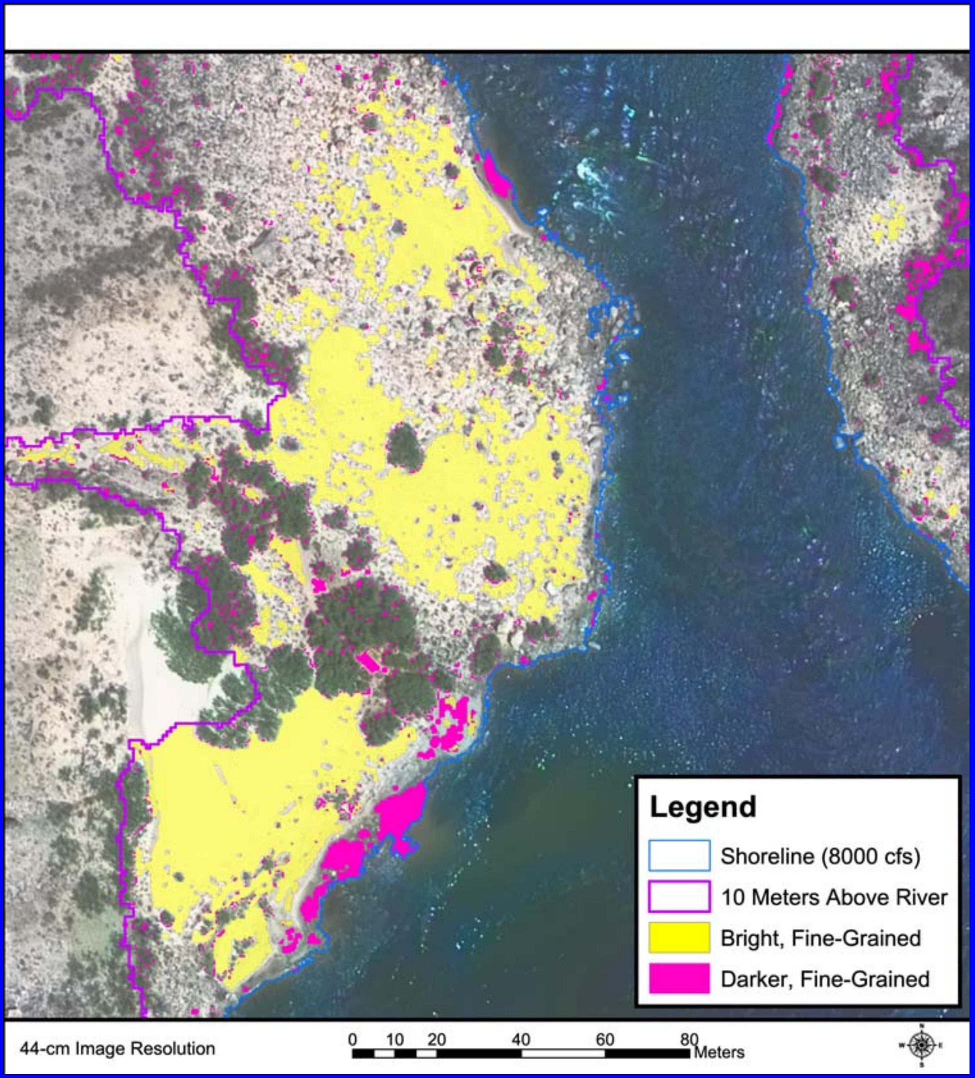
Camping Sites/Beaches

- **Requirement: Monitor quality of camp sites and beaches throughout the CRE; quality = open, smooth surfaces near river, but elevated above water's edge to avoid daily fluctuations.**

- **Approach: Image analysis of 44-cm, ortho-rectified, digital visible and near-infrared band imagery and 1-m DSM data produced from 22-cm stereo, b&w imagery (6,100-m AGL; $625); image data have 25-cm positional accuracy.**

Camping Sites/Beaches

- **Results**: Image color and texture and DSM data can be used to map *all* campable areas *throughout* the CRE in a matter of a few months, which cannot be achieved by ground surveys.



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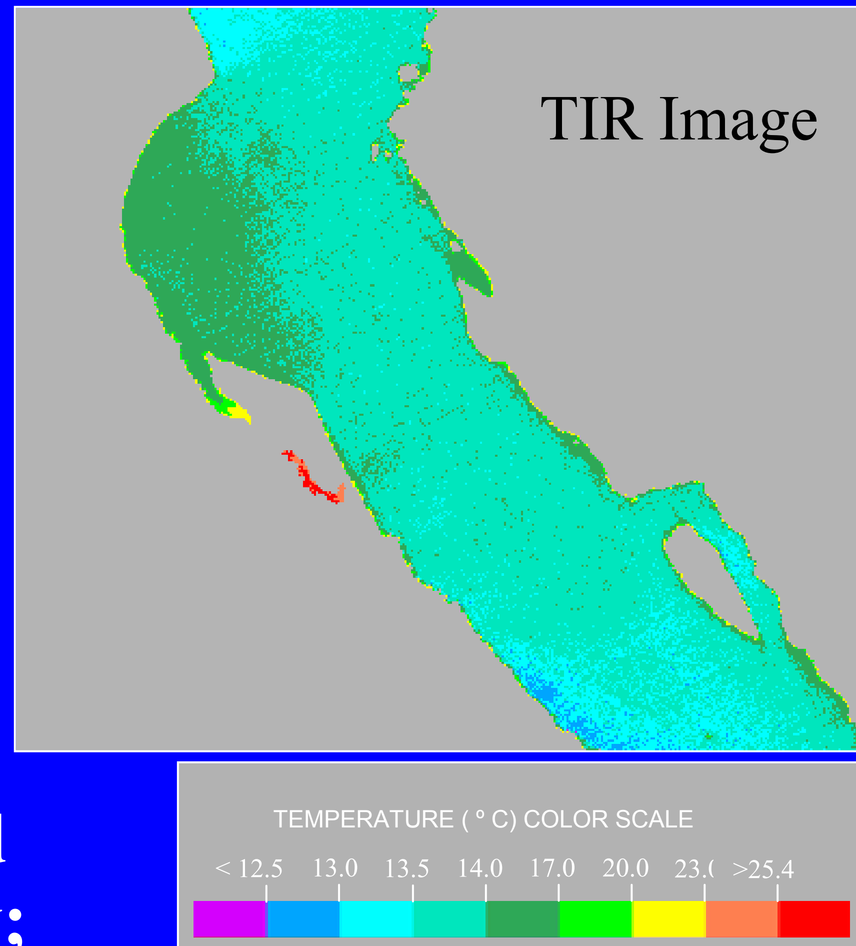
Physical Characteristics of Water

- **Requirements: Map the warm-water, fish habitats and monitor suspended sediment concentration.**

- **Approaches: 100-cm, georectified, daytime thermal-infrared imagery (365-m AGL; $600); 15-30 cm visible (blue-green and green) imagery (275-m AGL; $25 *unrectified*)**

Warm-water habitats - Awatubi Canyon



Georectification produced 1-2 m positional accuracy; 0.3 degree temperature sensitivity

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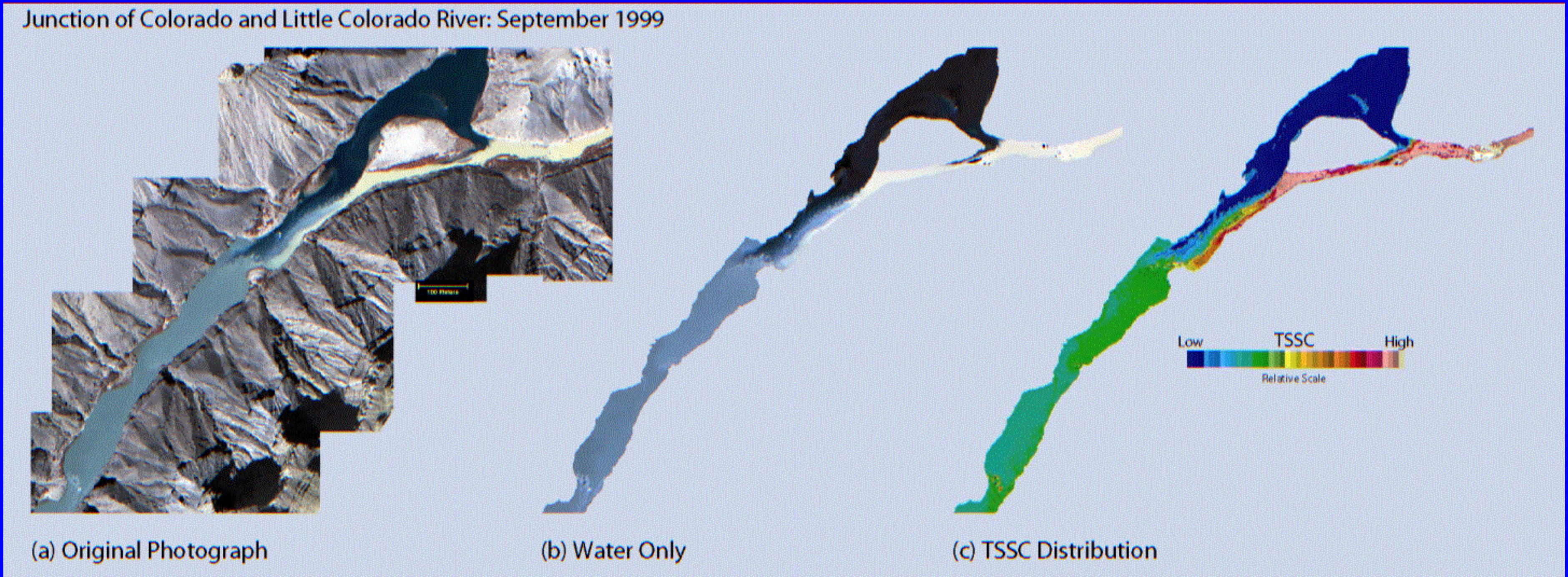
Warm-water habitats

- **Results: Mapped all warm-water habitats between RM30 and RM74 with a 20-minute multispectral flight and a week of data processing.**

- ***Note*: Mapping to absolute temperature requires ground-truth water temperature data from water gaging stations.**

Suspended Sediment - LCR



- **Results: Blue-green/green band ratio, calibrated with water-gage data, provide total suspended sediment concentrations. Cannot approach frequency of ground measurements, but does provide instantaneous, wide-area concentration maps.**

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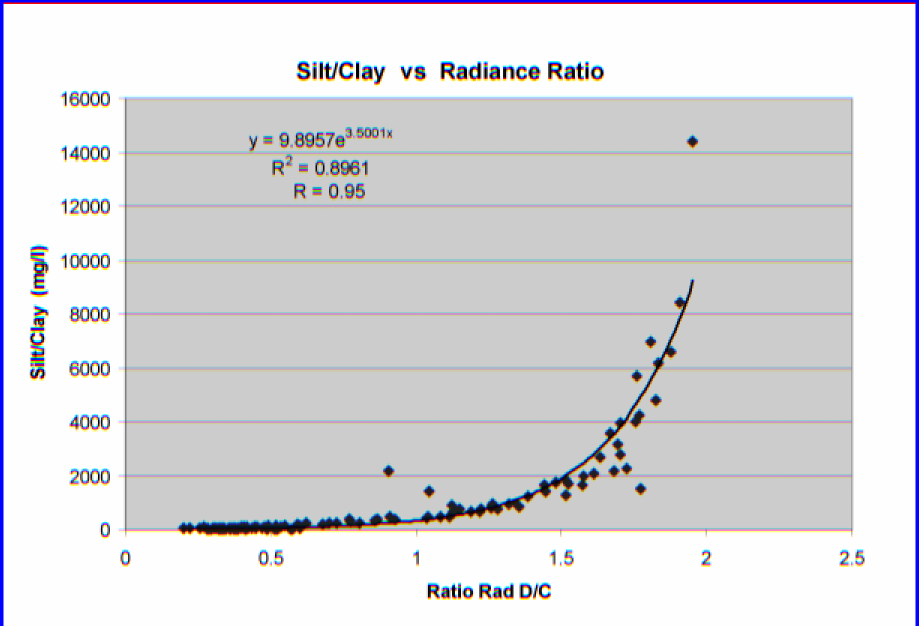
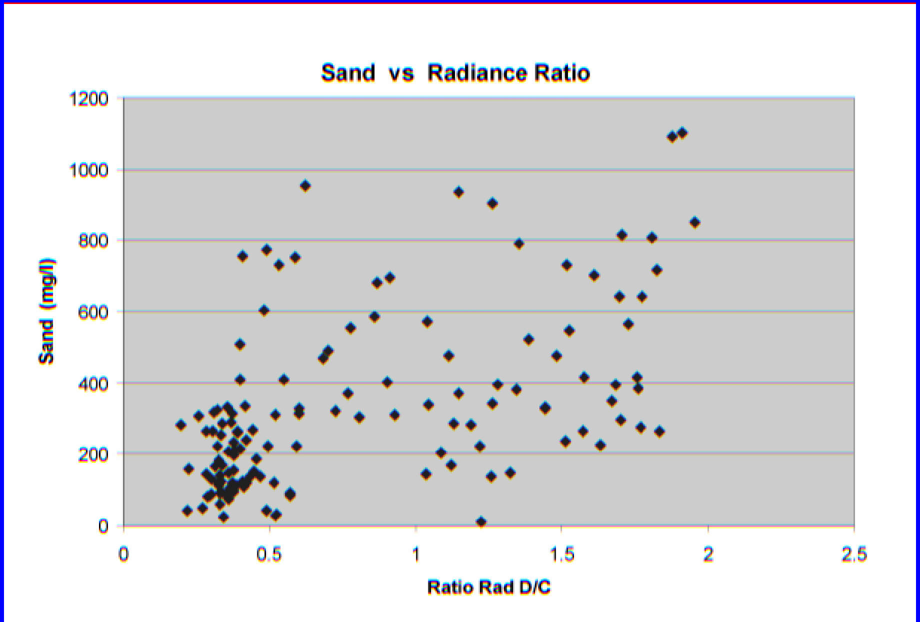
Suspended Sediment





- ***Note*****: Requires periodic ground calibration to insure accuracy. More accurate for silt/clay than sand-sized particle flux at this time.**

Channel Substrate

- **Requirements: (1) distribution of fine- and coarse-grained sediment and (2) substrate topography (bathymetry).**

- **Approaches: 15-cm, high-gain color imagery (275-m AGL; $25 *unrectified)*, 22-cm high-gain, b&w (1,100-m AGL; $1,250 *rectified*), and photogrammetry.**

Channel Sediments – northern 100 miles

positional accuracy = 30 cm.

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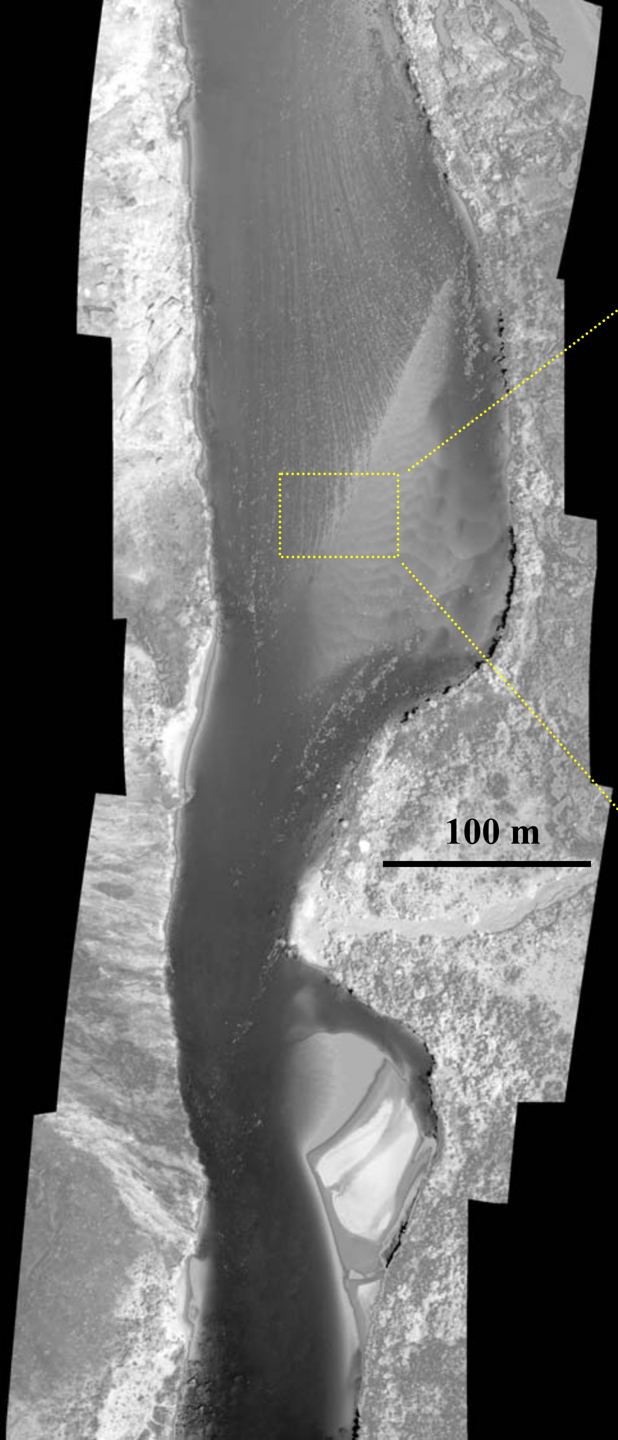
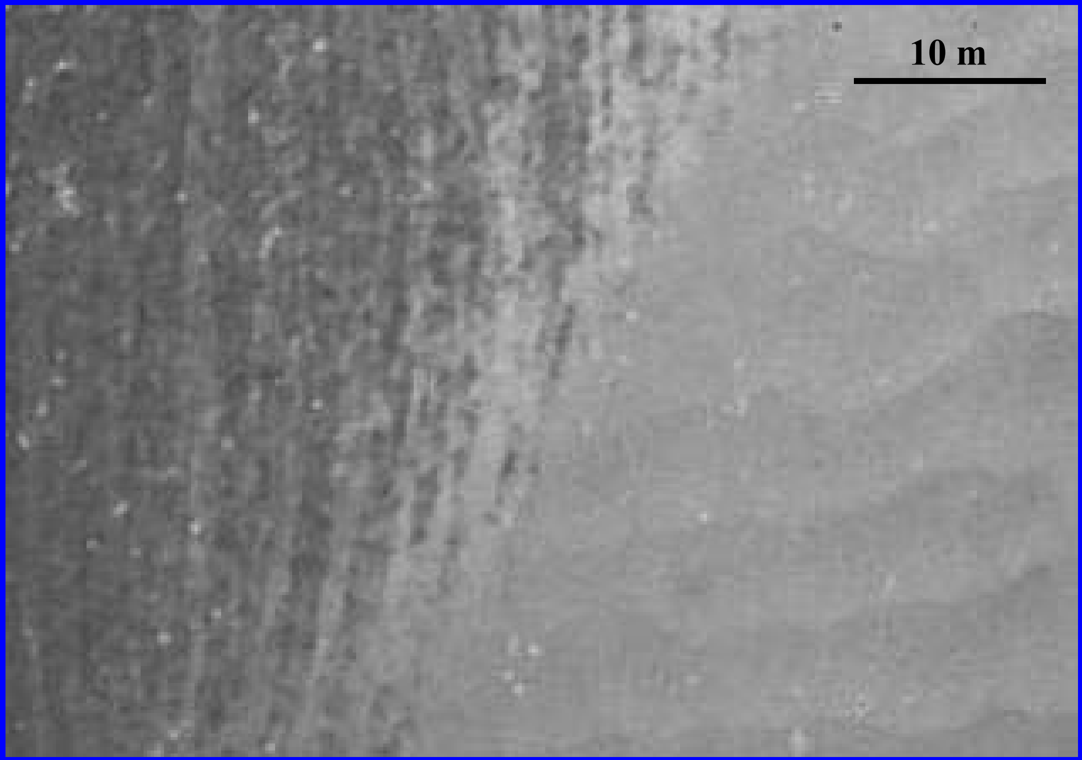
Channel Sediments





15-cm, georectified, digital blue-green imagery acquired with a high-gain state in May, 2003

Channel Morphology

- **Results: High-gain capability provided by digital cameras can map sediment distribution and grain size on channel substrate, but uncertain at this time what size ranges can be discerned.**

- ***Note*: Method limited by water clarity and depth, both of which attenuate light. Image rectification of inexpensive data to 1 m positional accuracy without accurate GPS/IMU information requires about 2 hours processing per image or about one-half year for 100 miles of 15-cm imagery.**

Bathymetry – channel topography

- **Photogrammetry is unable to model the channel topography due to a lack of surface texture on sediment deposits.**
- **SHOALS (green and NIR LIDAR) now worth testing; recent developments allow mapping to 20 m in turbid water and 40 m in clear water, but still 2 m point spacing.**
- **Acoustic multibeam data are slow to collect and process, but may be only viable approach, especially in deep water.**

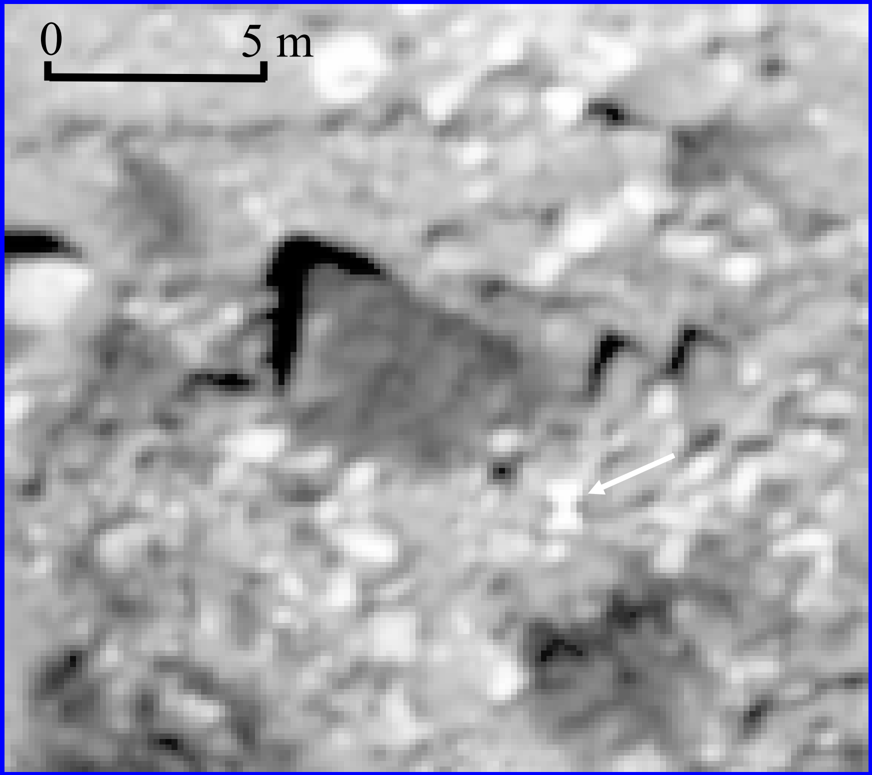
Terrestrial sediment deposits

- **Requirements: Map spatial distribution, geomorphology, and volume of fine- and coarse-grained sediment deposits. Initially, believed required image resolution near 6 cm provided by aerial photography; 30-cm positional accuracy; topography ≤ 25 cm vertical accuracy.**

Terrestrial sediment deposits

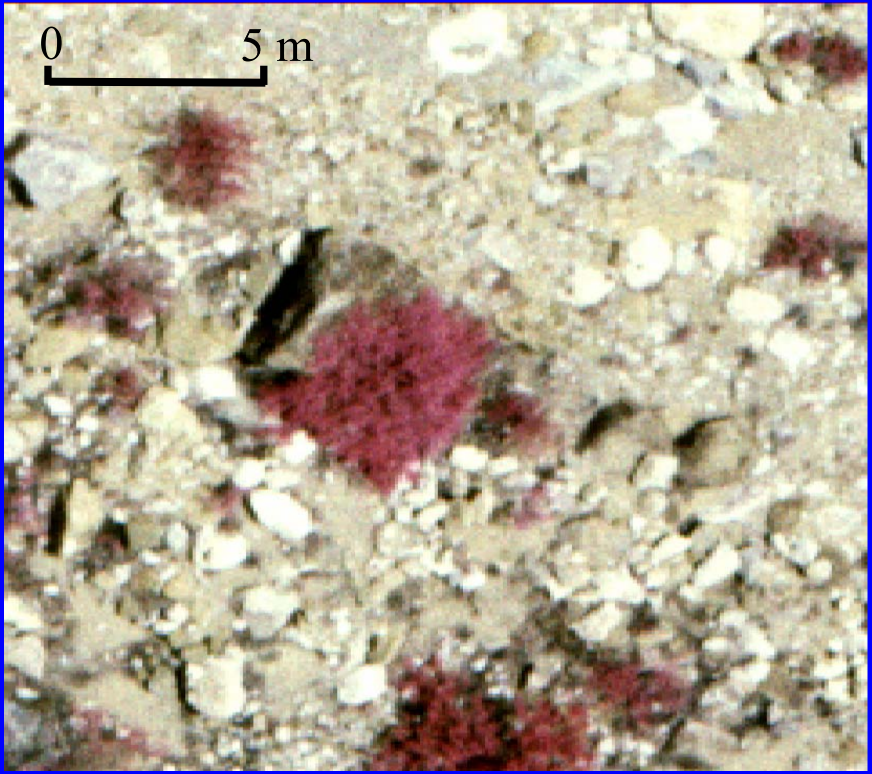
- **Approach: For geomorphic mapping, collected photographic and digital b&w, true-color, and color-infrared imagery at resolutions ranging from 6 cm to 30 cm. Determined ability and difficulty of different imagery for mapping spatial distribution and geomorphology of fine- and coarse-grained sediment.**

Geomorphology - Eminence



- **Results: Natural-color better than b&w imagery for distinguishing surface materials and surface texture.**

Geomorphology - Eminence



- **Results: CIR imagery provides more unambiguous vegetation identification, which allows better and more unsupervised texture analyses, which is an important attribute of sediment deposits.**

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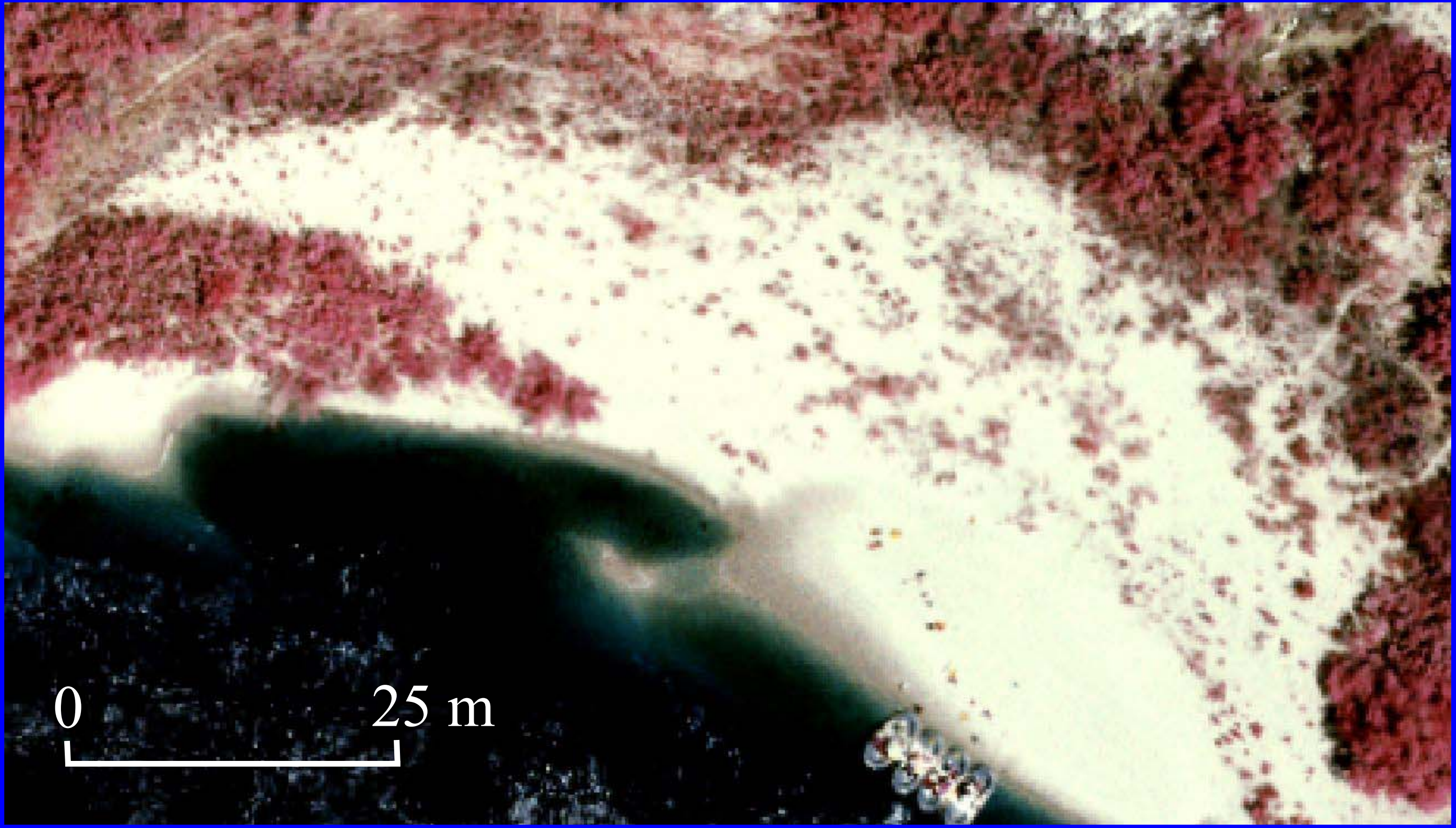
For Mapping in General

- **Results: For most GCMRC mapping applications, image resolution near 15-20 cm was found acceptable by the scientists. This result opened the door for digital sensors, which cannot obtain 6 cm resolution, but can provide calibrated, orthorectified data for many monitoring requirements.**

Topography – FIST LTM sites

- **Approach: Comparison of airborne elevations to ground surveyed elevations on bare and vegetated ground using following data:**
- **6-cm stereo photography (610-m AGL; $3,000)**
- **22-cm stereo digital imagery (6,100-m AGL; $625)**
- **LIDAR data – low res. (3,000-m AGL; $575) to very high res. (100-m AGL; $6,200)**

Topography – Eminence Area



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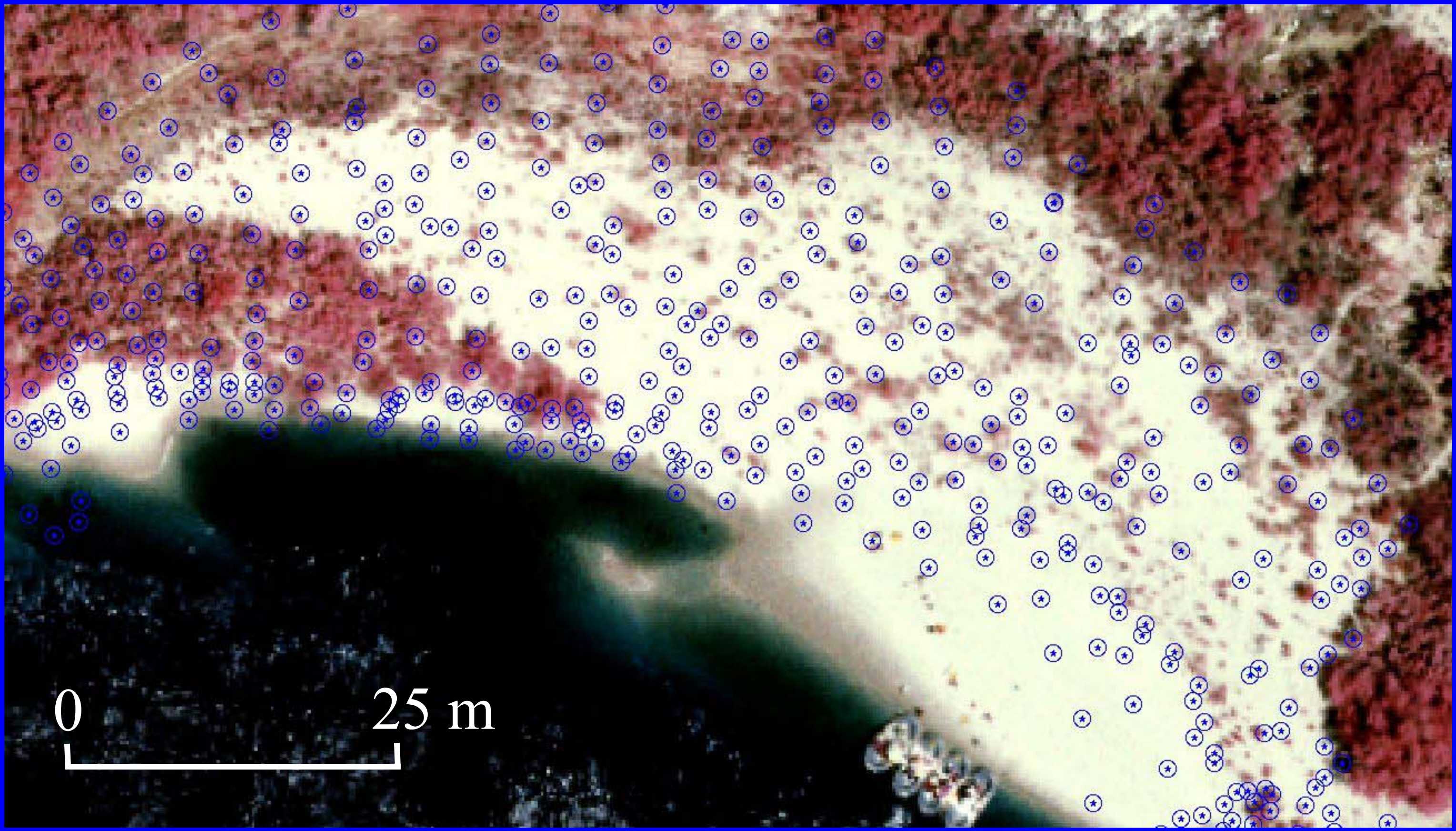
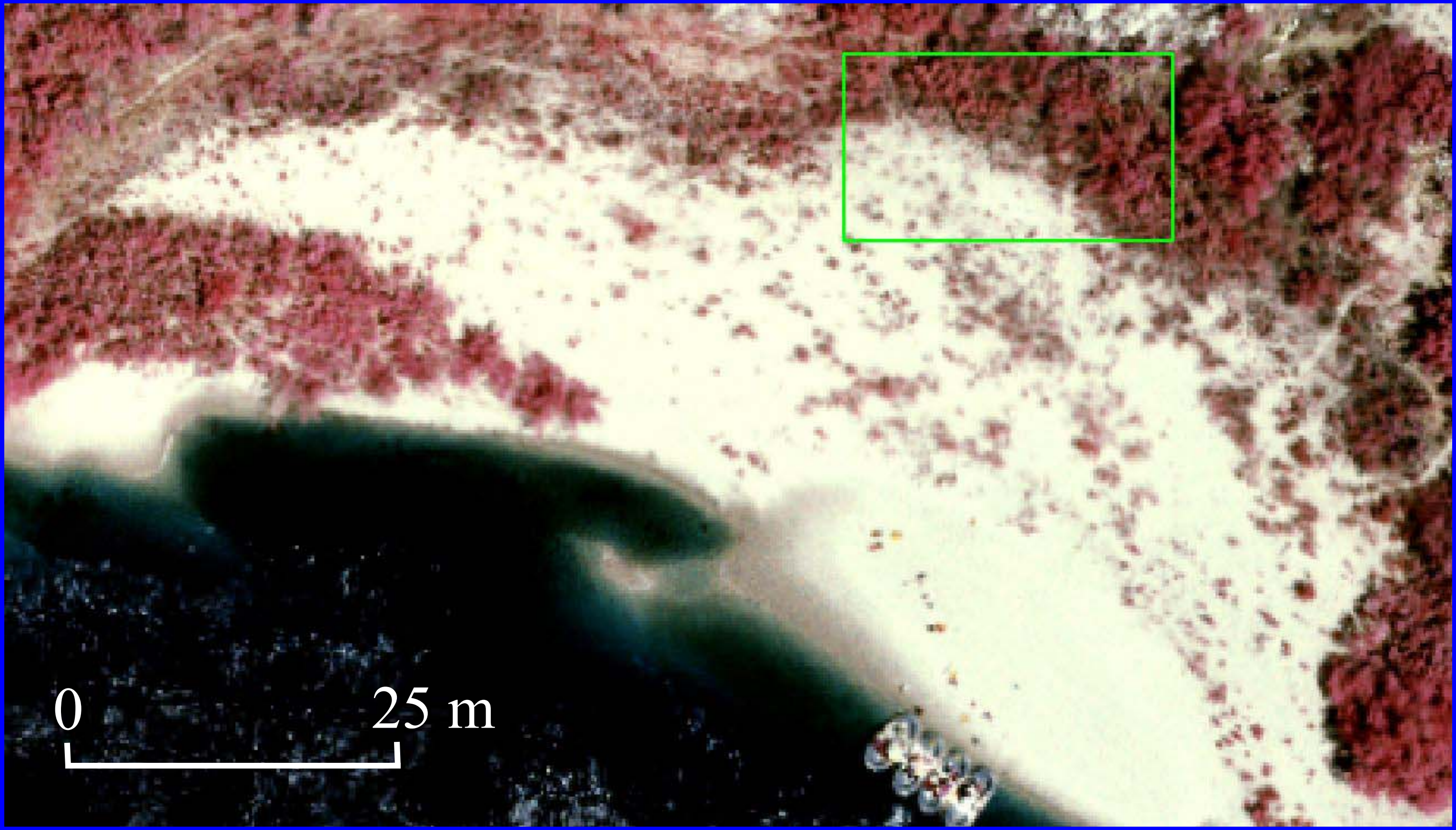
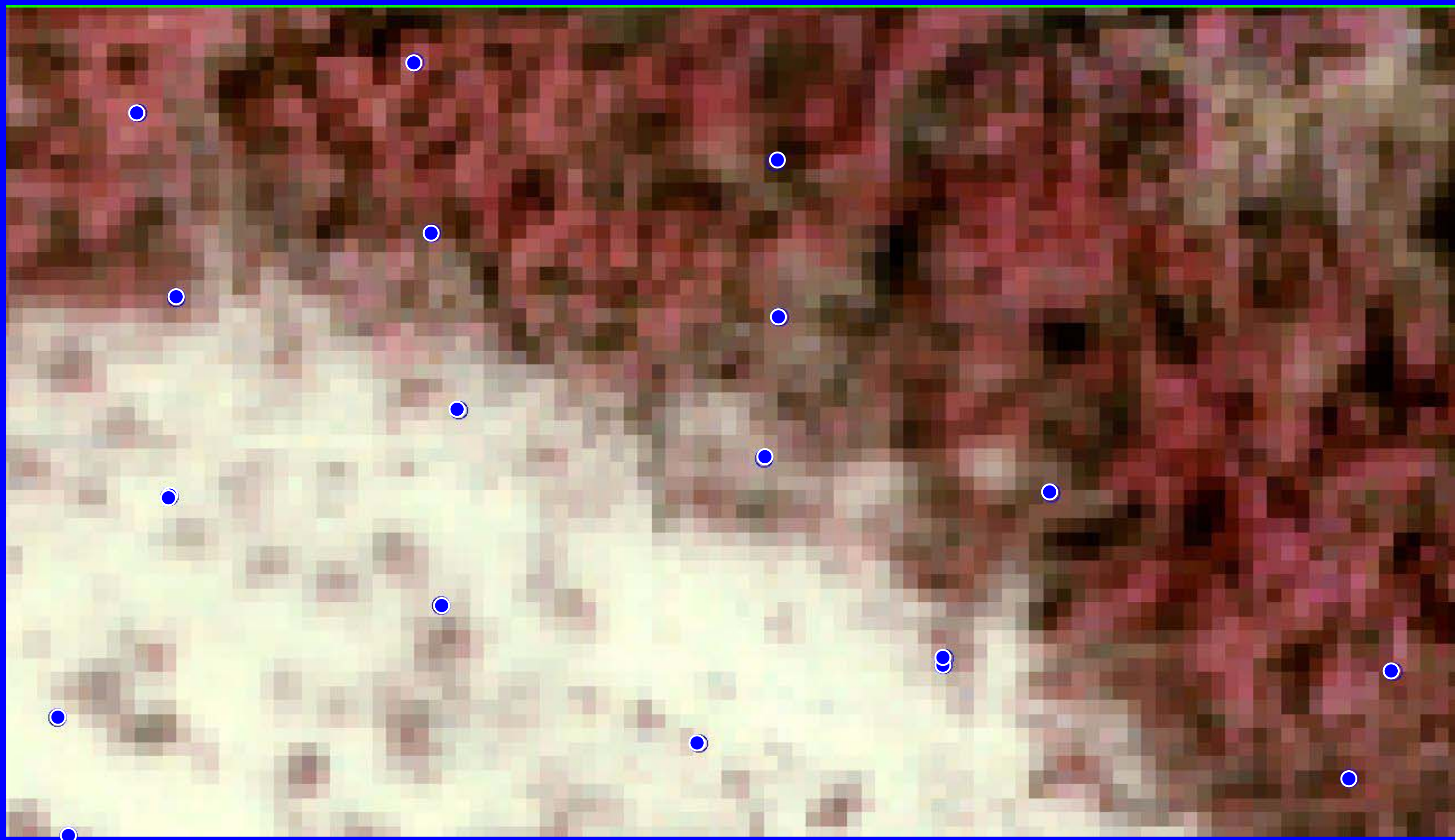
Ground Survey (2-3 m point spacing)



Subarea for DSM/LIDAR



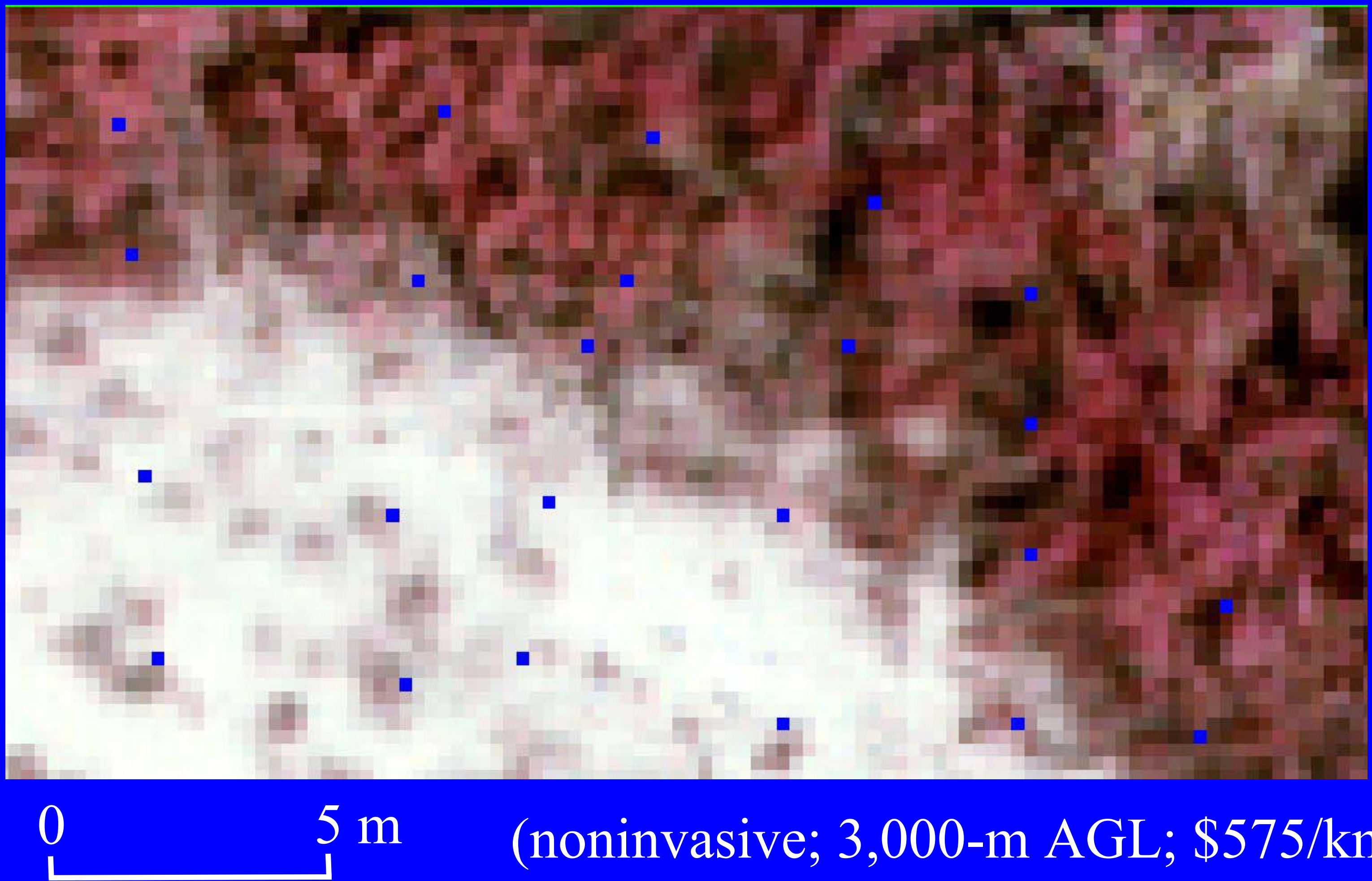
Ground Survey (2-3 m point spacing)



0 5 m

(invasive, $1,000/km)

Low Resolution (3.75 m) LIDAR



(noninvasive; 3,000-m AGL; $575/km)

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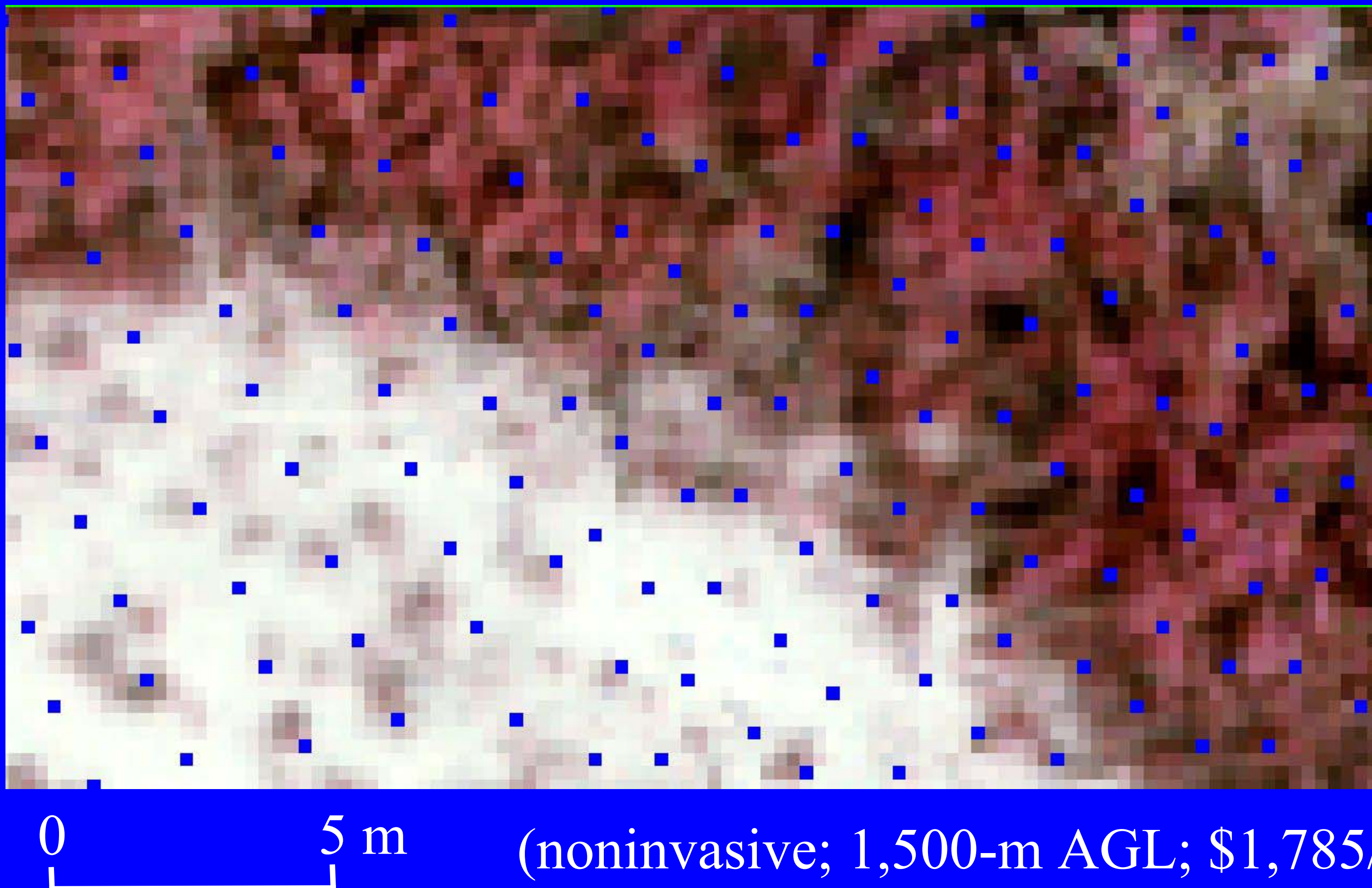
Moderate Resolution (1.5 m) LIDAR



(noninvasive; 1,500-m AGL; $1,785/km)

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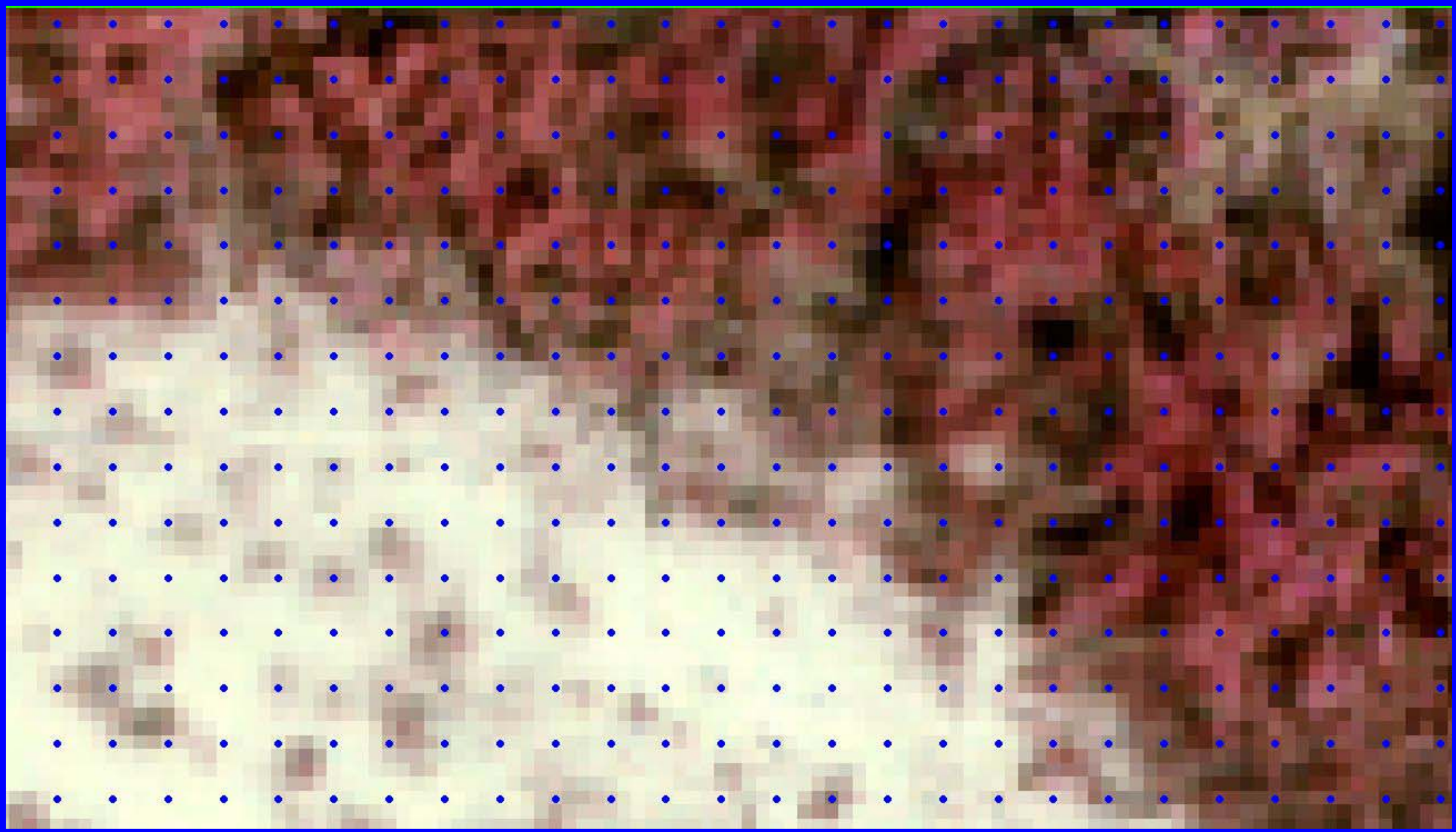
Automated Photog. (1 m) DSM



0 5 m

(~invasive; 2,400-m AGL; $625/km)

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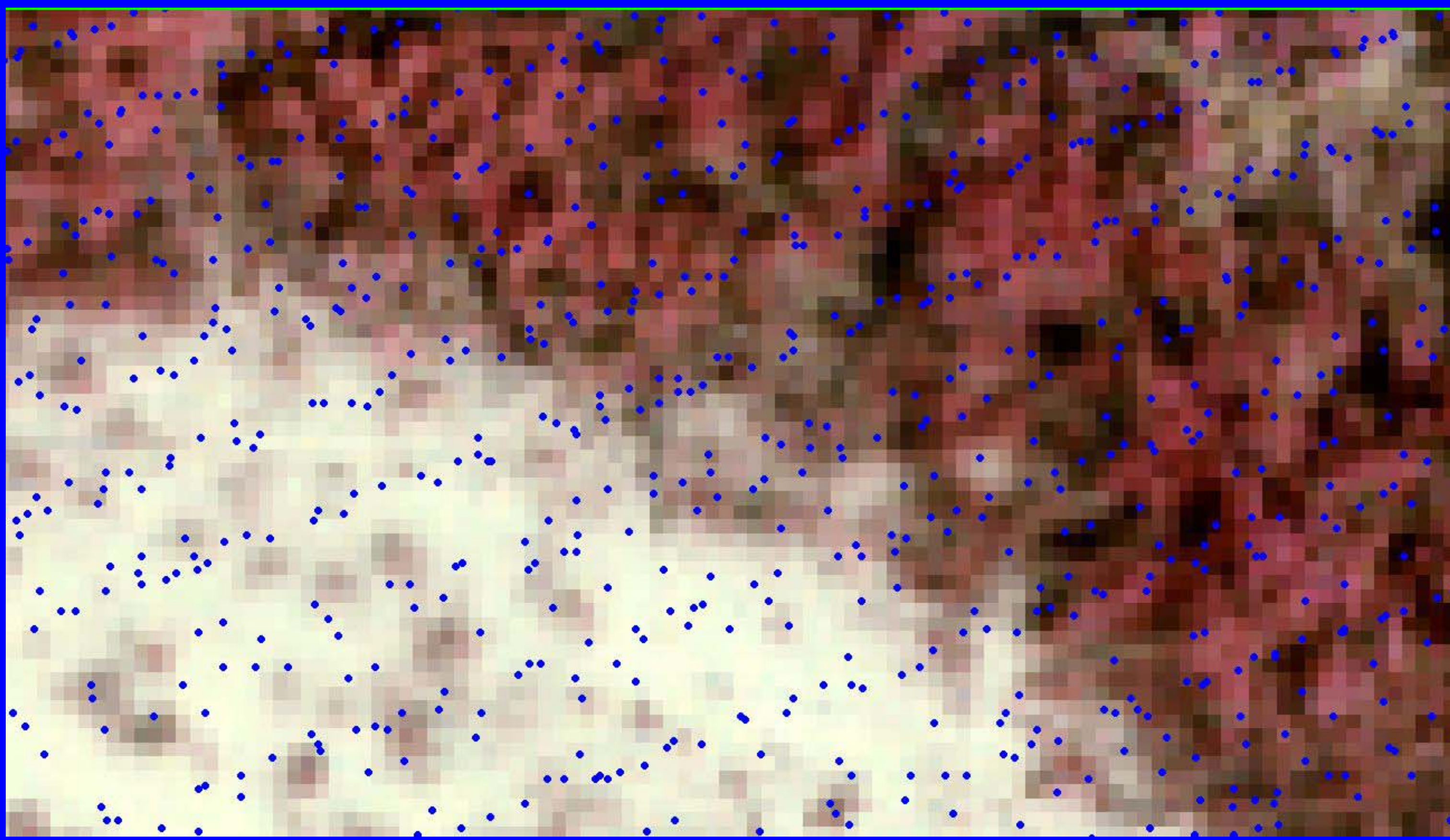
High Resolution (0.8 m) LIDAR



0 5 m

(noninvasive; 1,800-m AGL; $2,100/km)

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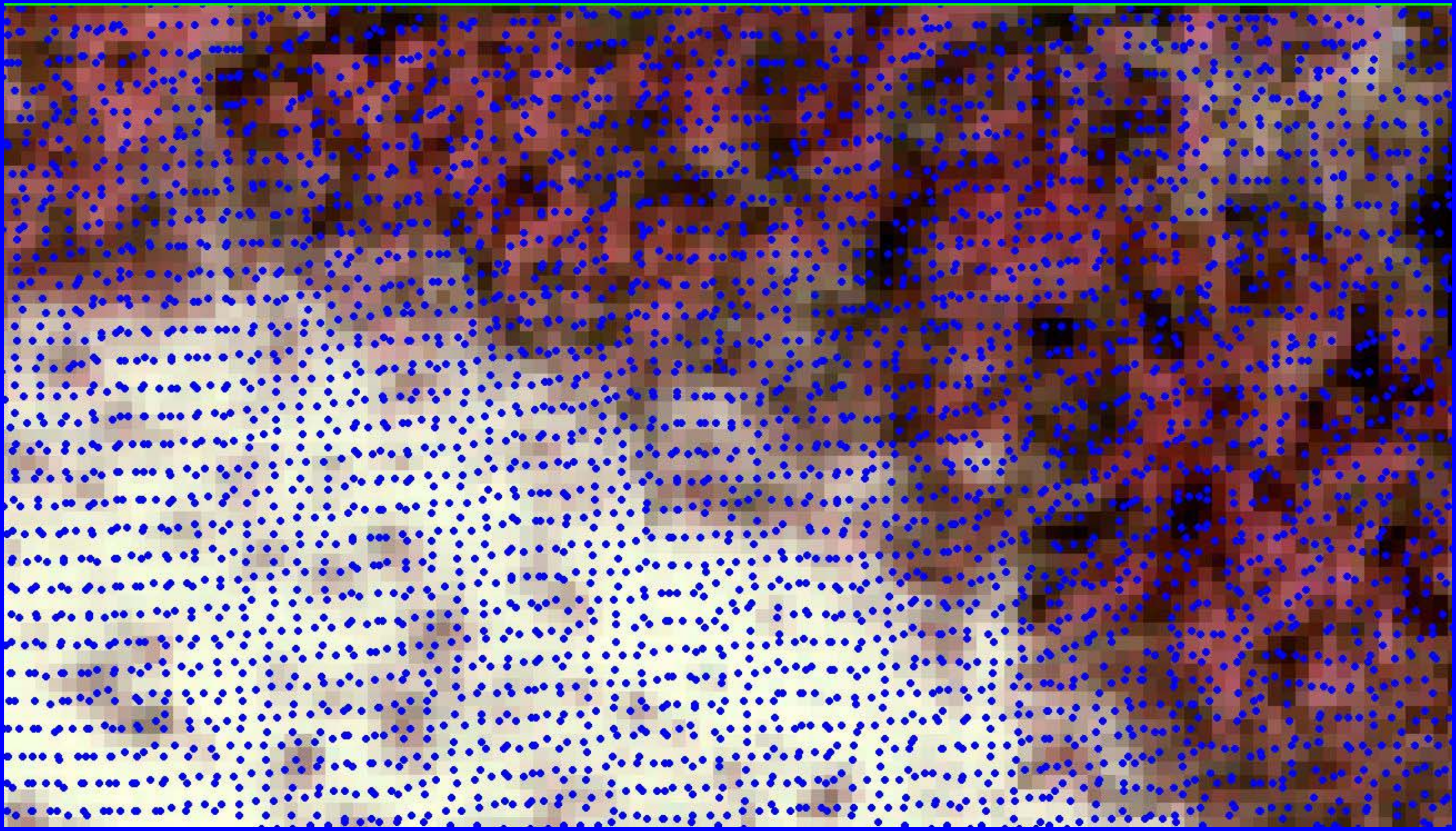
Very High Resolution (0.3 m) LIDAR



0 5 m

(noninvasive; 100-m AGL; $6,200/km)

Topography – Summary

Method	Accuracy Bare	Accuracy Veg.	Precision	Invasiveness	Cost/km
Ground Surveys	5 cm	5 cm	unknown	very	>$5,000
Manual Photogrammetry	32 cm	54 cm	unknown	panels every 200 m	$3,000
Automated Photogrammetry	44 cm*	129 cm	unknown	panels every 15 km	$625
Low-res. LIDAR	45-100 cm*	30-200 cm	unknown	None	$575
Mod.-res. LIDAR	15-40 cm *	60-280 cm	25-30 cm	None	$1,785
High-res. LIDAR	17 cm	*71 cm***	6 cm	None	$2,100
Very high-res. LIDAR	8 cm	*133 cm***	4 cm	None	$6,200

* have vertical offsets, some variable
** better processing may reduce these values

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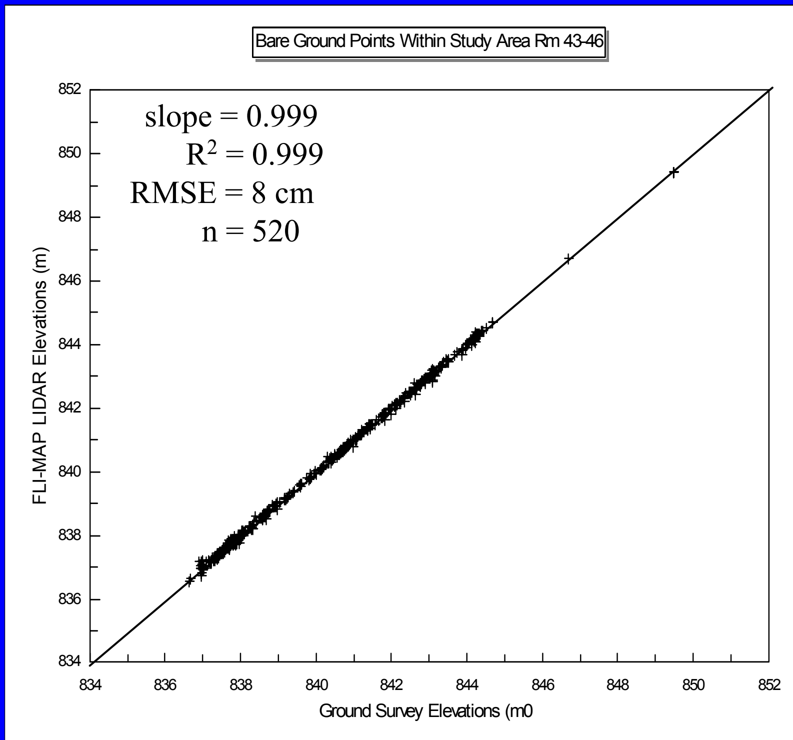
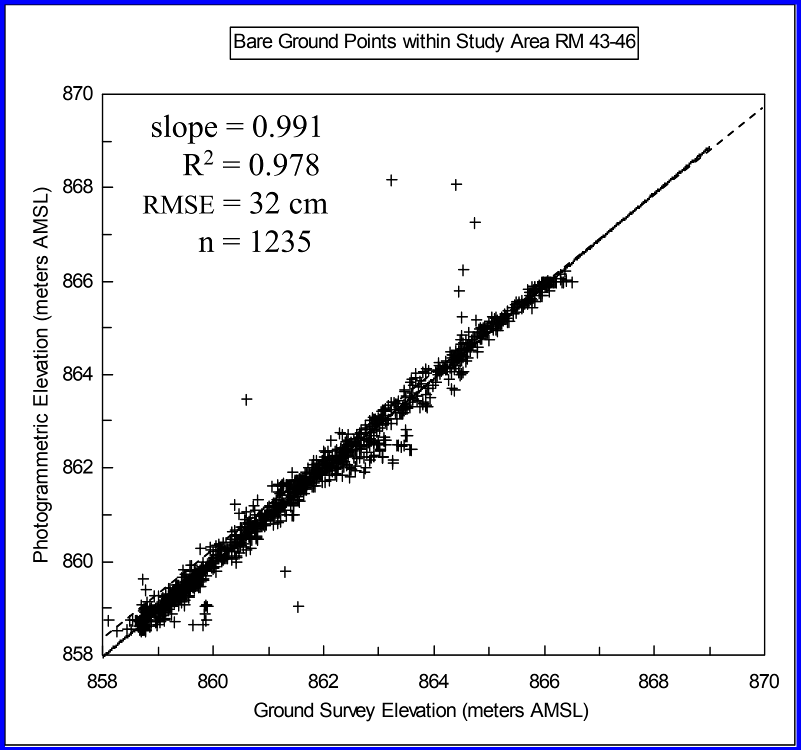
Results on Bare Ground





Very High Res. LIDAR
(noninvasive; 100-m AGL; $6,200/km)

Manual Photogrammetry
(invasive; 365-m AGL; $3,000/km)

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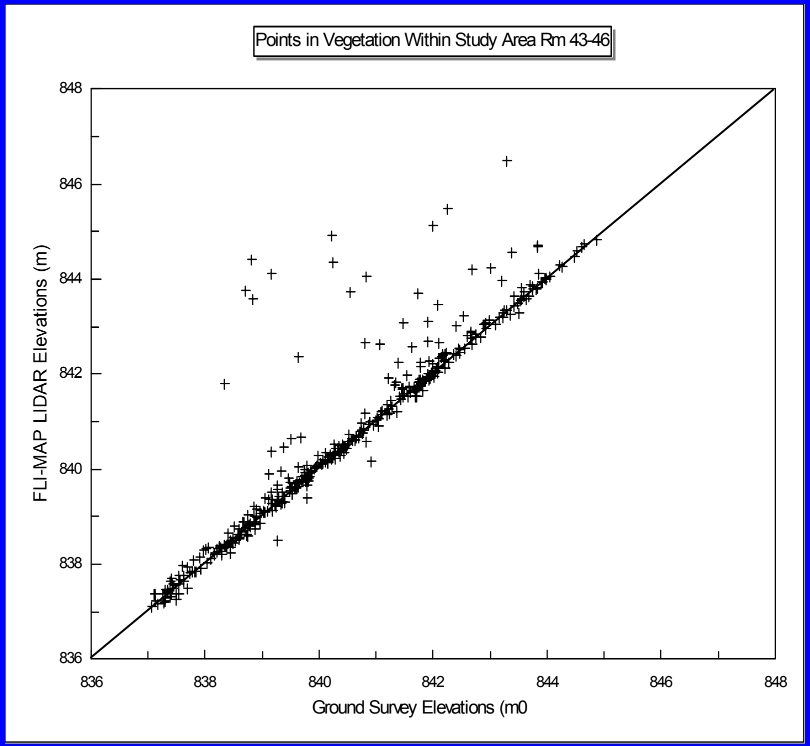
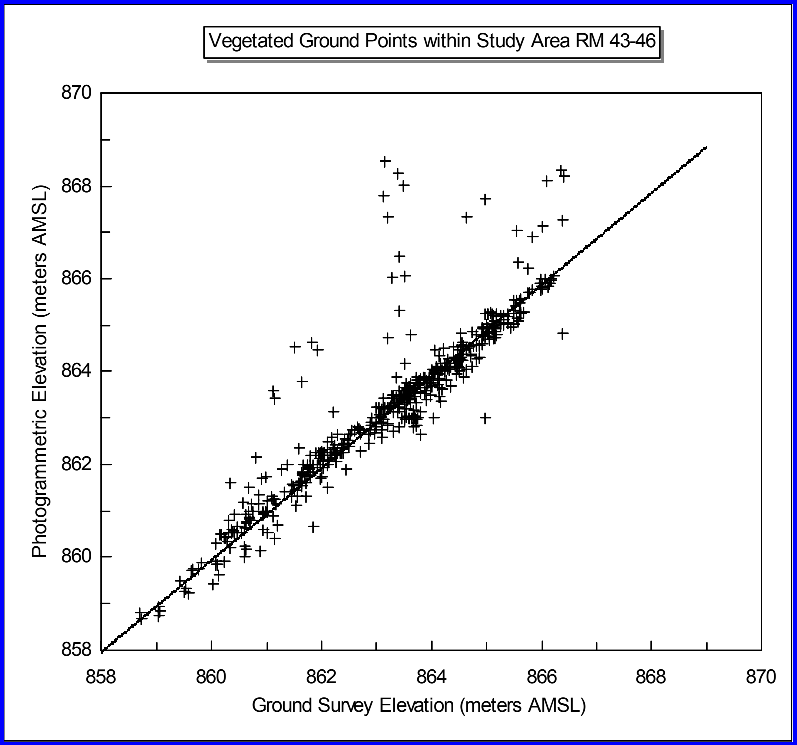
Results on Vegetated Ground



Very High Res. LIDAR



Manual Photogrammetry

Topography – Comments

- ***Manual photogrammetry* – Although acceptable accuracies obtained for bare and vegetated ground, method is invasive due to required control panels and method may not provide acceptable accuracies in vegetation during winter months due to extensive shadows.**

- ***Automated photogrammetry* – provides inexpensive DSM data for monitoring system-wide changes, but not for detailed sediment monitoring.**

Topography – Comments

- ***High and very high resolution LIDAR* – Both systems provide good bare-ground accuracies, are completely non-invasive, are not effected by shadows or cloud cover. In fact, *accuracy of very high resolution LIDAR data is close to accuracy of ground surveys, and may be useful for Archaeology requirements*. Improved data processing might produce much higher accuracies within vegetation and may also provide accurate canopy volumes.**

Canopy Volume

- **Requirements: Provide estimates of vegetation volumes within the CRE with 80-90% accuracy. Data used to model carbon budget for aquatic environment and to provide relative measure of quality of habitats for birds.**

Canopy Volume

- **Approach: Compared all previous topographic data (photogrammetric, LIDAR) within vegetated terrain with ground measurements of canopy heights.**

- **Evaluated manual photogrammetry and low and moderate-resolution LIDAR. Automated photogrammetry and higher resolution LIDAR data currently being evaluated.**

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Canopy Volume

- **Results:**
  - **Low and moderate resolution LIDAR too inaccurate (>40% error) for estimating canopy volume.**
  - **Manual photogrammetry approaches 80% accuracy, but processing very difficult, time-consuming, and expensive.**

Vegetation Monitoring

- **Requirements: Map the distribution of native and non-native species and vegetation alliances throughout the CRE with 30-cm positional accuracy and 80% vegetation mapping accuracy. Provides base map for future and retrospective temporal change analyses.**

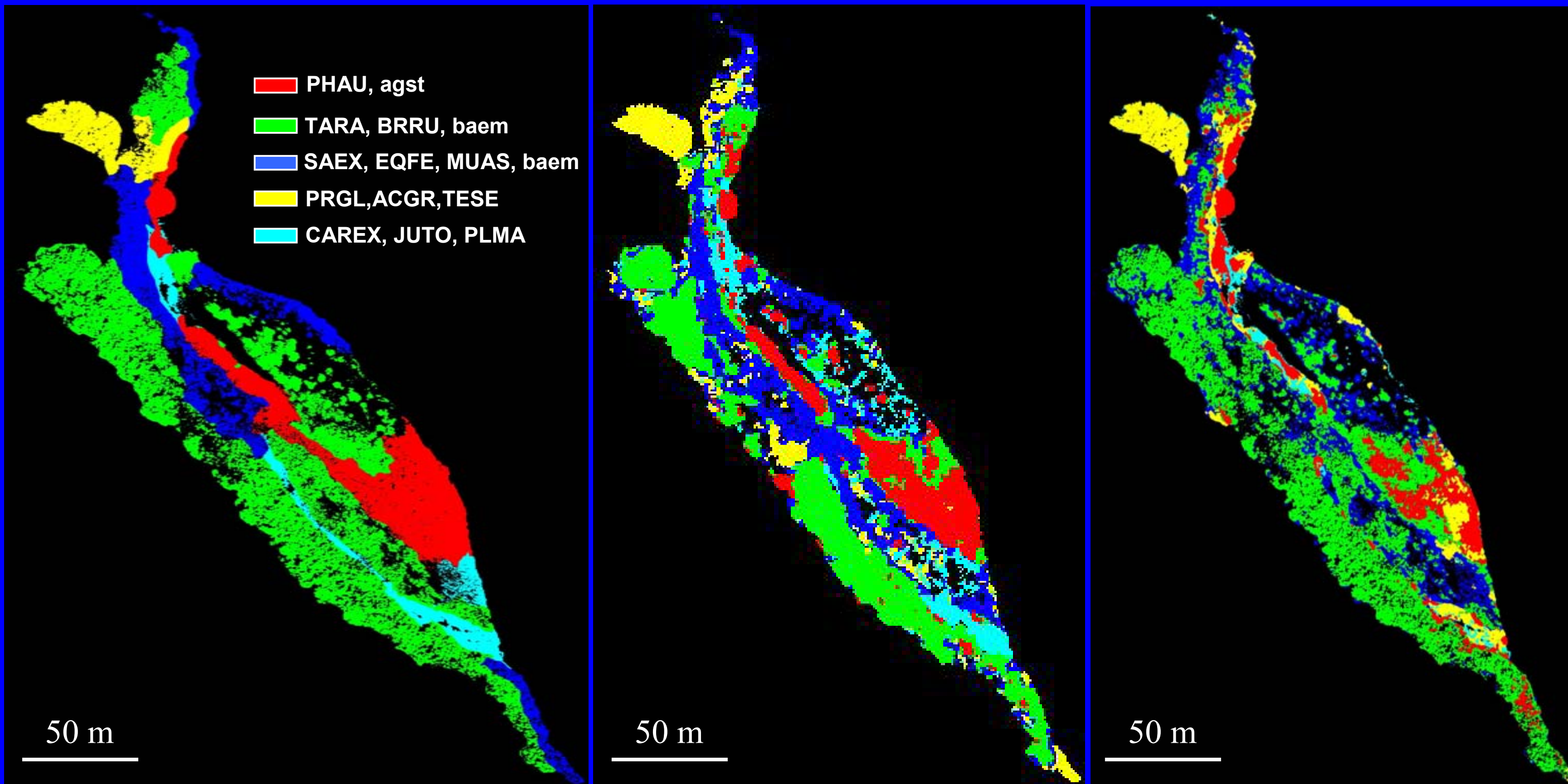
Vegetation Monitoring

- **General Approach: Examined color-infrared film and digital imagery, and digital multispectral (4 to 12 bands) imagery at spatial resolutions from 11 cm to 100 cm for the long-term vegetation monitoring sites. Considered hyperspectral data acquired in 1998, but data were found to be too noisy. Multispectral data acquired at 365-m to 6,100-m AGL for $600; CIR film 730-m to 3,050-m AGL for $350.**

Vegetation Monitoring

- **Initial Approach: Determined mapping accuracies for various vegetation communities within the vegetation LTM sites using the spectral and textural information provided by each type of image data for the vegetation communities.**

Kwagunt Marsh



Field mapping

100-cm multispectral
67% accuracy

11-cm CIR
63% accuracy

Initial Results for Sites

- **Accurate mapping requires data that can be calibrated for large regions = digital imagery.**
- **MS data produces higher accuracies, but at 100-cm resolution cannot be used for visual verification.**
- **CIR data approaches MS mapping accuracies, only using vegetation texture, which diminishes at resolutions > 30 cm and is non-existent at 100-cm resolution.**

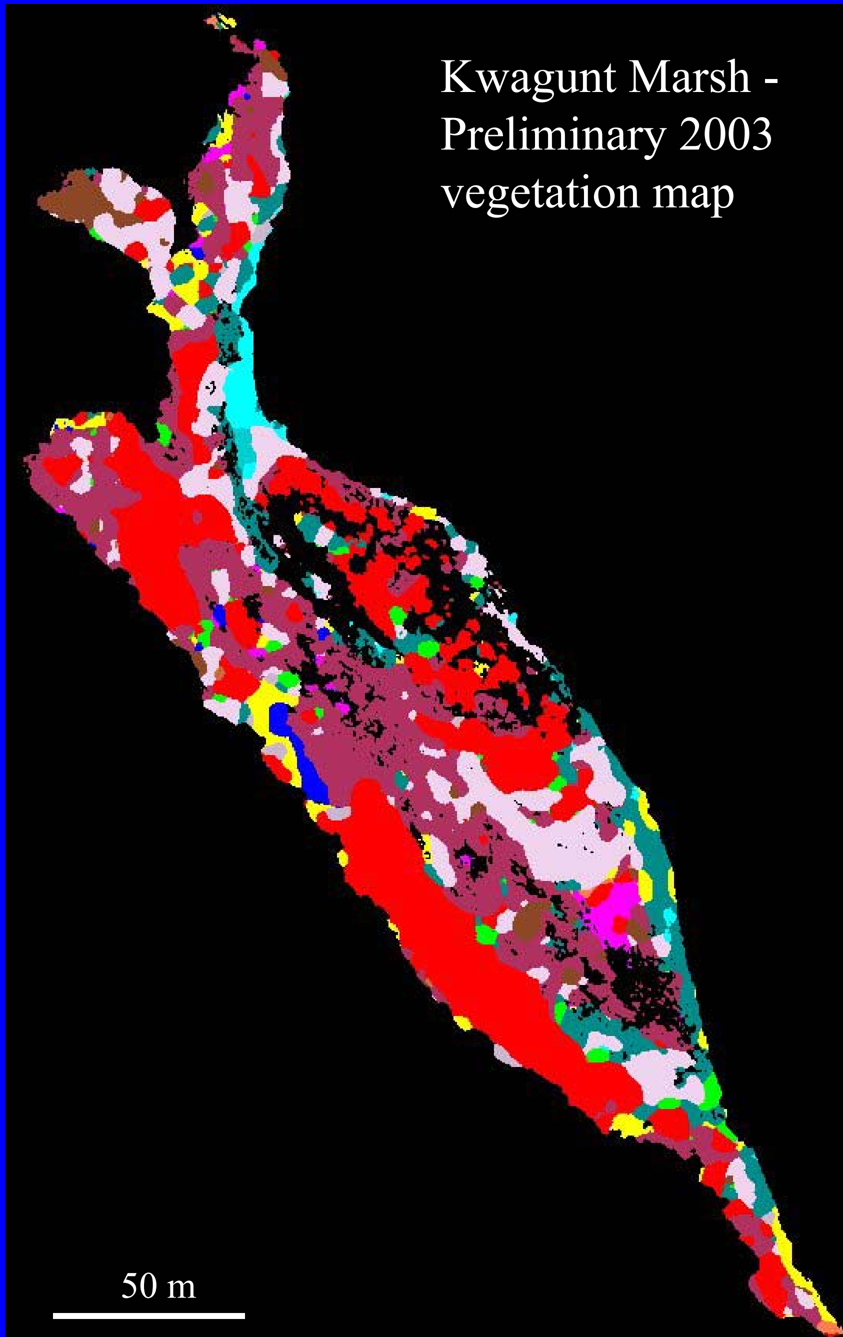
2002-3 CRE Inventory

- **Employed a “calibrated,” digital system that acquired 4-band imagery at 44 cm and b&w imagery at 22-cm and a DSM at 1 m cell size.**

- **Acquired at 6,100-m AGL at $625/km in 6-8 days for entire CRE.**

- **Automated rectification to 25 cm positional accuracy.**

Current mapping using 44-cm digital, orthrectified 4-band imagery



- PRGL (Mesquite)
- ACGR (Catclaw acacia)
- FAPA (Apache plume)
- Seasonally dry grass
- CERE (Hackberry)
- BAxx (Baccharis)
- Wetlands
- CLMA (Sawgrass)
- EQFE (Horsetail)
- Litter
- FONE (New Mexican olive)
- SAGO (Gooding willow)
- SAEX (Coyote willow)
- QUTU (Live oak)
- TARA (Salt cedar/Tamarix)
- Sparse shrubs (ACTA, LATR)
- TESE (Arrowweed)

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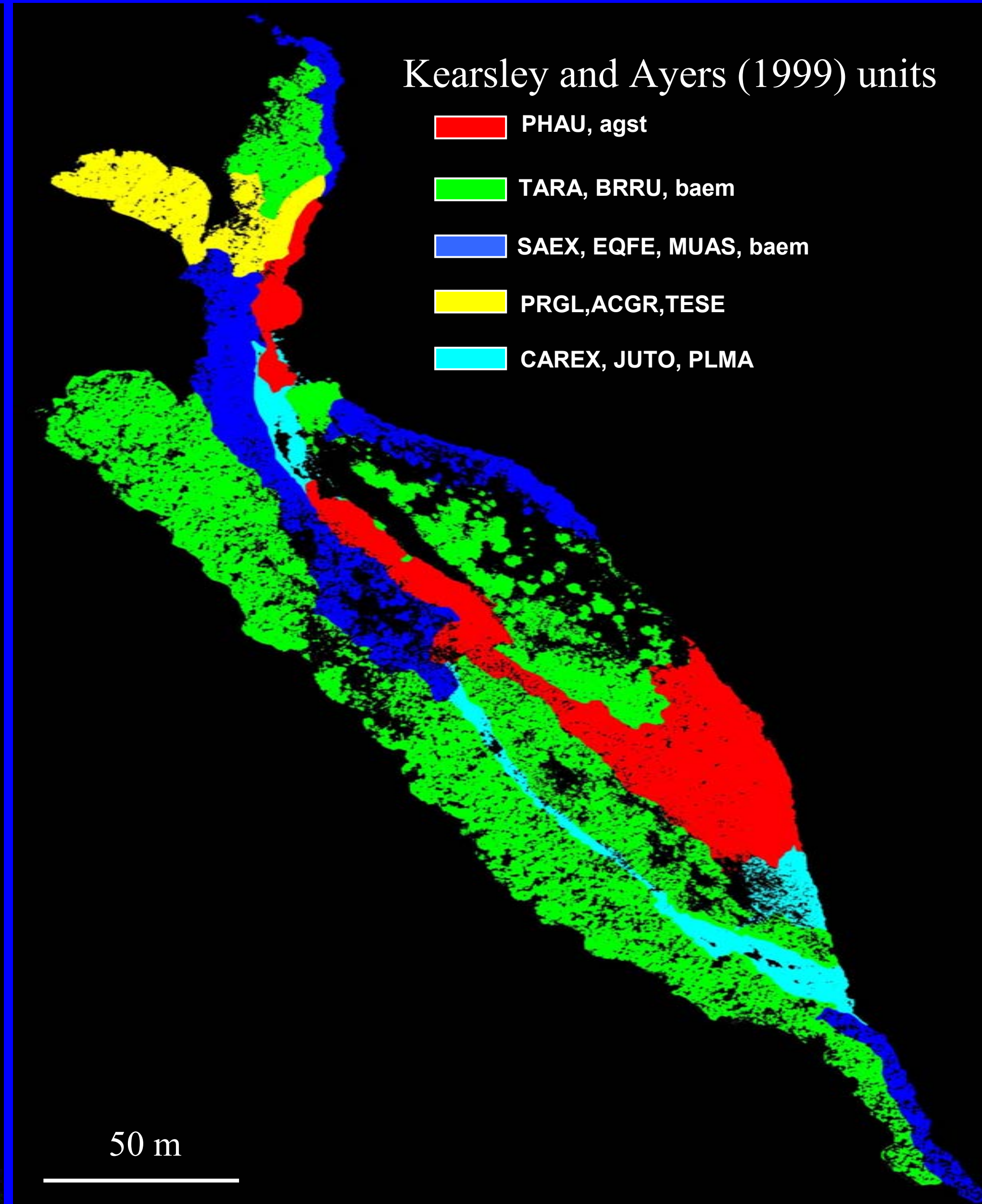
1999 field unit outlines
superimposed on
2003 preliminary
vegetation map
50 m


Kearsley and Ayers (1999) units
PHAU, agst
TARA, BRRU, baem
SAEX, EQFE, MUAS, baem
PRGL,ACGR,TESE
CAREX, JUTO, PLMA
50 m

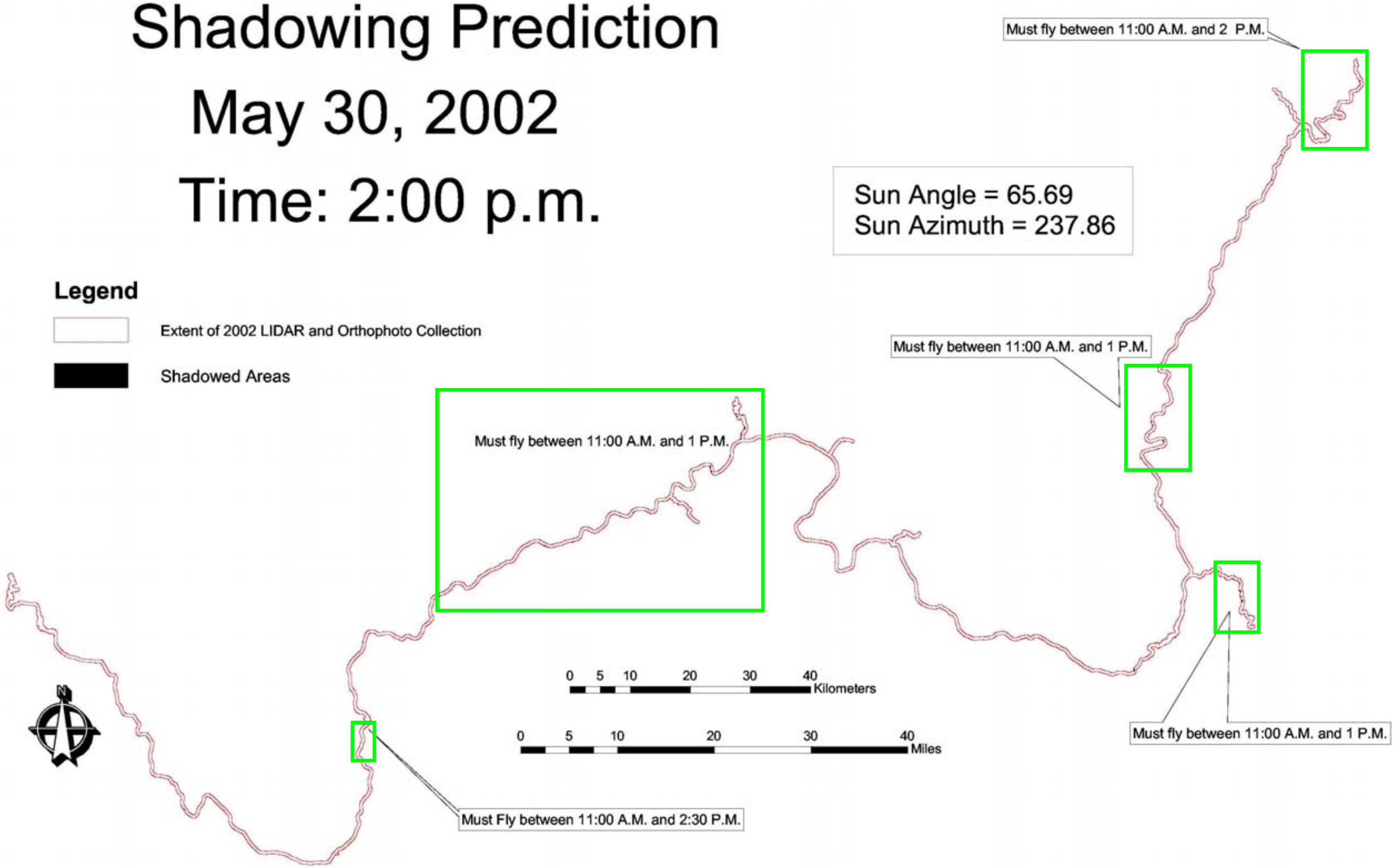
2002-3 CRE Inventory Results

- **Unknown at this time whether additional bands (MS data) would be better for vegetation mapping, which precludes texture, or whether better calibrated 4-band data will provide map accuracies near the 70-80% level. In any case, some field work will be required to reach >80% accuracy for all species, but remote sensing does significantly reduce the time for CRE vegetation inventory mapping.**

Minimum Imagery Protocols

- **For most applications:**
  - **Spatial resolution 15-20 cm (archaeology ≤ 6 cm; TIR = 100 cm)**
  - **If analog imagery, scanned at 15 microns**
  - **Color-infrared (TIR for warm-water habitat mapping)**
  - **GPS/IMU instrumentation (φ, κ, α for analog data)**
  - **Dual sensors/aircraft to insure against weather and equipment failures; 50% reduction in collection time (only 15% more cost)**
  - **Accurate and complete metadata**
  - **Acquired under TOD flight restrictions predicted by GCMRC shadow models to minimize shadows**

Shadowing Prediction
May 30, 2002
Time: 2:00 p.m.



Boxes indicate areas with restricted time windows for airborne data collection to *minimize* shadows with the riparian zone.

Optimum Imagery Protocols

- **Calibrated, digital sensors (12-16-bit data preferred for vegetation and aquatic monitoring) – assumes variable detector gains**

- **Orthorectified to 30-cm positional accuracy**

- ***Note*: EarthData Corp. has dual sensors that provide these minimum and optimum protocols, plus a 1-m DSM, with a 4-5 day mission for $625/km.**

Elevation Data Protocols

- **Terrestrial sediments ($\leq$ 25 cm accuracy)**
  - **Minimum = 1:4,800-scale, stereo photogrammetry**
  - **Optimum = high or very high resolution LIDAR**

- **Archaeology ($\leq$ 6 cm accuracy)**
  - **very high resolution LIDAR (limited area)**

- **Canopy Volume ($\leq$ 50 cm accuracy)**
  - **1-m DSM (automated photogrammetry)**
  - **High or very high resolution LIDAR (but more limited area coverage)**

Elevation Data Protocols

- **Channel (≤ 15 cm accuracy)**
  - **Minimum = acoustic multi-beam**
  - **Possibly = SHOALS LIDAR will probably work in areas of *clear*, *calm* water to depths 20-40 m (cost unknown). In the rapids, there will be data gaps due to the water's mirror surface. Recently, the Corps of Engineers have achieved 20 m depth penetration in *turbid* water, and therefore, the system may now be worth considering, but its best point spacing is 2-m**