Effects of dam operations and vegetation management on the preservation and geomorphic condition of archaeological sites

- **Glen Canyon Dam Adaptive Management Program Annual Reporting Meeting**
- **January 23-24, 2024, Phoenix, AZ**

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  - **[4]Fort Lewis College**

Program Goals: Archaeological and Cultural Resources

GCDAMP Regulatory Goals:

- **GCPA goal**: Operate Glen Canyon Dam so as to protect, mitigate adverse impacts to, and improve … natural and cultural resources…
- **LTEMP and NHPA goals**: “Preservation in place.”
    - LTEMP Goal 1: Maintain the integrity of potentially affected NRHP-eligible or listed historic properties in place, where possible, with preservation methods employed on a site-specific basis.

Photo credit: J. Caster (USGS)

FY 21-23 TWP Projects: Archaeological and Cultural Resources

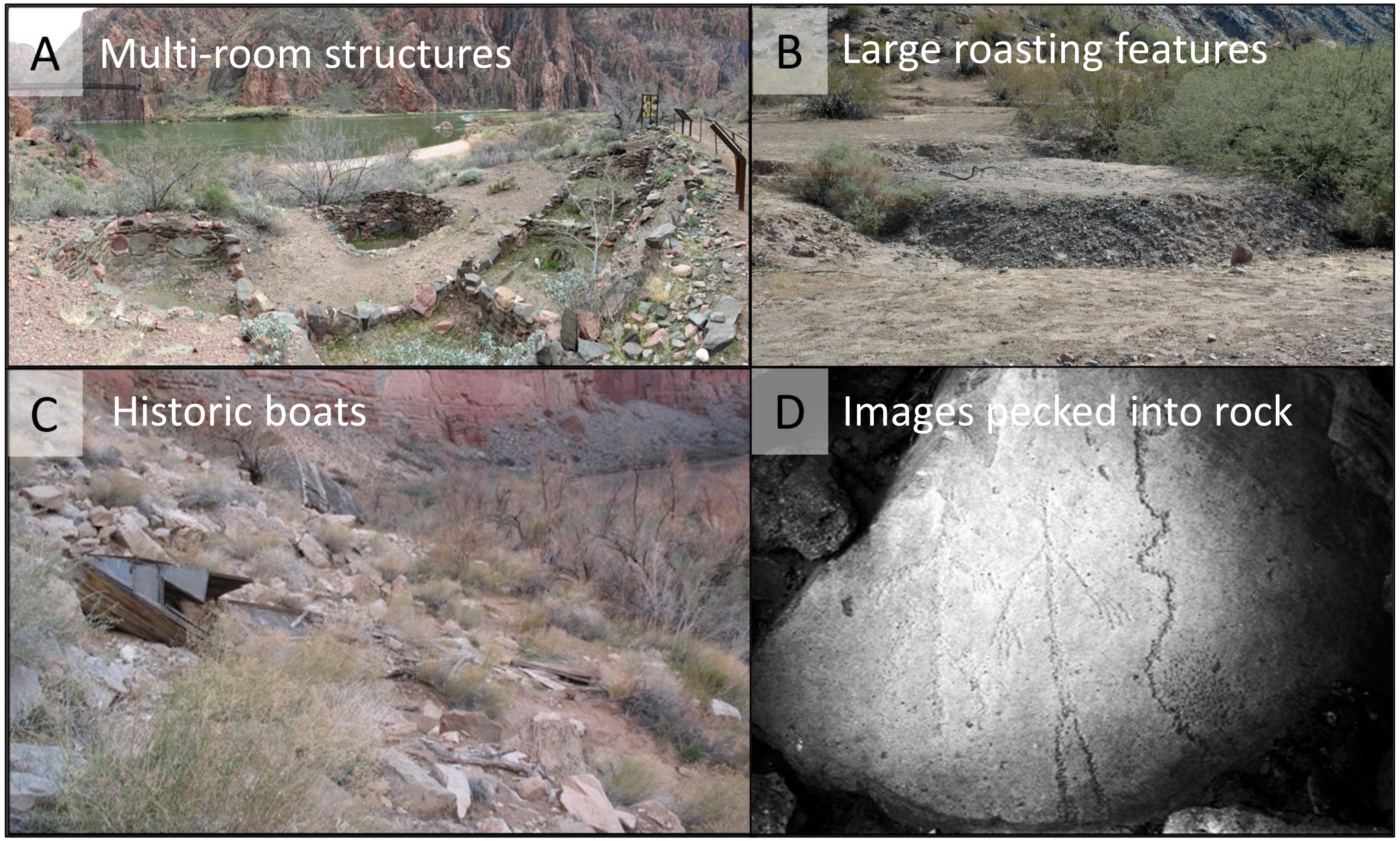
Triennial Workplan (TWP) projects collectively examine whether and how dam operations and experiments like HFEs, vegetation management, and site management by NPS help to achieve the LTEMP goal of preservation in place:

- GCMRC TWP
  - **Project D: Dam Operations, Vegetation Management, Archaeological Sites (USGS, Sankey, Fairley)**
    - FY2021/2022/2023/2024 ($258k/250k/266k/$349k)
  - Project Element O.3. Aeolian Response to a Spring Pulse Flow
    - FY2021 ($10k)
- Reclamation TWP
  - Project D.3. Cultural Resources Monitoring – Grand Canyon (NPS, Brennan, Dierker) and Glen Canyon NRA (NPS, Amy Shott)
  - Project C.7. GRCA Experimental Vegetation Treatment (NPS, Pilkington)

Photo credit: J. Caster (USGS)

Human Activity and Archaeology Along the Colorado River in Grand Canyon

- People have occupied and used resources in Grand Canyon for at least 9,000 years
  - Indigenous peoples have inhabited the Canyon region periodically since time immemorial
  - European explorers first visited the Canyon ~480 years ago
- Today, evidence of ancestral peoples and recent historic activities is displayed in 100s of archaeological sites along the river in Grand Canyon National Park
- Many sites are deteriorating due to dam operation effects (lack of floods, vegetation encroachment, loss of sediment) and other factors (rainfall run-off, and visitor impacts)



A. Prehistoric hearth in alluvial cutbank

B. Prehistoric bowl exposed by rainfall-runoff

C. Slab structure in gully

D. Fire-altered rock exposed by wind deflation

Photo credits: J. Dierker and other National Park Service staff

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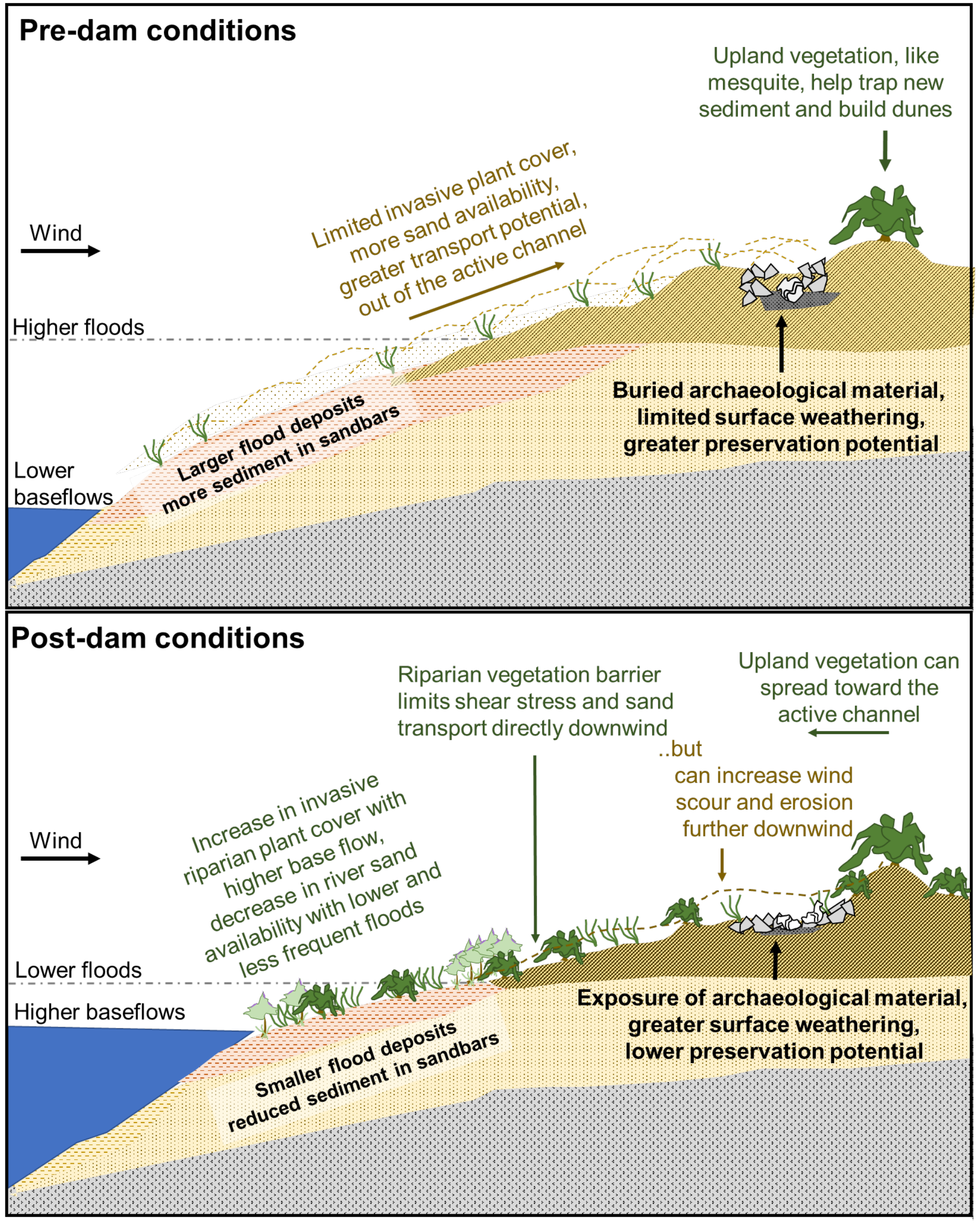
River management and archaeological site preservation

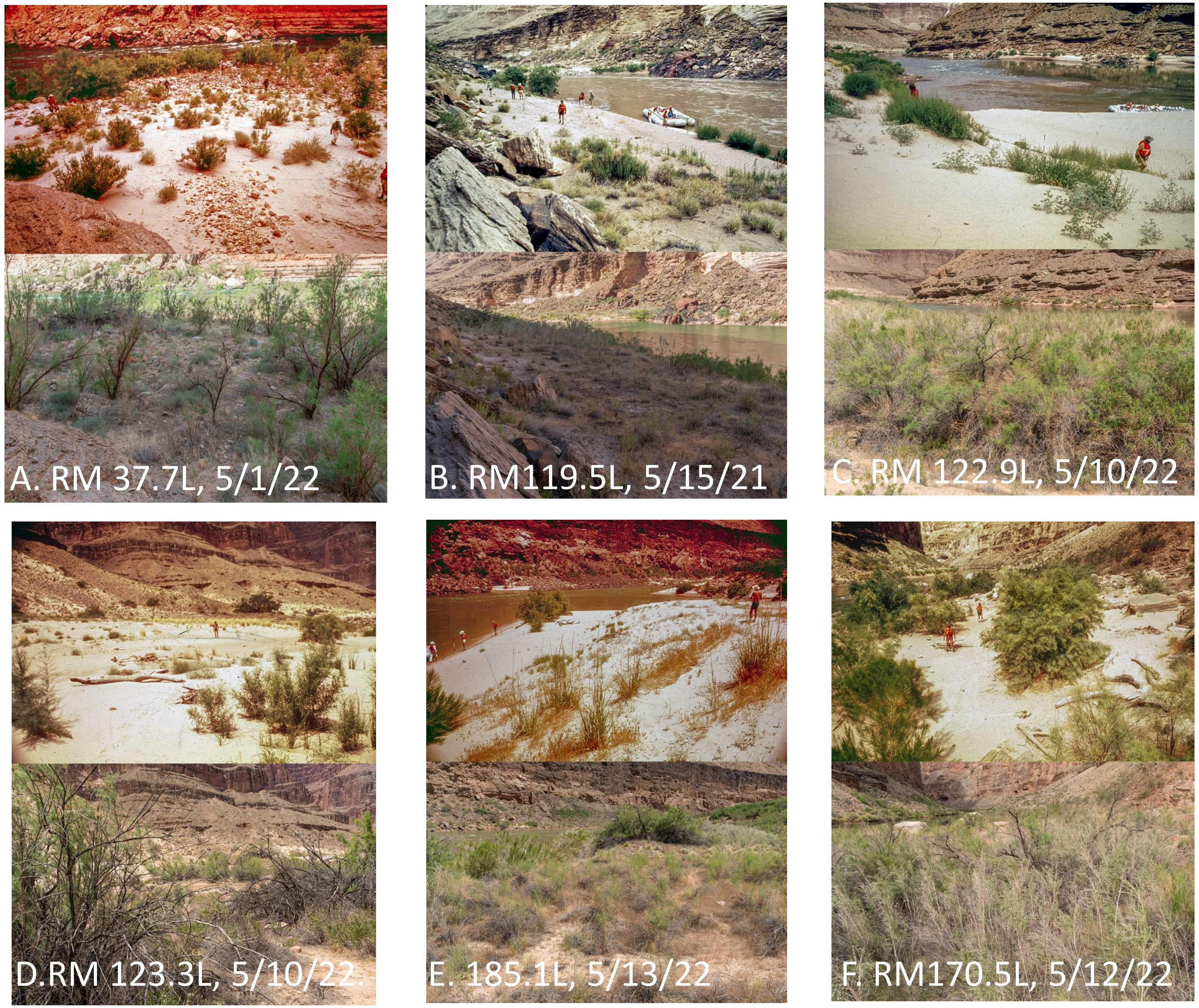
- Burial of archaeological sites by river-sourced aeolian sand provides a protective cover and resilient surface, reducing erosion potential
  - Important for site preservation
- Long term reduction in sediment supply and increase in riparian vegetation since closure of Glen Canyon Dam has increased archaeological site erosion and decreased preservation potential



Sankey et al., 2023, Journal of Environmental Management

Documentation of changes in sand source conditions using repeat photographs

- 250 matches of pre-dam conditions (pre-1957)
- Additional 190 matches of early post-dam (1973) conditions
- Matches document changes in amount of open sand area, riparian vegetation growth, and geomorphology



Figures A-F illustrate examples of conditions in July 1973 (top photos) matched with identical views of current (2021-2022) conditions.

1973 photos by unknown photographer; 2021-2022 matches by A.H. Fairley.

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We use two different but complementary methods to monitor dam effects at archaeological sites

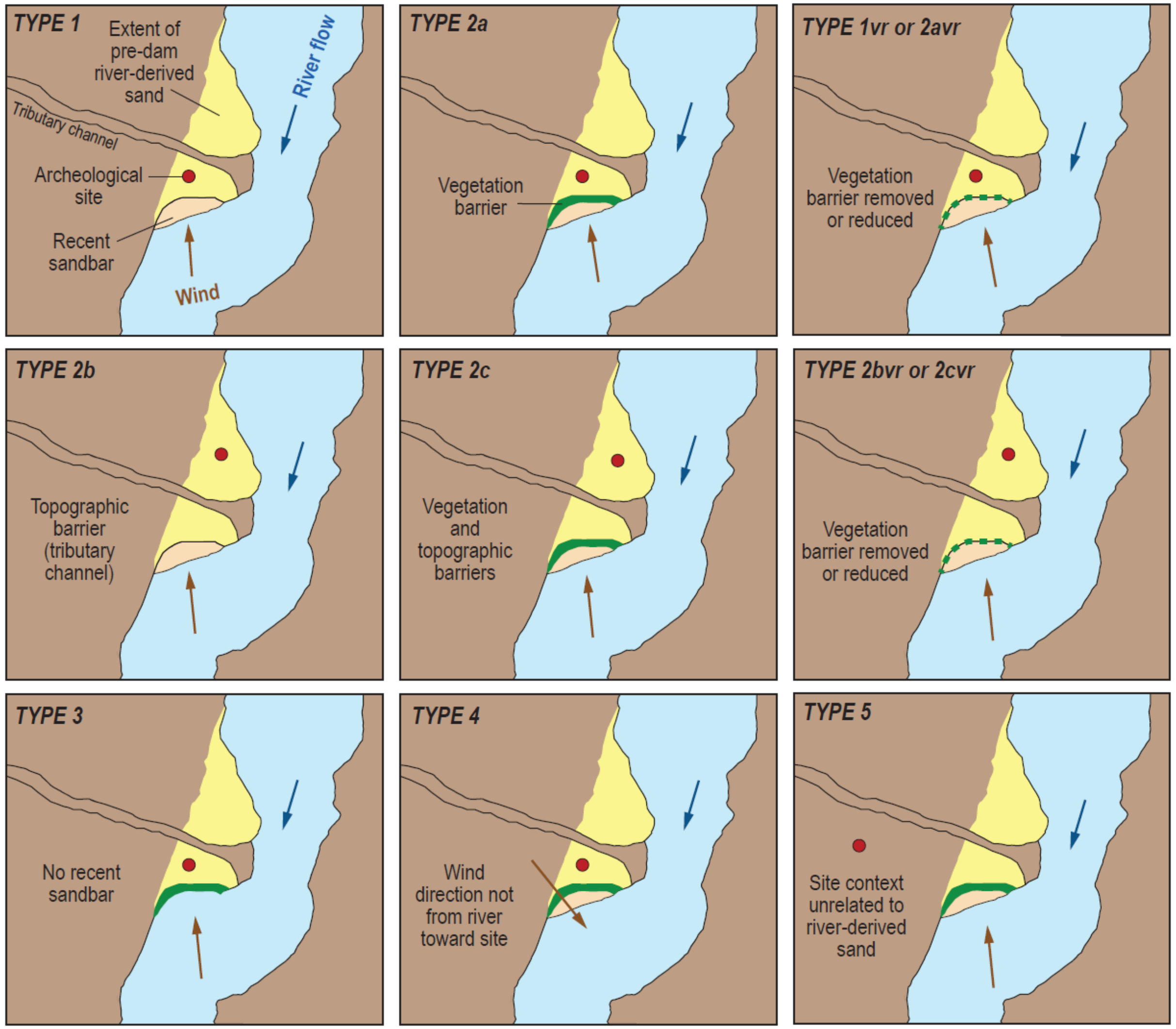
Method 1:

For entire population of sites within the Area of Potential Effect (n=362), we monitor changes in two classifications-- drainage evolution and fluvial sand connectivity -- at ~5-10 year intervals

Method 2:

For a sample of sites, we monitor change in topography (sediment deposition and erosion) using repeat lidar surveys, once every ~3 years

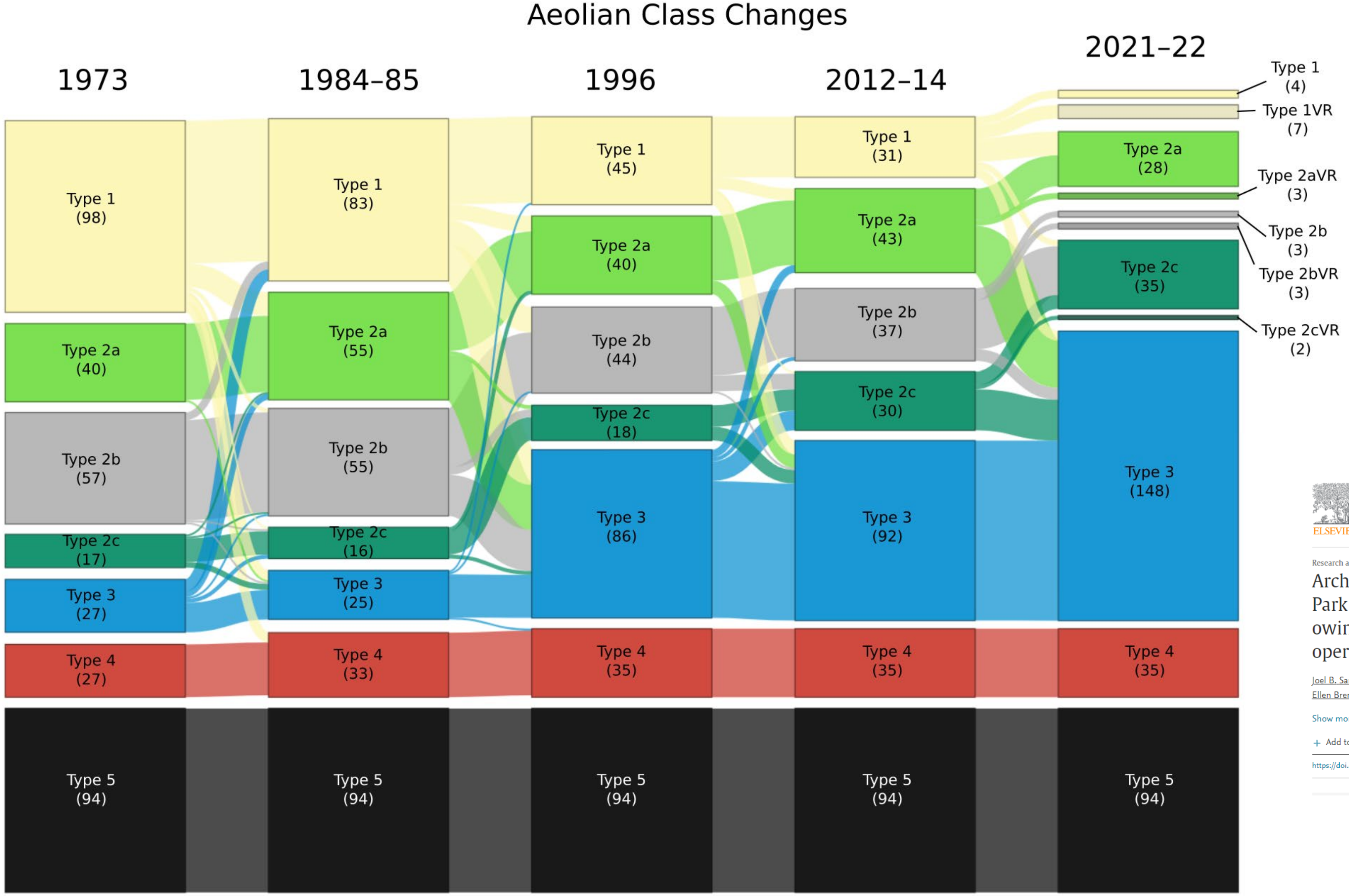
Method 1: Site type classification system for windblown (aeolian) sand supply from sandbars to archaeological sites



(adapted from East et al., 2016, 2017)

Fluvial Sediment Connectivity (FSC) (a.k.a. "Aeolian Classification") is a ranked classification of the relative potential for archaeological sites to receive windblown sand from upwind river sandbar deposits which might keep sites buried with a protective cover of sand that can potentially offset erosion that otherwise occurs.

Results: Fluvial Sediment Connectivity Classification



Journal of Environmental Management
Volume 342, 15 September 2023, 118036

Research article

Archaeological sites in Grand Canyon National Park along the Colorado River are eroding owing to six decades of Glen Canyon Dam operations

Joel B. Sankey [a], Amy East [b], Helen C. Fairley [a], Joshua Caster [a], Jennifer Dierker [c], Ellen Brennan [c], Lonnie Pilkington [c], Nathaniel Bransky [a], Alan Kasprak [a d]

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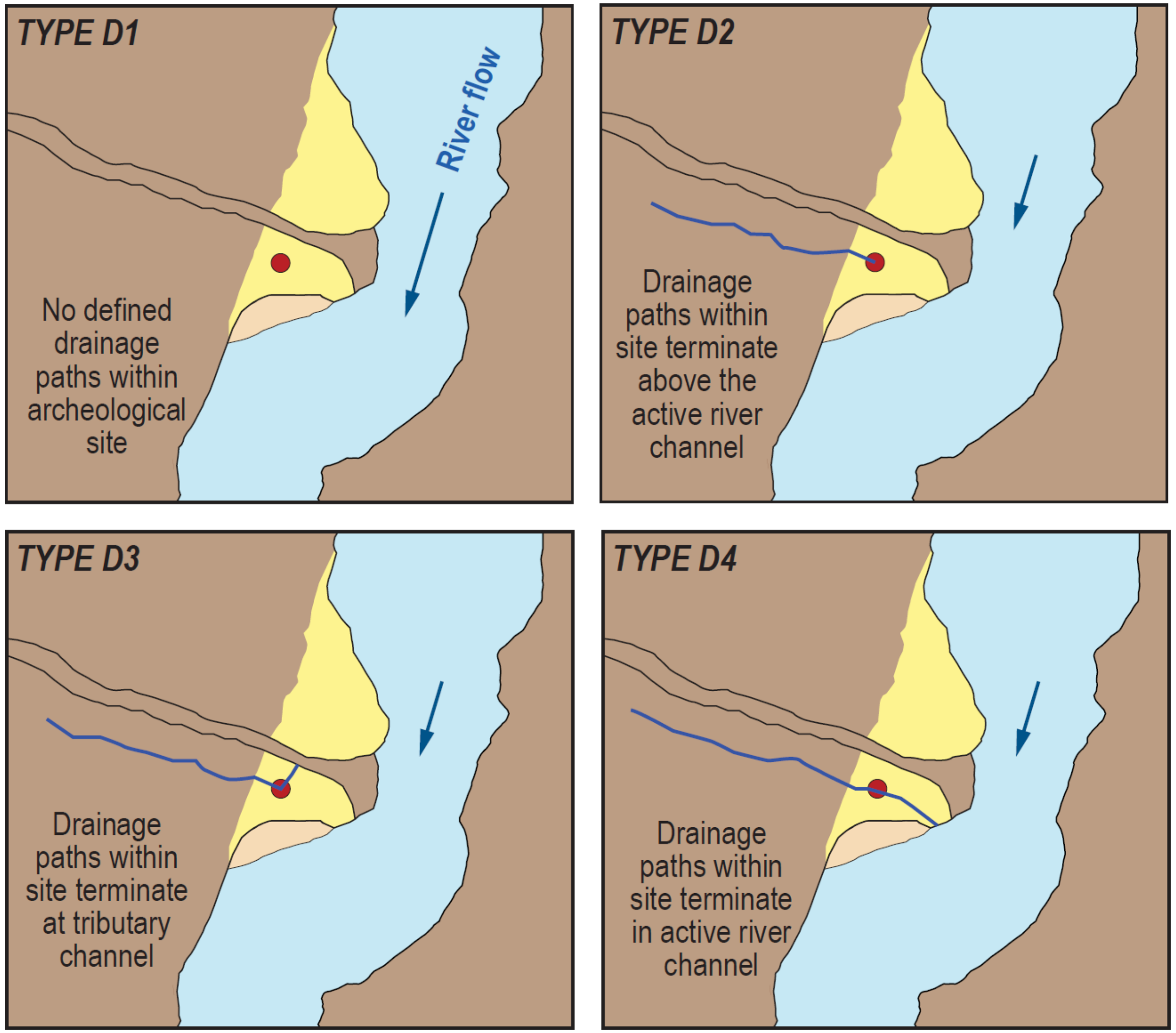
From Sankey et al., 2023, Journal of Environmental Management

Method 1: Site type classification system for extent of gullying at archaeological sites ("Drainage Classification")

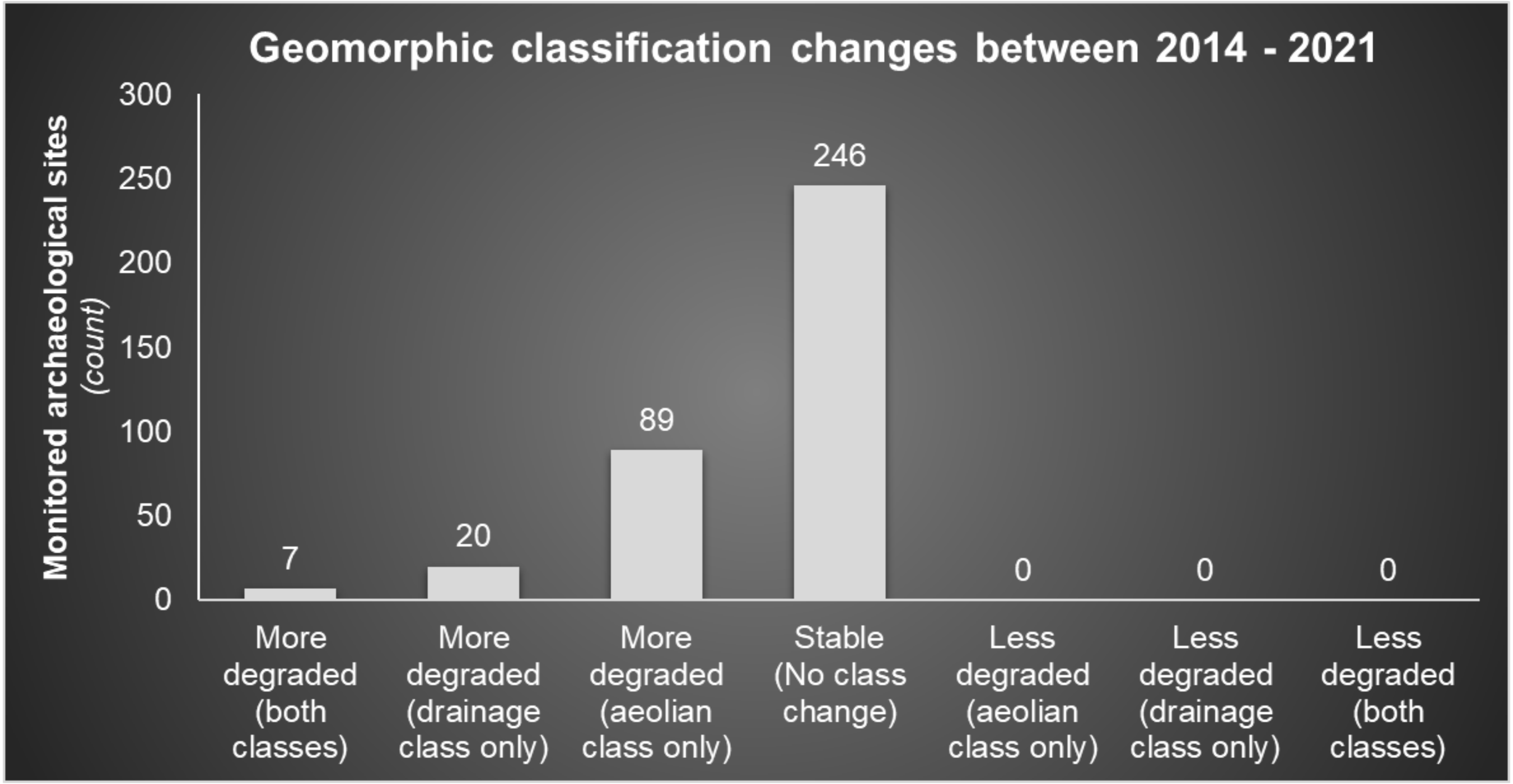


- The drainage classification system assesses the maximum local maturity of gully networks.
- River-based (D4) and side-canyon-based (D3) drainages are graded to the lowest possible local base level in this system and represent the evolutionary endpoint of drainage development.
- Terrace-based (D2) drainages represent an intermediary stage of development and may, in the future, become river-based or side-canyon based drainages.

(adapted from East et al., 2016, 2017)

Changes in aeolian and drainage classifications reflect changes in site stability and condition linked to dam ops (Metric 1.3)

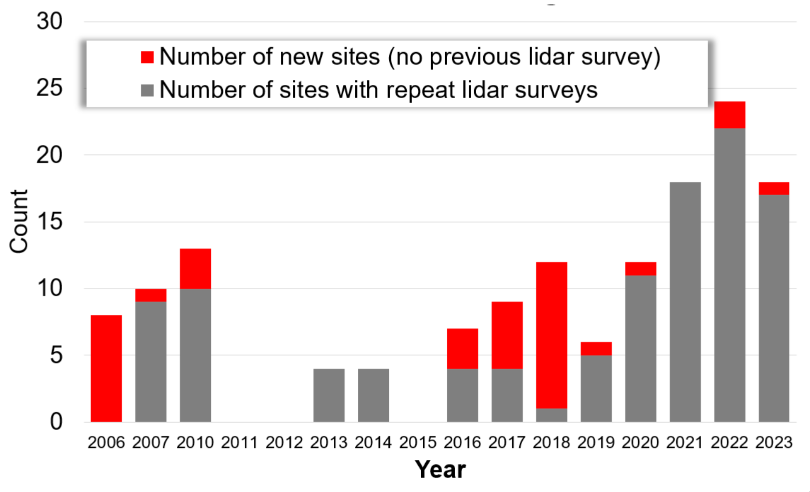
- 89 sites (24%) changed to a "less connected" aeolian class
- 20 sites (6%) changed to a more degraded drainage classification
- 7 (2%) sites changed in both respects to a more degraded condition
- Majority of sites (n=246, 68%) did not change
- No sites showed "improvement" in terms of their classifications

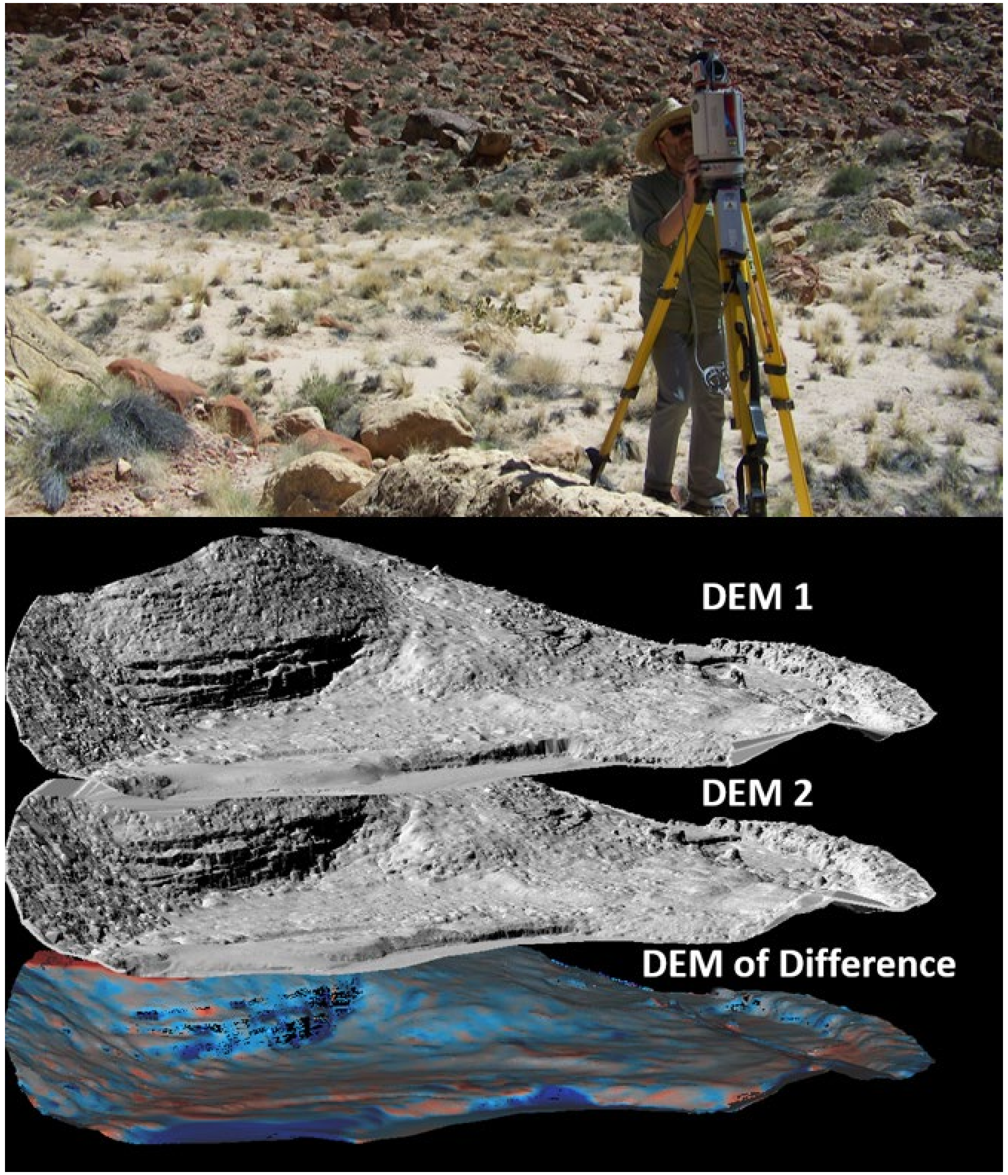


Sankey et al., 2023, Journal of Environmental Management

Method 2: Lidar Topographic Change Detection

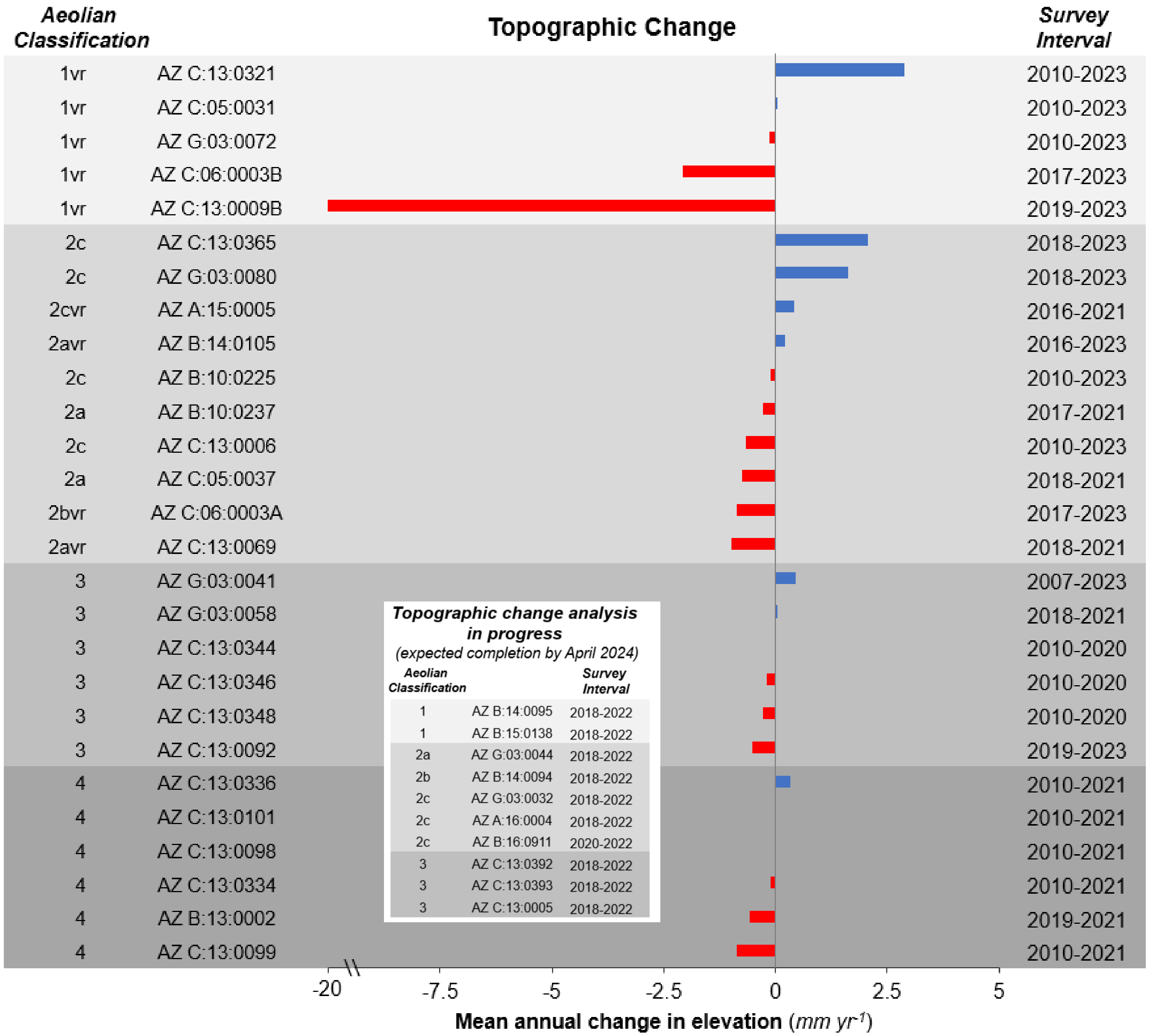
- Repeat lidar surveys are used to accurately measure topographic changes associated with erosion and deposition of sediment over time within archaeological sites and surrounding landscape (Caster et al., 2022)





Lidar Topographic Change Detection (Metric 1.2)

- Currently, sample includes 27 sites with multiple repeat surveys that document net change in erosion or deposition
- Net deposition documented at 33% of these sites (n=9); most are Aeolian Class 1 or 2
- Approximately 55% of monitored sites have lost surface sediment (eroded)
- 11% have neither aggraded nor eroded
- Long-term effects of April 2023 HFE are not reflected in these results



Preliminary results, please don't cite

Metric 1.1: Change in Integrity

- Metric 1.1 is a recently added metric that is specifically focused on Integrity
- Integrity has a specific meaning in the historic preservation field and the National Historic Preservation Act: “the ability of a historic property to convey its significance”
- Integrity is not measurable. It is a professional judgment and is either present or absent (i.e., there are no “degrees” of integrity)
- Metric 1.1 documents number of sites that have lost integrity during LTEMP
- Currently all sites in the APE continue to retain integrity, despite erosion continuing to affect many sites

Eroding archaeological sites in Grand Canyon, 2017 (photos by J. Sankey)

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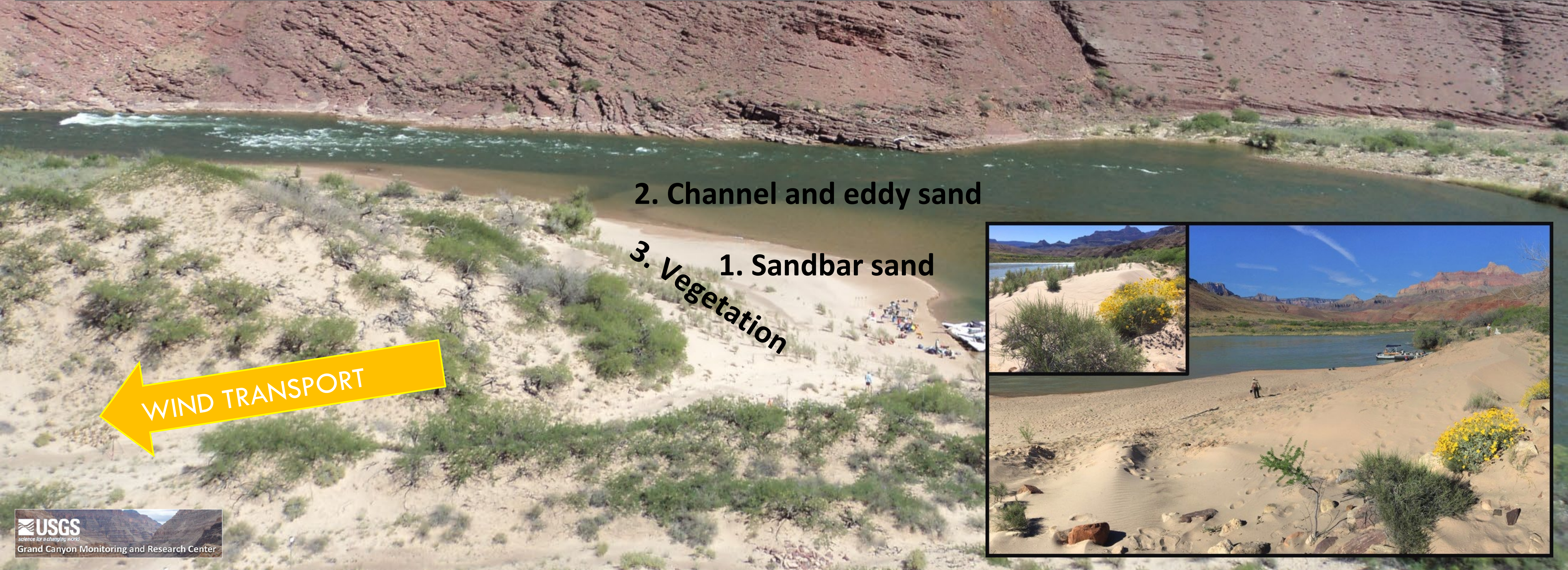
Experimental management to increase wind transport of river-sourced sand

Increase aeolian sediment supply:

1. HFEs to rebuild river sandbars (*Sankey et al., 2018, Aeolian Research*)
2. Lowering dam releases to expose sand that is normally underwater in the river channel & eddies (*Sankey et al., 2022, JGR*)

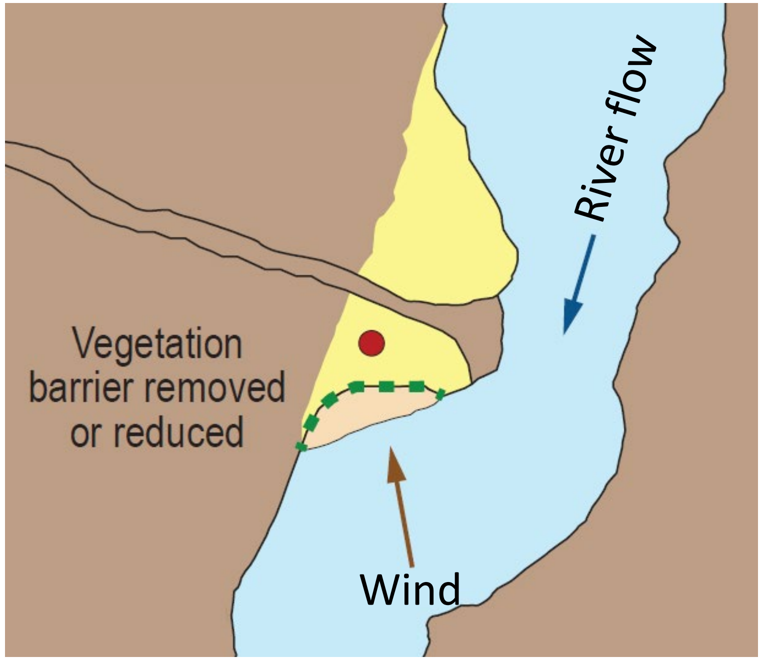
Minimize vegetation blocking aeolian sand transport:

3. Vegetation-management to remove riparian vegetation on sandbars (*Pilkington et al., 2022, Park Science*)



Research question

- Does removal of riparian vegetation barriers located between river sandbars and archaeological sites increase the resupply of aeolian sediment to sites?



Vegetation management for dunefield archaeological site restoration

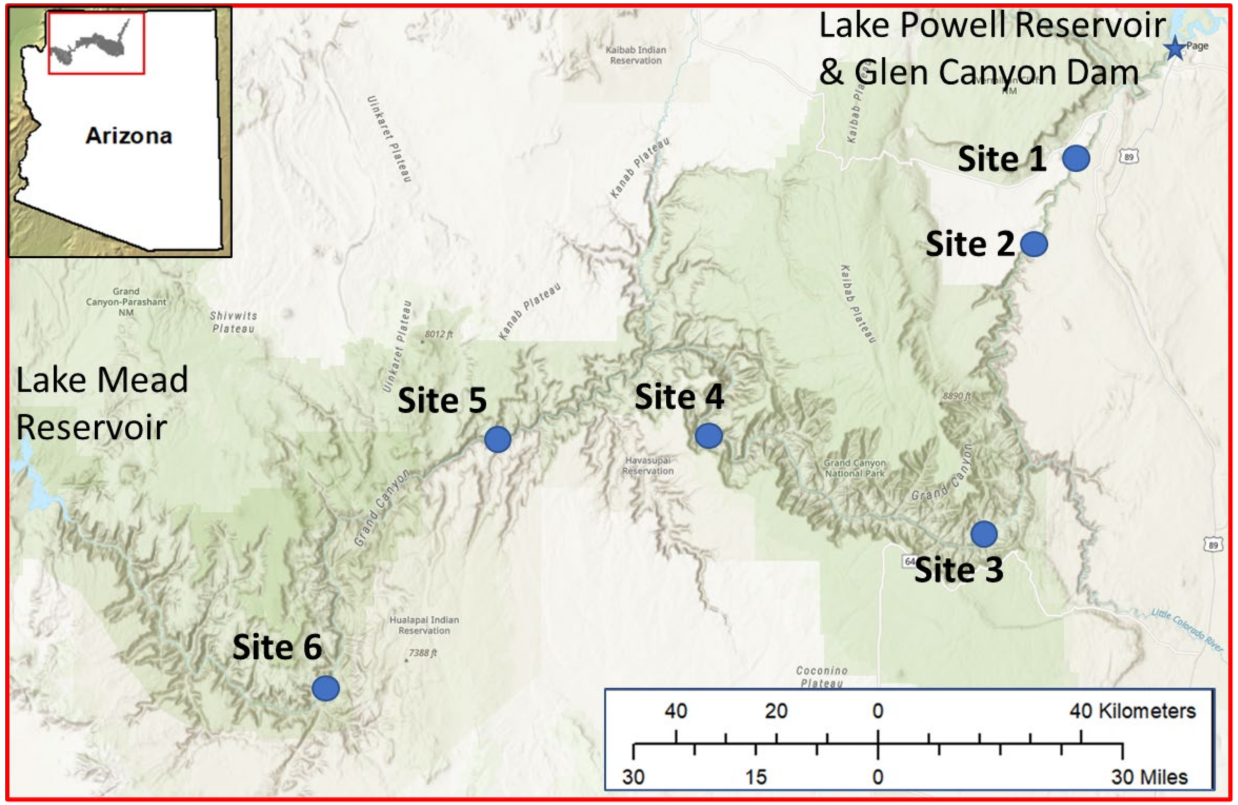
- Implemented in coastal dunefields around the world
  - Improve cultural, ecological, recreational resources
  - Protect infrastructure
- Not common for aeolian dunefield and archaeological sites in river environments

b) June 2013

Photos taken before (top) and after (bottom) removal of invasive vegetation to restore a coastal dunefield at Doughboy Bay, Stewart Island, New Zealand (Konlechner et al., 2014)

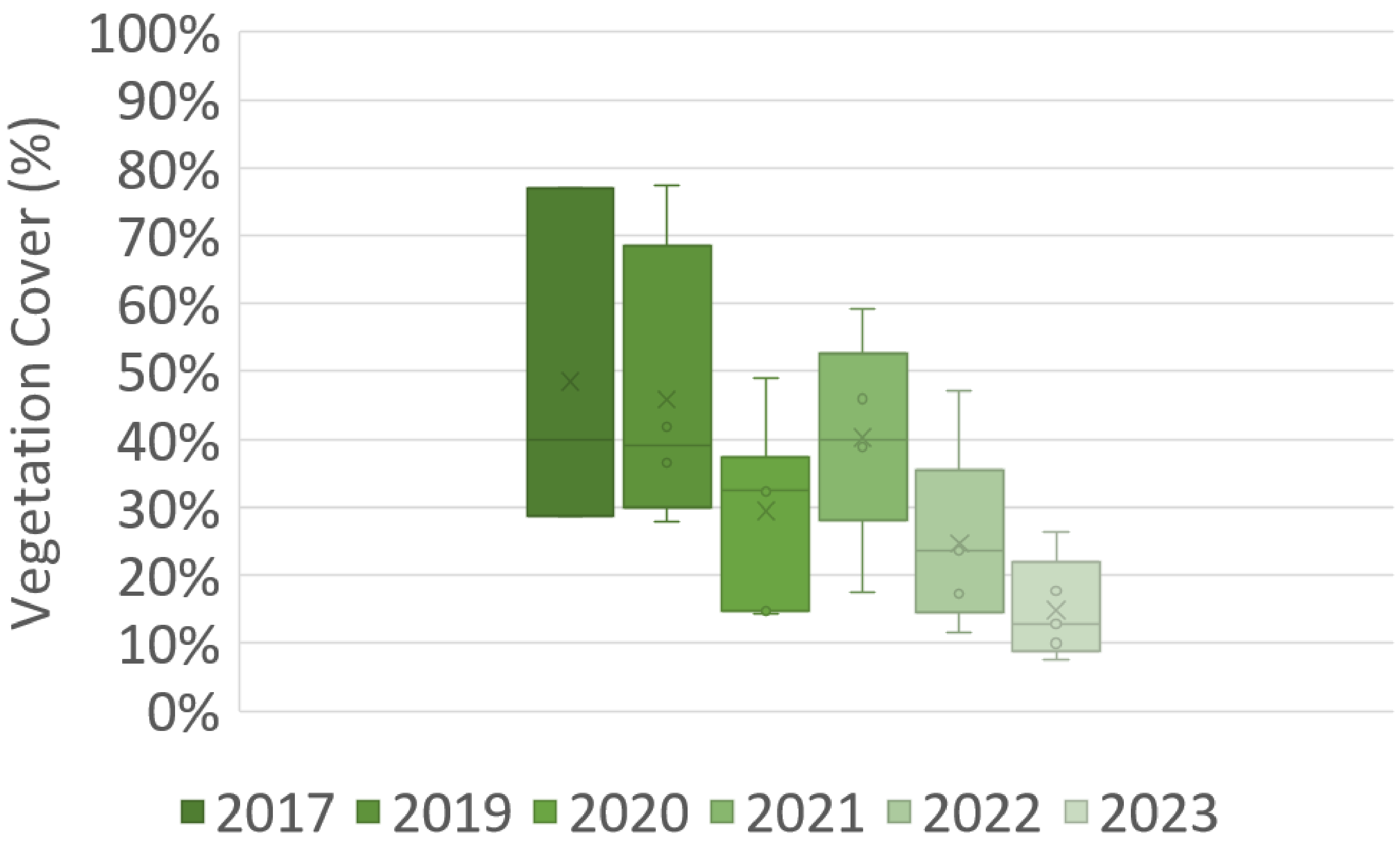
An intact oven (top) in a coastal dunefield archaeological site occupied by Maori ancestors, Mason Bay, New Zealand. The oven was exposed (top) and eroded (bottom) due to reduction in the supply of windblown coastal sand owing to encroachment of invasive vegetation (e.g., panel a). (Hilton and Konlechner, 2014)

Colorado River in Grand Canyon National Park



Lidar measured vegetation cover

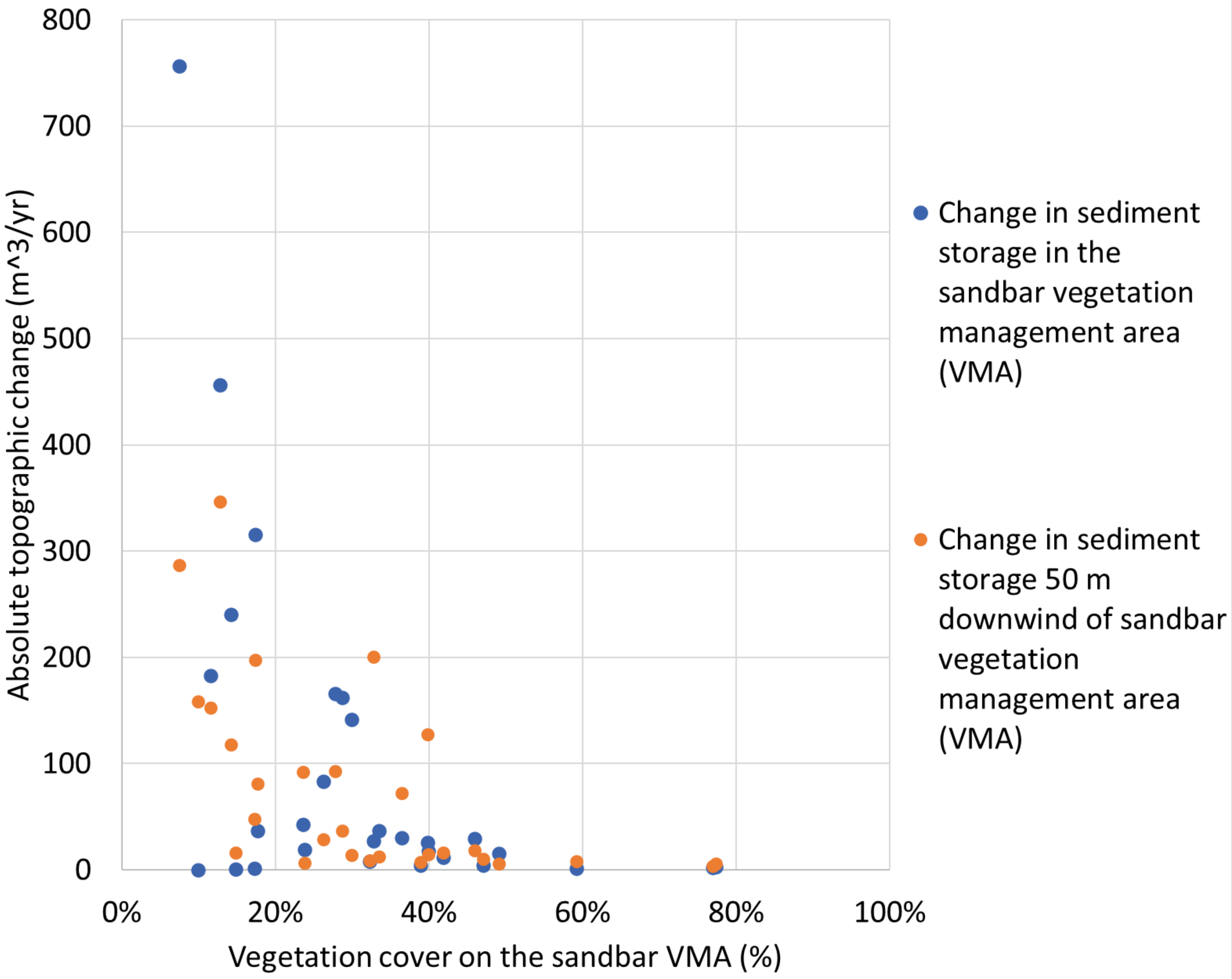
- Decrease in vegetation cover at the six sites since annual sandbar vegetation removal implemented by NPS began in 2019
  - Successfully reduced vegetation cover in the vegetation management areas



Preliminary results, please don't cite

Lidar measured topographic change

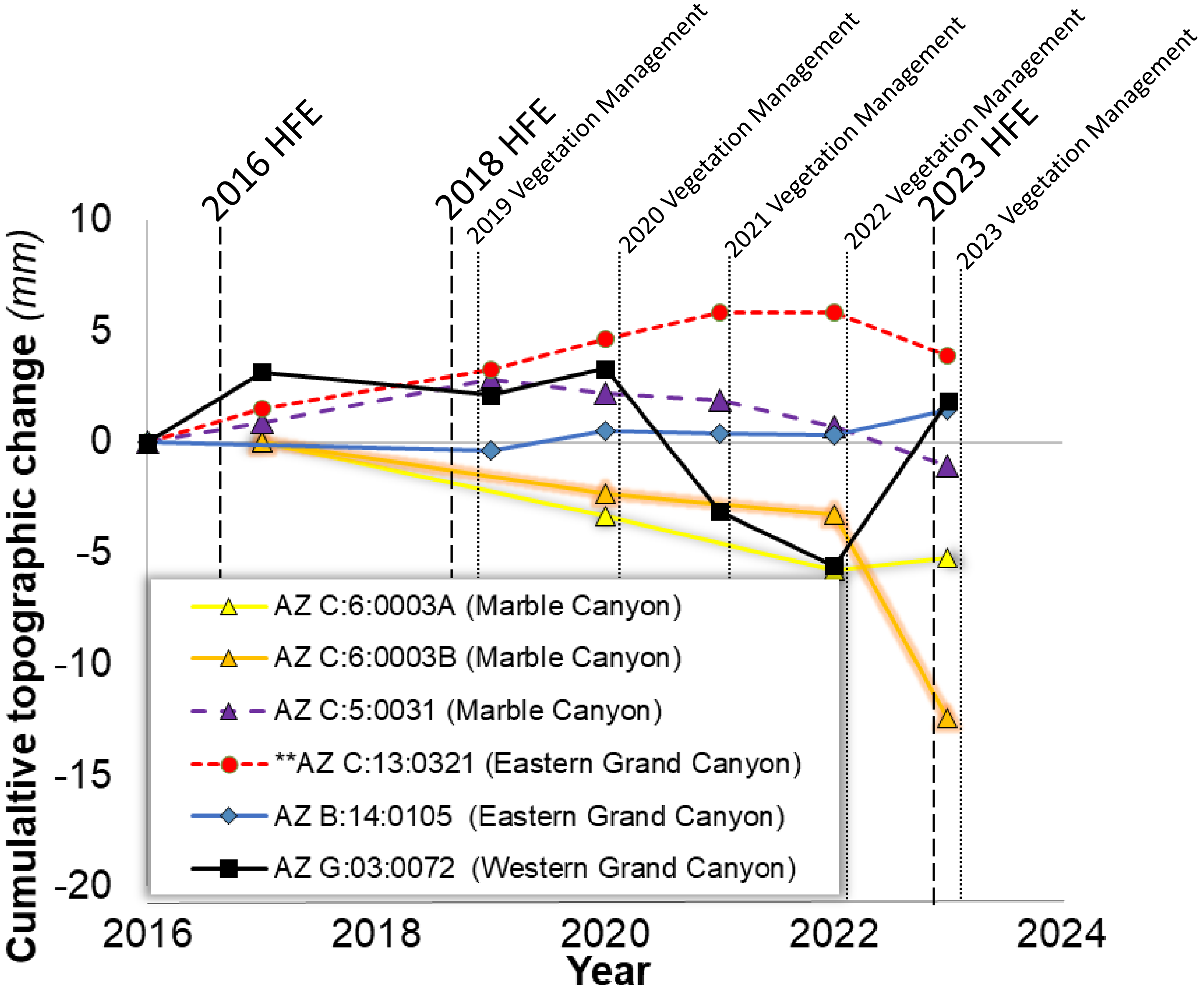
- Greatest total topographic change occurred at sites and years with lower vegetation cover
    - Observed within the vegetation management areas on the sandbars and at long distances (50m) downwind of the sandbar vegetation management areas
    - Threshold level of vegetation cover on sandbars (e.g., < 20% or < 40%) could be managed to promote aeolian transport of river sand to downwind dunefield archaeological sites



Preliminary results, please don't cite

Lidar measured topographic change at downwind archaeological sites

- Experimental management of vegetation on the river sandbars has contributed to some, but not all, of the associated downwind archaeological sites being buried by windblown river sand over time
- Cumulative topographic changes likely dependent on frequency and timing of HFEs and vegetation management, as well as downwind distance from sandbar vegetation management area to archaeological site, and other factors



*** Results for AZ C:13:0321 were reduced by a factor of 10*

Preliminary results, please don't cite

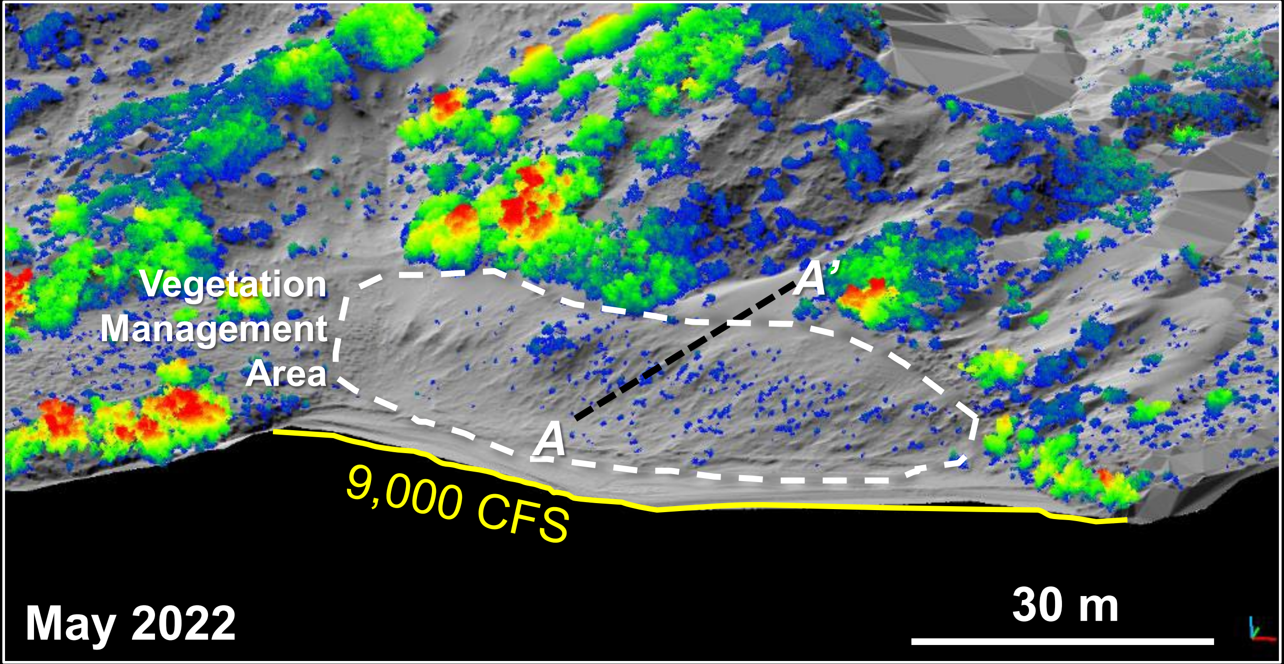
Vegetation Management and HFE: Basalt Camp example 2018 - 2023

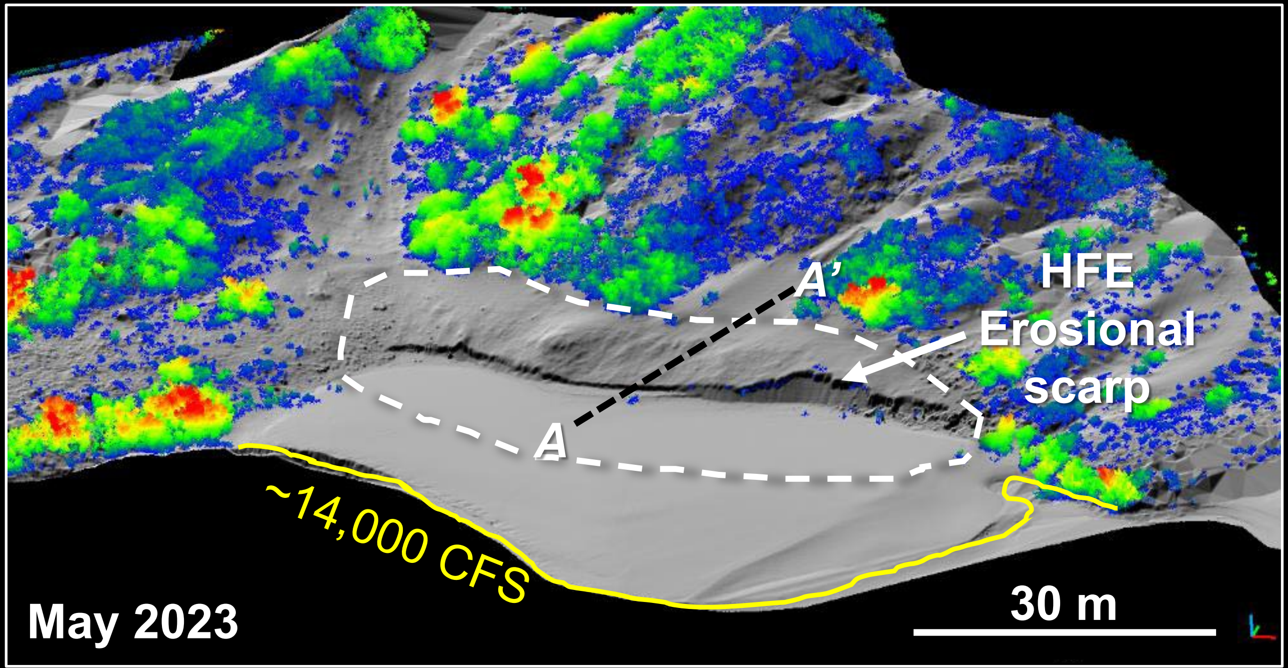
- National Park Service (NPS) with Ancestral Lands Conservation Corps tribal crews have worked to remove invasive plants annually on sand bars since 2019

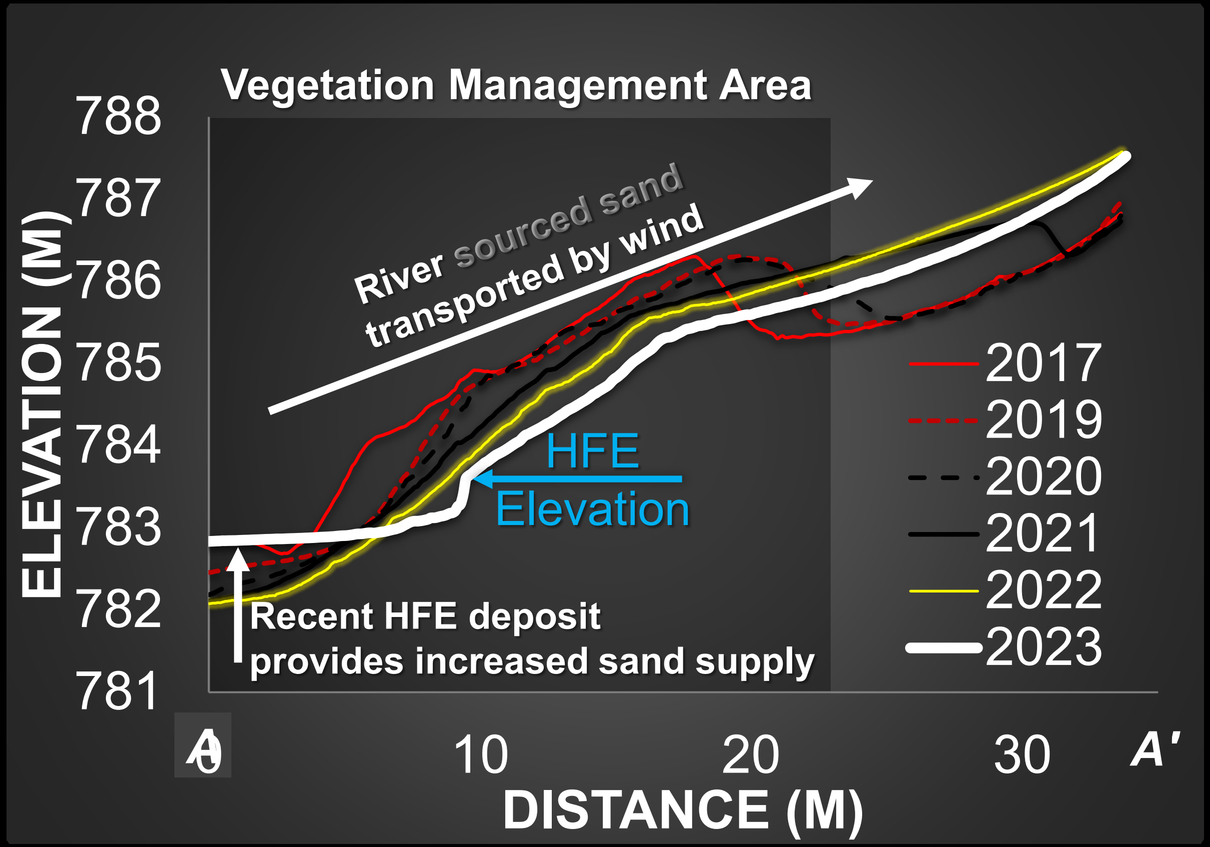
- April 2023 – first HFE since the effort began
- September 2023 – NPS revisited sites and repeated vegetation management

Preliminary results, please don't cite

Lidar Observations at Basalt Camp



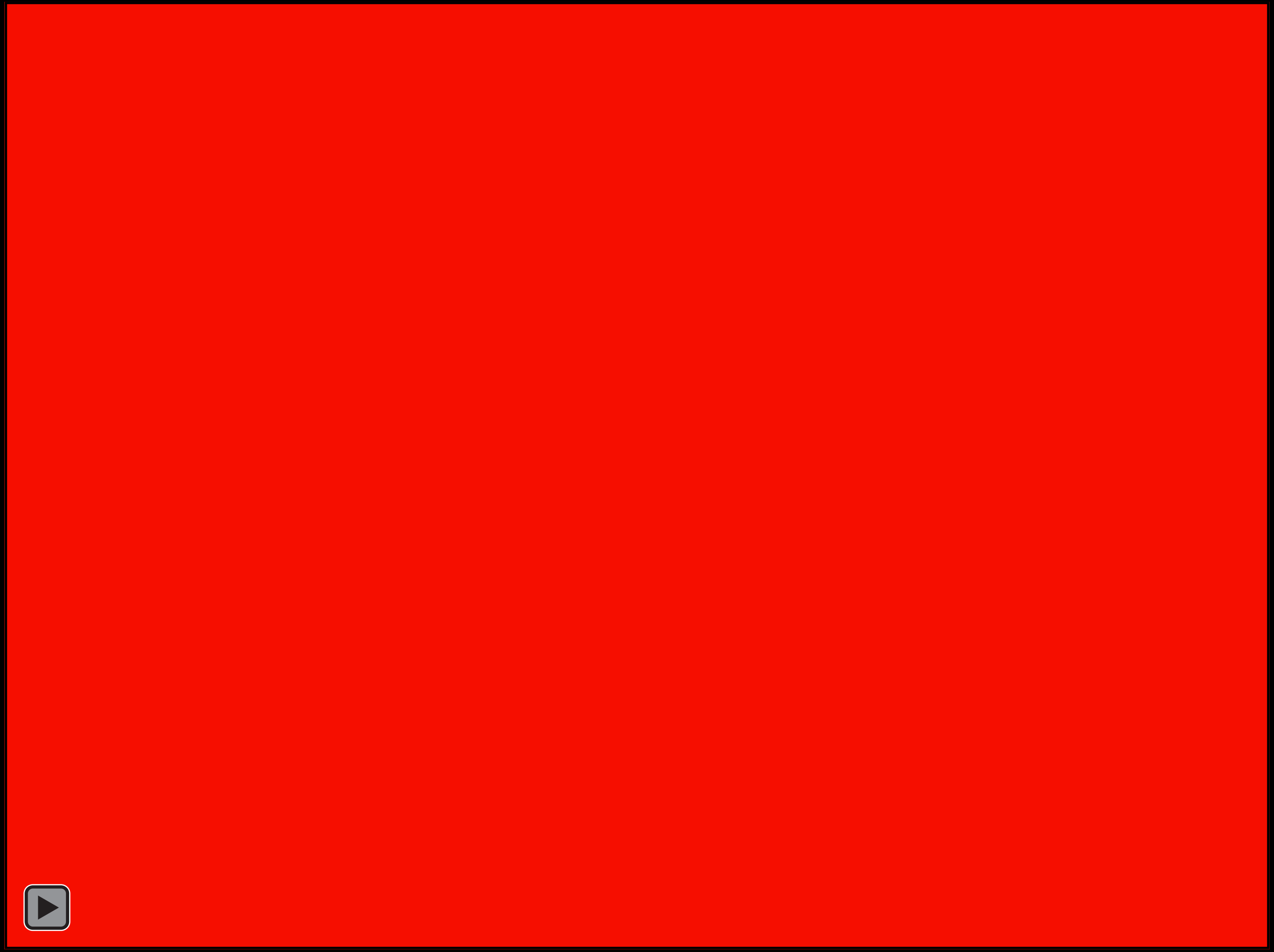




Preliminary results, please don't cite

Vegetation Management and HFE:
Mile 122 Camp example 2018 - 2023

- Lidar monitoring occurs at 6 vegetation management sites
  - 2 sites (Basalt and 122 mile camps) are also sand bar monitoring locations
  - Sites respond uniquely to management actions



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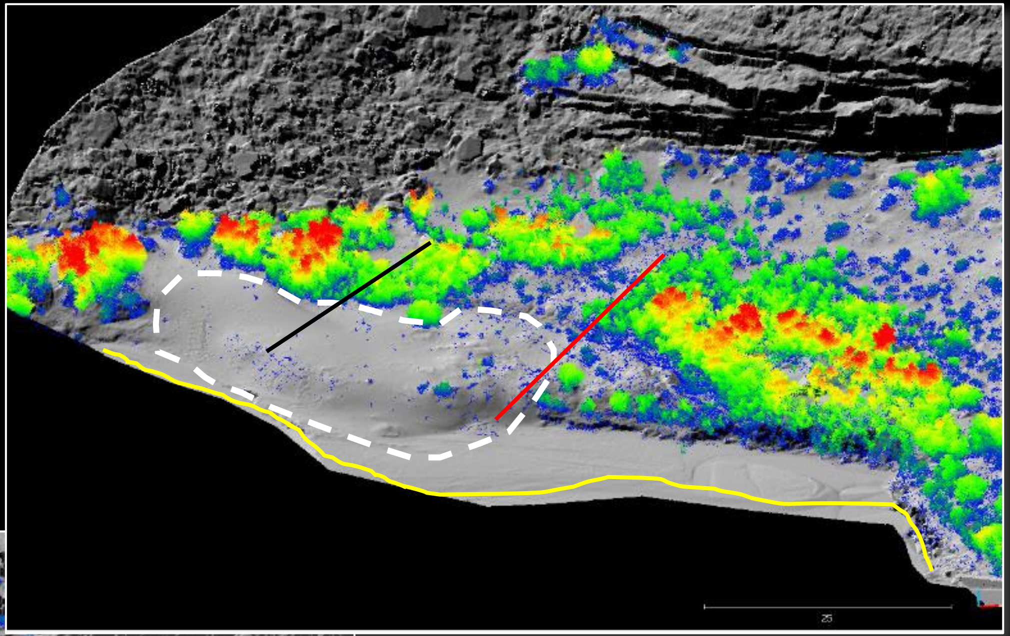
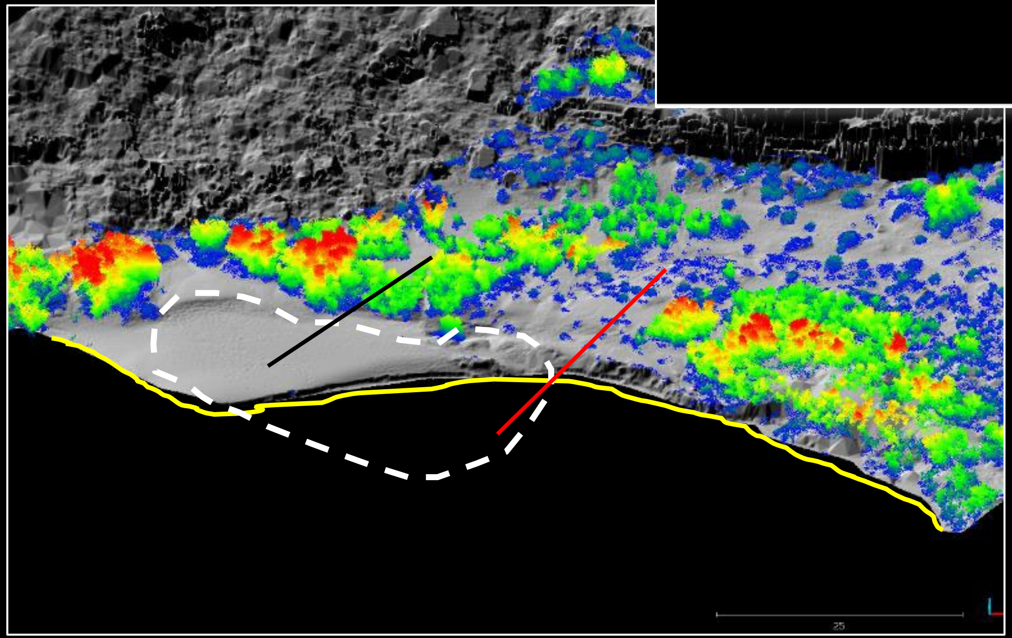
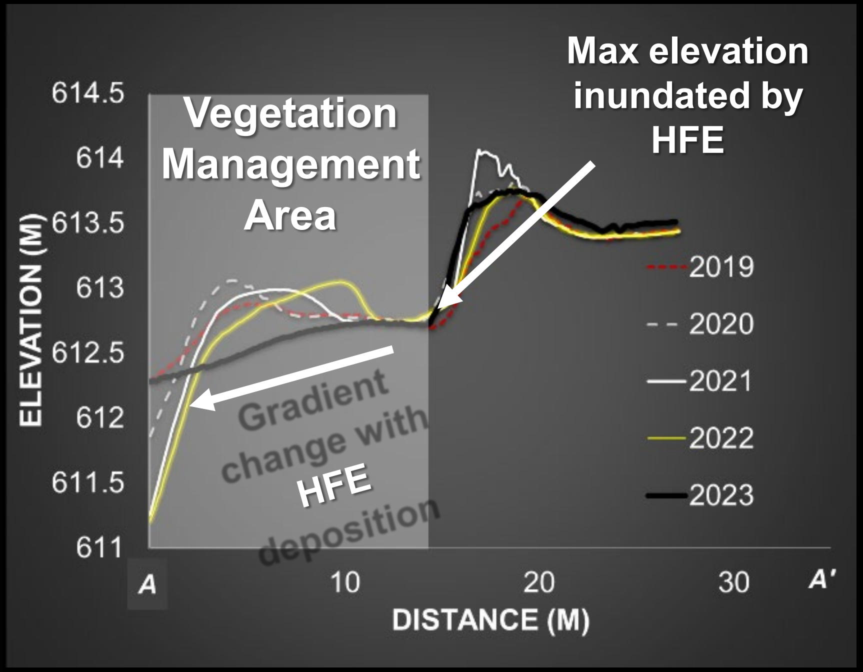
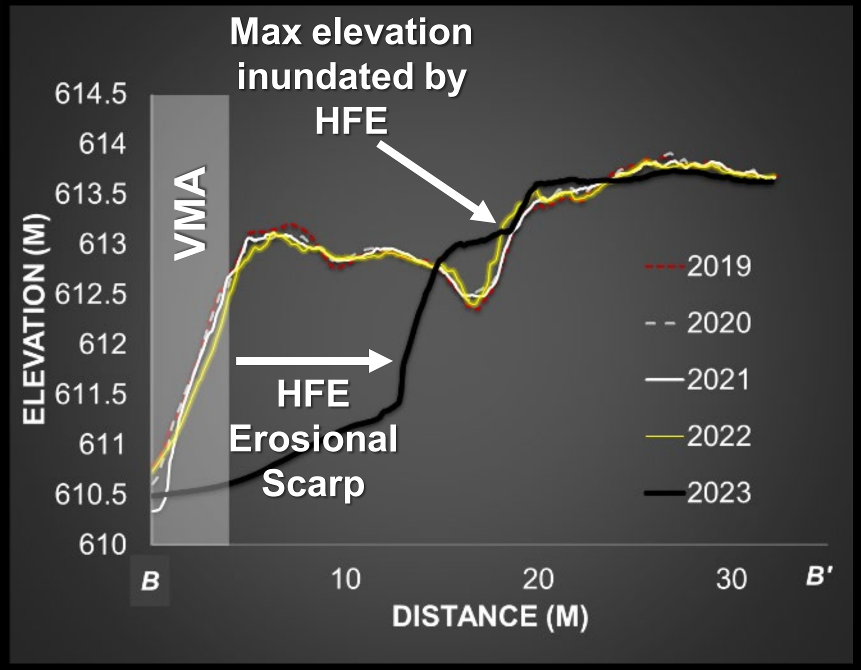
Lidar Observations at Mile 122 Camp





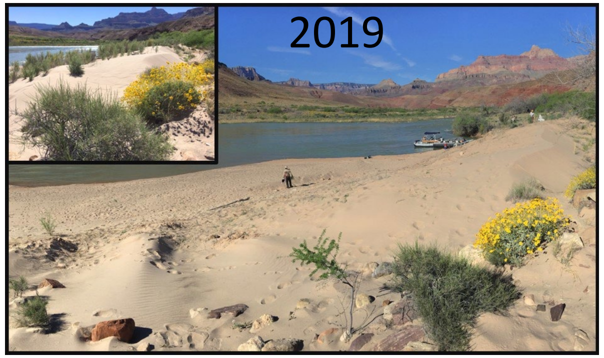


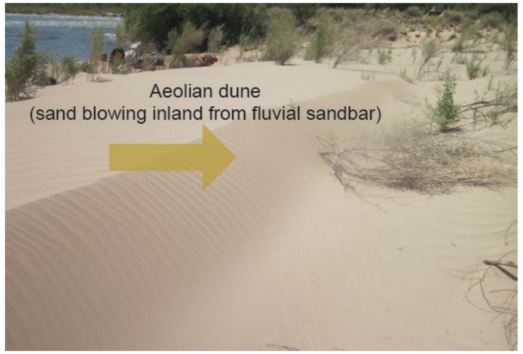


Preliminary results, please don't cite

Summary of Vegetation Management and HFE Effects

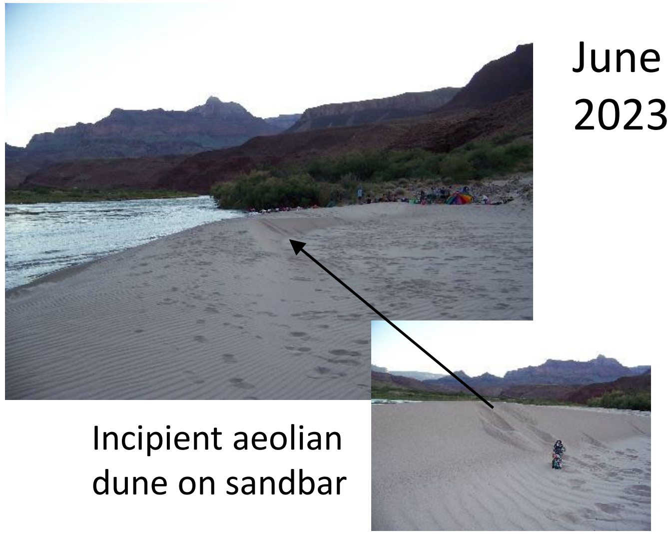
- Annual removal of riparian vegetation on river sandbar increased aeolian transport and dune migration of river sourced sand: 2019-2023
- HFE (April 2023)
  - Rebuilt sandbar deposit that is source area of aeolian sand
  - Eroded foredune and vegetation removal area
- Post-flood (April-June 2023)
  - Sandbar erosion by fluctuating river flows
  - Aeolian sand transport, incipient dune building on sandbar
  - Aeolian deposition, annealing of eroded vegetation management area





Rapid erosion of sandbar by post-flood river flows

June 2023



Incipient aeolian dune on sandbar

Aeolian sand deposition, annealing of flood-eroded scarp

Preliminary results, please don't cite

September 2023

Incipient aeolian dune on sandbar (wind blown river sand) grew and migrated inland towards vegetation management area, downwind dunefield and archaeological sites.

Preliminary results, please don't cite

Next Steps for Project D

- Continue to monitor archaeological sites and collect data to report on metrics 1.1-1.3
- Continue to evaluate effectiveness of LTEMP vegetation management experiment
- Consider new vegetation experimental activities to achieve LTEMP goals (e.g., strategic plantings to capture sand or maintain low levels of plant cover on sand bars)

Preliminary results, please don't cite