

# Delta Landscape Metrics

*Creating a Spatial Framework to Inform Restoration Planning*

Robin Grossinger

Ruth Askevold

Julie Beagle

Letitia Grenier

April Robinson

Sam Safran



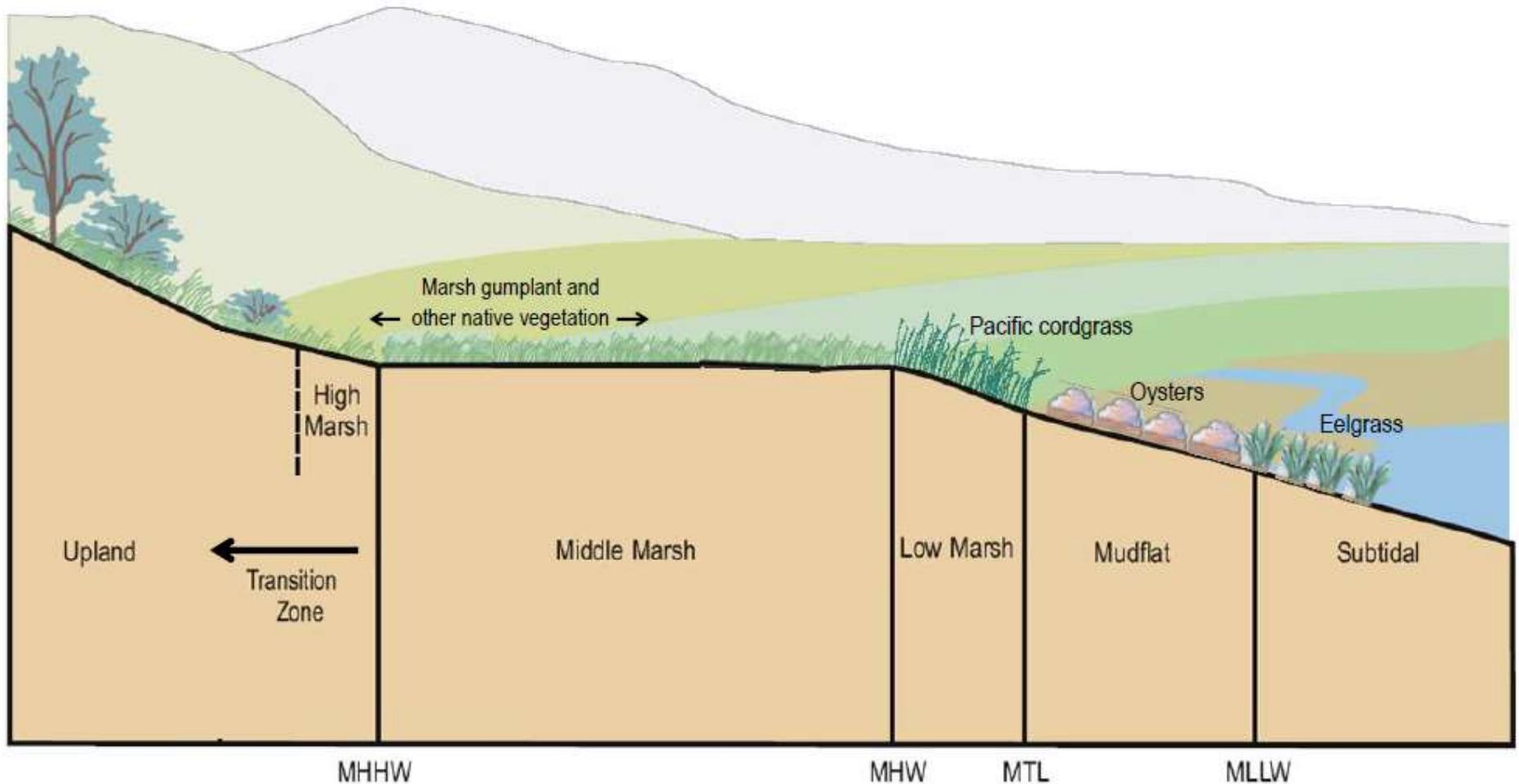
**San Francisco Estuary Institute-Aquatic Science Center**

*Bay-Delta Science Conference  
October 29, 2014*



AQUATIC  SCIENCE  CENTER

# Complete tidal wetland system



# Baylands Goals Update Regional Recommendations

- 1 Restore estuary-watershed connections.**
- 2 Design complexity and connectivity into the Baylands [and Delta] landscape.**
- 3 Restore and conserve complete tidal wetlands systems.**
- 4 Plan for the Baylands [and Delta] to migrate.**

# The Delta Landscapes Project

## *Management Tools for Landscape-Scale Restoration*

*Funded by the Ecosystem Restoration Program*





# A DELTA TRANSFORMED

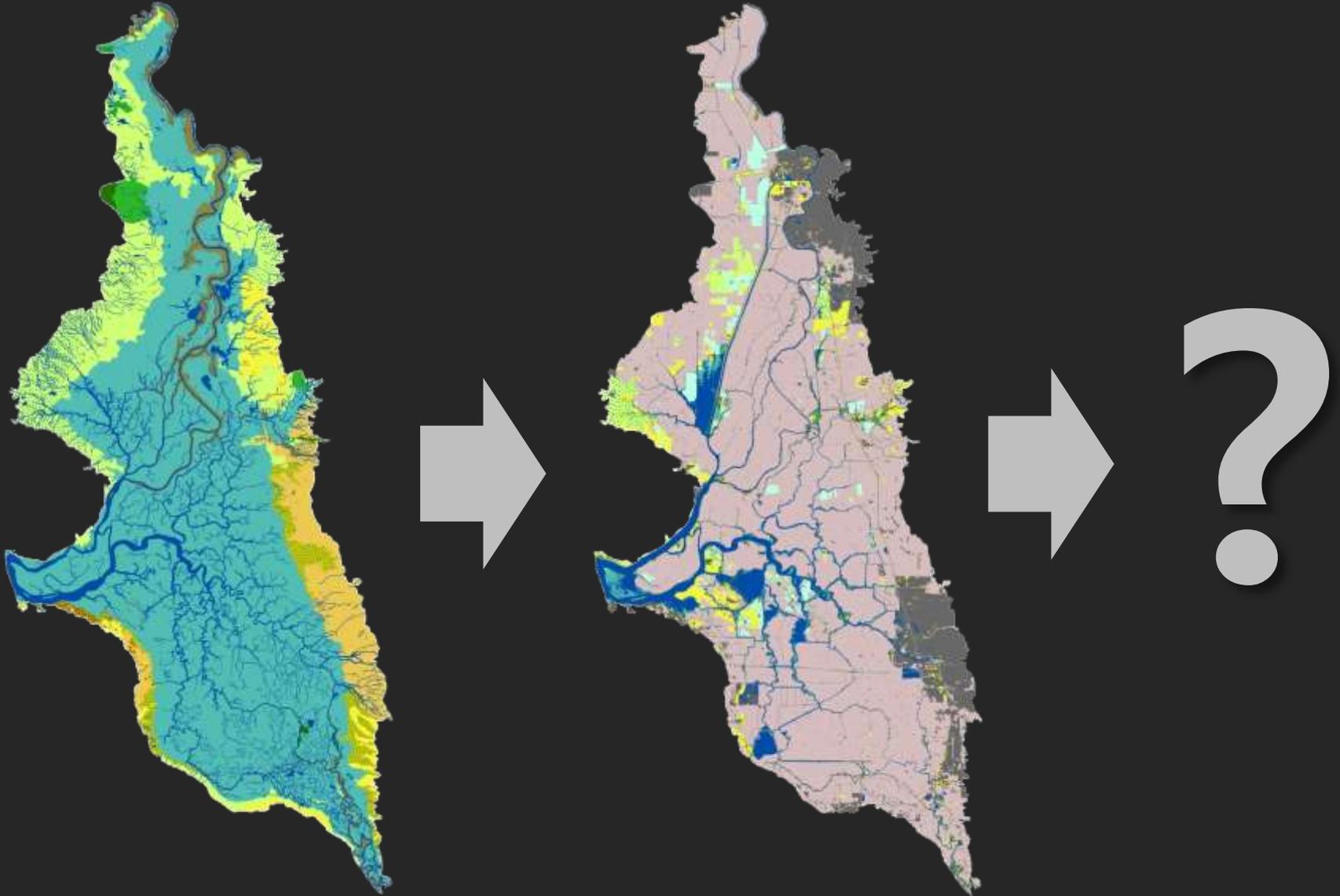
ecological functions, spatial metrics,  
and landscape change

IN THE SACRAMENTO-SAN JOAQUIN DELTA

SAN FRANCISCO ESTUARY INSTITUTE **SFEI**  
AQUATIC SCIENCE CENTER **A+B+C**

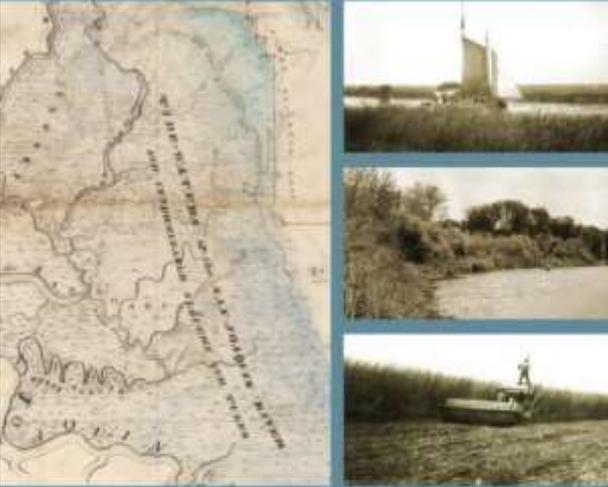


How do we create ecologically functional,  
resilient *landscapes*? (not just nice projects)



- 1. Provide a framework that helps individual projects add up to a larger functional landscape** (pieces of the puzzle)
- 2. Provide guidance for what kinds of projects make sense where** (avoid one-size-fits-all)
- 3. Reduce conflicts and mistakes** (shared understanding of priorities and current science)
- 4. Make better use of long-term physical/climatic trajectories** (work with processes, not against them)
- 5. Meet landscape-scale species needs** (connectivity, migration)

Sacramento-San Joaquin Delta Historical Ecology Investigation:  
EXPLORING PATTERN AND PROCESS

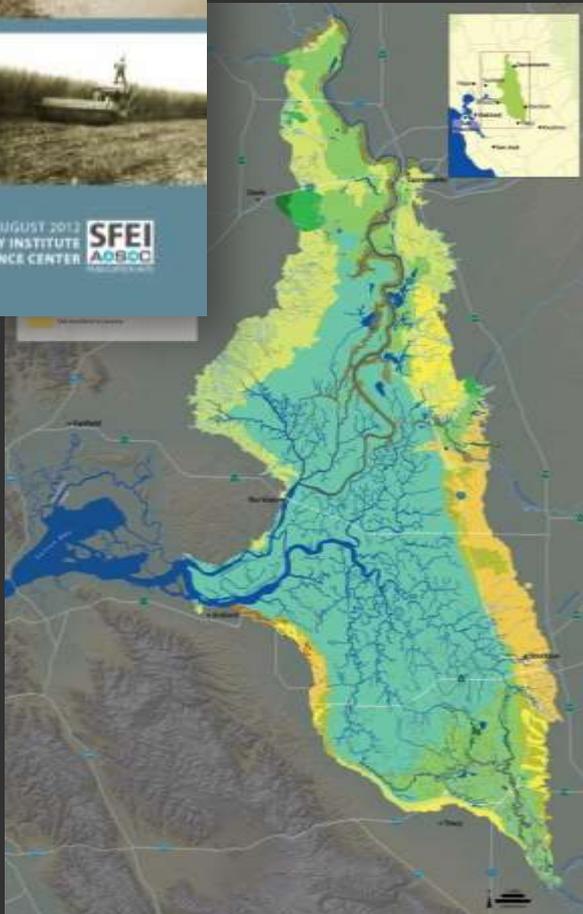


AUGUST 2012  
SAN FRANCISCO ESTUARY INSTITUTE  
AQUATIC SCIENCE CENTER



# Sacramento-San Joaquin Delta Historical Ecology Investigation: Exploring Pattern and Process

- Funded by Ecosystem Restoration Program (CDFG, NOAA, US FWS)
- Final Report/GIS Available: [www.sfei.org/DeltaHEStudy](http://www.sfei.org/DeltaHEStudy)
- Collaboration with KQED QUEST and Stanford's Bill Lane Center for the American West: [science.kqed.org/quest/delta-map/](http://science.kqed.org/quest/delta-map/)



- 1. Define target ecological functions**
- 2. Identify associated system attributes (spatial metrics)**
- 3. Quantify landscape change metrics**
- 4. Describe subregional potential (physical drivers, opportunities)**
- 5. Create conceptual Operational Landscape Units (e.g. “archetypes”)**
- 6. Produce restoration guidelines and potential performance metrics**

# Landscape Interpretation Team (LIT)

Stephanie Carlson (UC Berkeley)

Jim Cloern (USGS)

Brian Collins (University of Washington)

Chris Enright (Delta Science Program)

Joseph Fleskes (USGS)

Geoffrey Geupel (PRBO Conservation Science)

Todd Keeler-Wolf (CDFW)

William Lidicker (UC Berkeley)

Steve Lindley (NMFS)

Jeff Mount (UC Davis)

Peter Moyle (UC Davis)

Anke Mueller-Solger (USGS)

Eric Sanderson (Wildlife Conservation Society)

Dave Zezulak (CDFW)

## **Fish/Waterbird-specific**

John Durand (UCD)

Jim Hobbs (UCD)

Carson Jeffres (UCD)

Dave Shuford (Point Blue)

Dan Skalos (CDFW)

Ted Sommer (DWR)

LEVEL	POPULATION					COMMUNITY		
	Life history support					Adaptation potential	Food webs	Biodiversity
THEME								
FUNCTION	Provides habitat and connectivity for fish	Provides habitat and connectivity for marsh wildlife	Provides habitat and connectivity for waterbirds	Provides habitat and connectivity for riparian wildlife	Provides habitat and connectivity for marsh-terrestrial transition zone wildlife	Maintains adaptation potential within wildlife populations	Maintains food supplies and nutrient cycling to support robust food webs	Maintains biodiversity by supporting diverse natural communities
METRICS	Inundation extent, duration, timing, and frequency	Marsh area by patch size (patch size distribution)	Ponded area in summer by depth and duration	Riparian habitat area by patch size	Length of marsh-terrestrial transition zone by terrestrial habitat type	To be addressed with qualitative conceptual models in Task 4.	Expected to be addressed with a related project.	To be addressed with qualitative conceptual models in Task 4.
	Marsh to open water ratio	Marsh area by nearest neighbor distance	Wetted area by type in winter	Riparian habitat length by width class				
	Adjacency of marsh to open water by length and marsh patch size	Marsh core area ratio						
	Ratio of looped to dendritic channels (by length and adjacent habitat type)	Marsh fragmentation index						

# Ecological Functions list (Task 3)

## ecological functions list



Habitat and connectivity for pelagic fish



Habitat and connectivity for resident mammals



Habitat and connectivity for native plants



Maintain genetic/phenotypic diversity



Nutrient movement and recycling



Habitat and connectivity for demersal fish



Habitat and connectivity for marsh birds



Habitat and connectivity for anadromous fish



Maintain connectivity for fragmented populations



Gross food supply



Habitat and connectivity for littoral fish



Habitat and connectivity for riparian birds



Habitat and connectivity for migratory waterfowl



Maintain diverse native communities

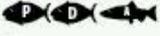


Net food supply

# Landscape Metrics list (Task 3)

## landscape metrics list

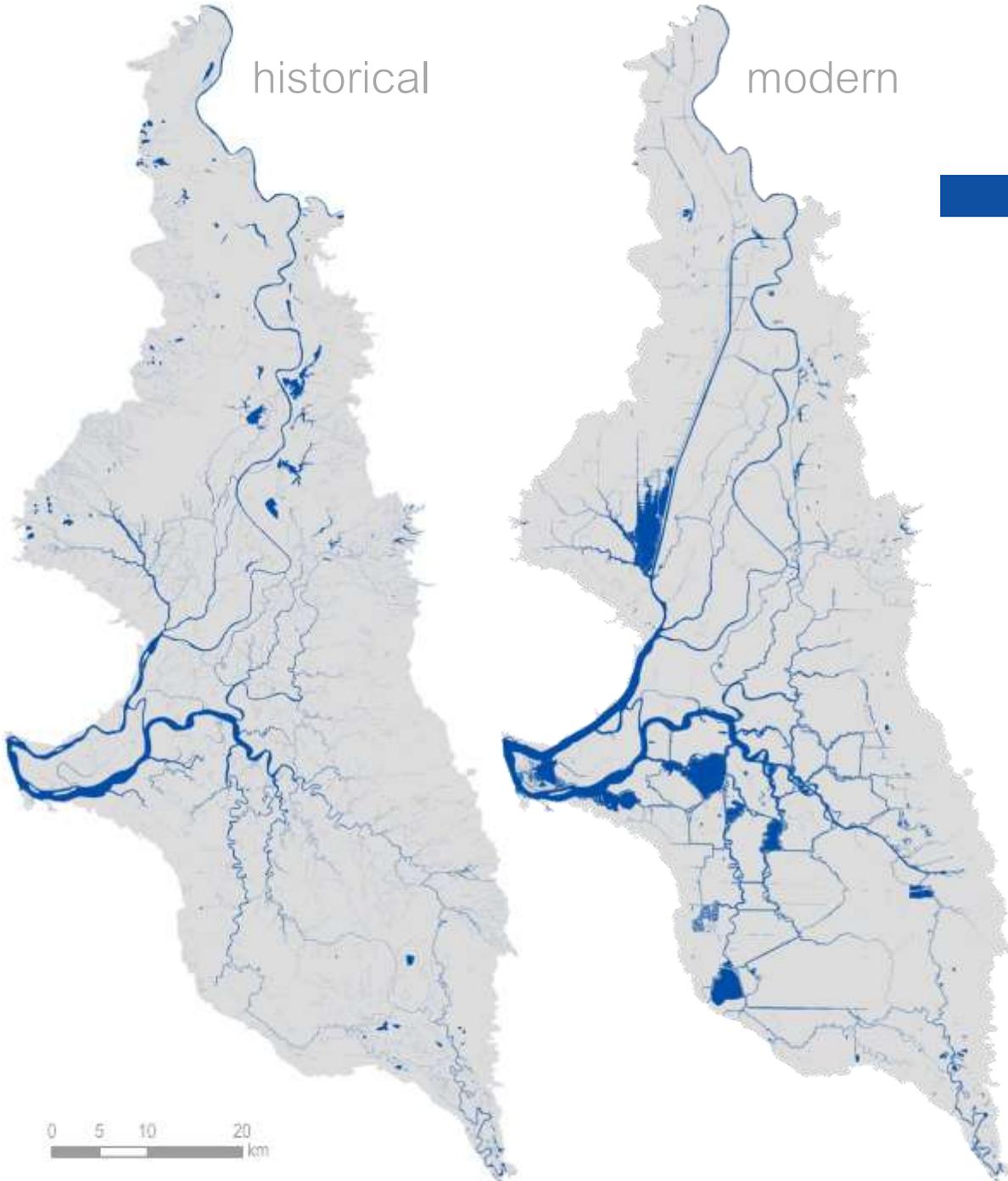
### Associated ecological functions

Landscape metric family	Associated ecological functions
Channels	 <ul style="list-style-type: none"> <li>- Sinuosity</li> </ul>
	 <ul style="list-style-type: none"> <li>- Density (by depth class)</li> </ul>
	 <ul style="list-style-type: none"> <li>- Total length (by width class and depth class)</li> </ul>
	 <ul style="list-style-type: none"> <li>- Total area (by depth class and season)</li> </ul>
Riparian	 <ul style="list-style-type: none"> <li>- Ratio of flow-through to blind channels</li> </ul>
	 <ul style="list-style-type: none"> <li>- Total riparian forest area</li> </ul>
	 <ul style="list-style-type: none"> <li>- Number of riparian forest patches</li> </ul>
Edge	 <ul style="list-style-type: none"> <li>- Riparian forest patch length (by type and width class)</li> </ul>
	 <ul style="list-style-type: none"> <li>- Gap-absence</li> </ul>
Maish Productivity	 <ul style="list-style-type: none"> <li>- Linear extent adjacent to wetlands (by type)</li> </ul>
	 <ul style="list-style-type: none"> <li>- Total length of wetland/upland or wetland/riparian edge</li> </ul>
Habitat mosaics	 <ul style="list-style-type: none"> <li>- Patch size distribution (for select habitat types)</li> </ul>
	 <ul style="list-style-type: none"> <li>- Edge to area ratio (for select habitat types)</li> </ul>
	 <ul style="list-style-type: none"> <li>- Nearest neighbor distance (for select habitat types)</li> </ul>
	 <ul style="list-style-type: none"> <li>- Patch adjacency diversity</li> </ul>
Inundation	 <ul style="list-style-type: none"> <li>- Patch type richness</li> </ul>
	 <ul style="list-style-type: none"> <li>- Area of wetland habitat (by depth class and season)</li> </ul>
	 <ul style="list-style-type: none"> <li>- Ponded area in summer (by depth class and duration)</li> </ul>
Maish Productivity	 <ul style="list-style-type: none"> <li>- Wetted area in winter (by type)</li> </ul>
	 <ul style="list-style-type: none"> <li>- Estimated annual primary production (by habitat)</li> </ul>
Maish Productivity	 <ul style="list-style-type: none"> <li>- Volumes of net auto- vs. net hetero-trophic habitat</li> </ul>
	 <ul style="list-style-type: none"> <li>- Area of marsh (by type)</li> </ul>

There has been a 73-fold reversal in the ratio between marsh and open water in the Delta, affecting the character and quality of aquatic habitats.

historical

modern



open water

historical

16,300 ha

modern

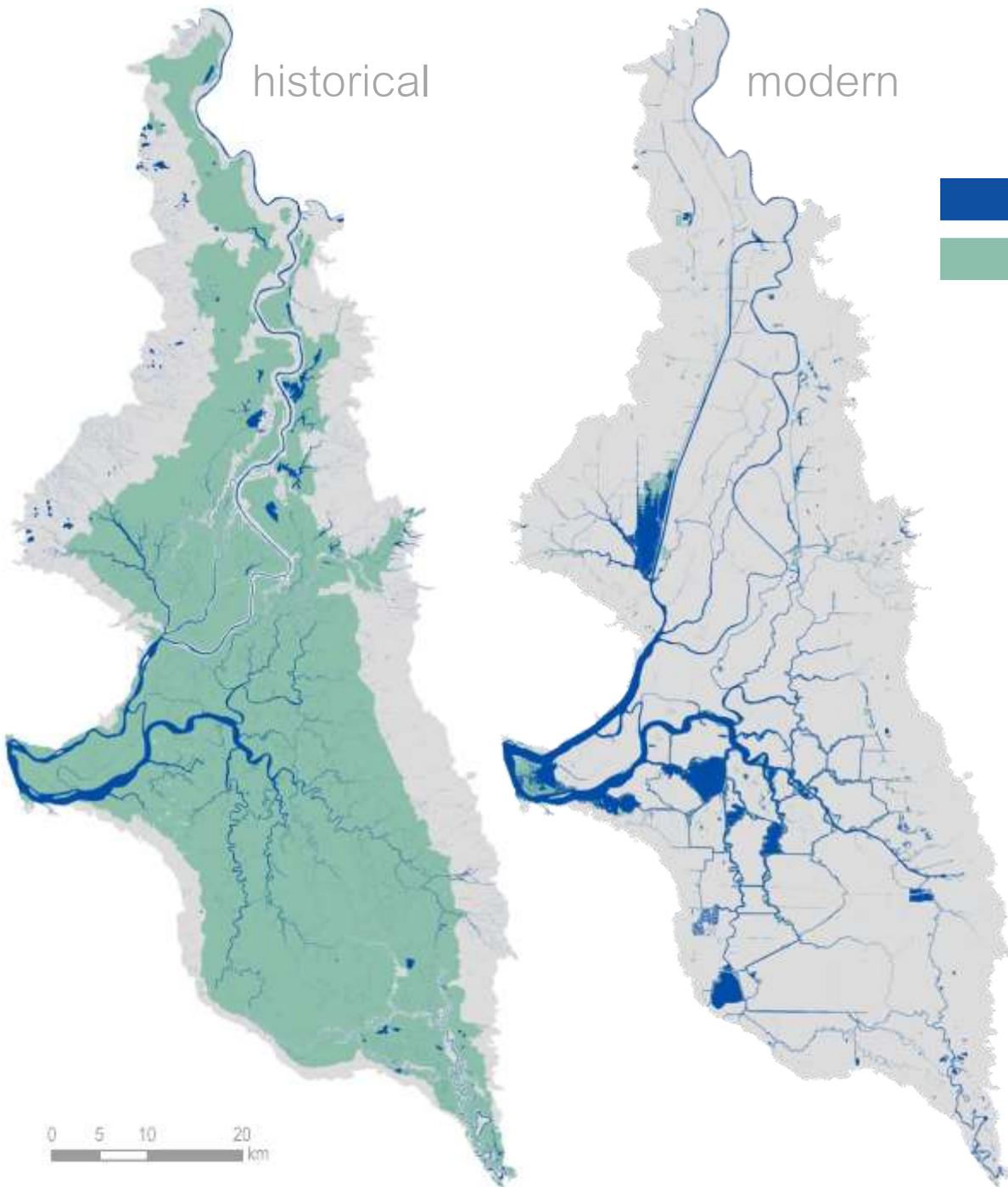
26,600 ha



+ 63%

0 5 10 20 km

# support for native fish



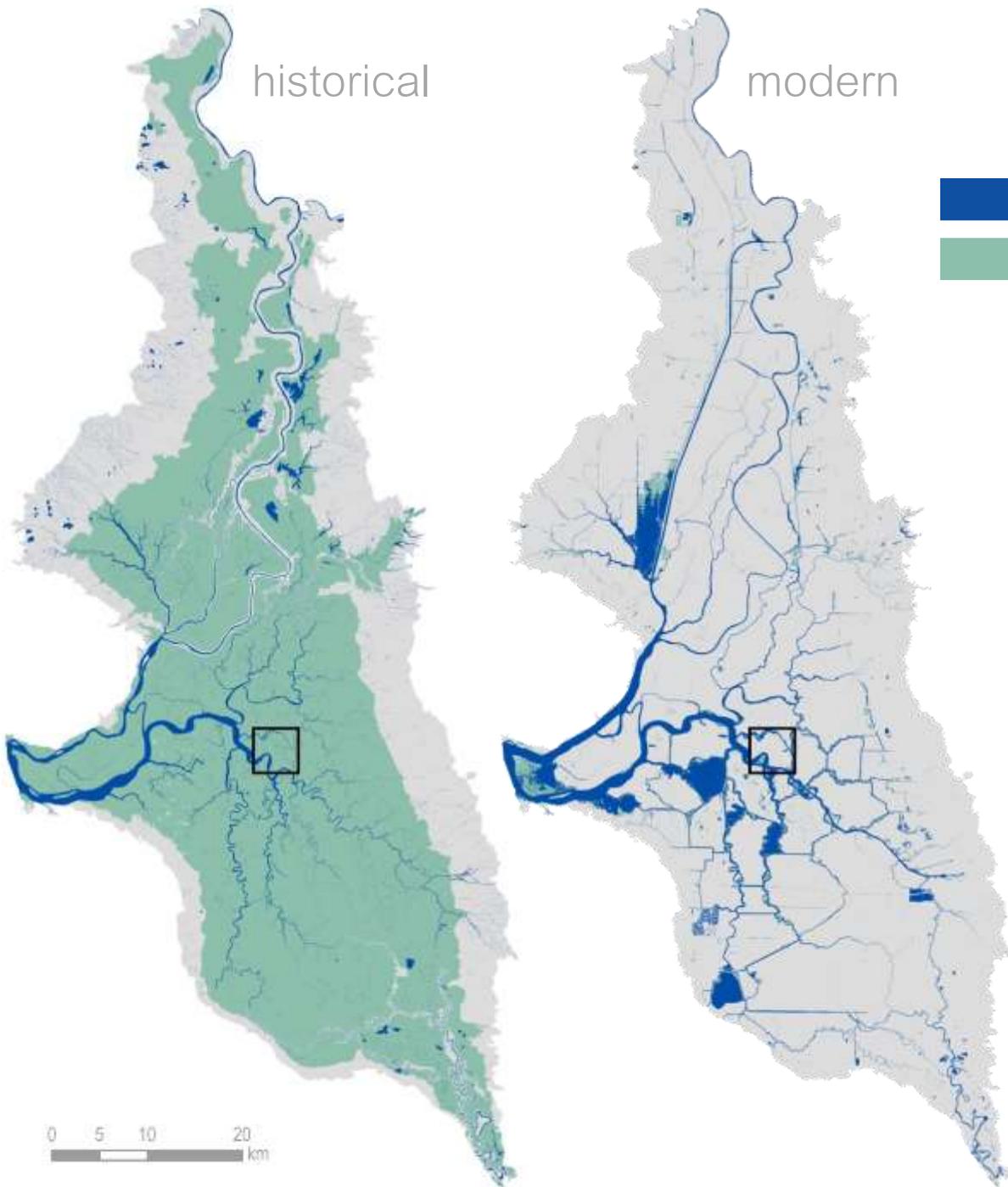
**open water**

**marsh**

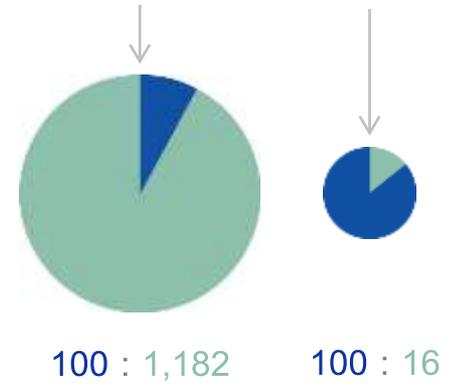


74x decrease in marsh to open water ratio

# support for native fish



	historical	modern
 open water	16,300 ha	26,600 ha
 marsh	193,200 ha	4,300 ha



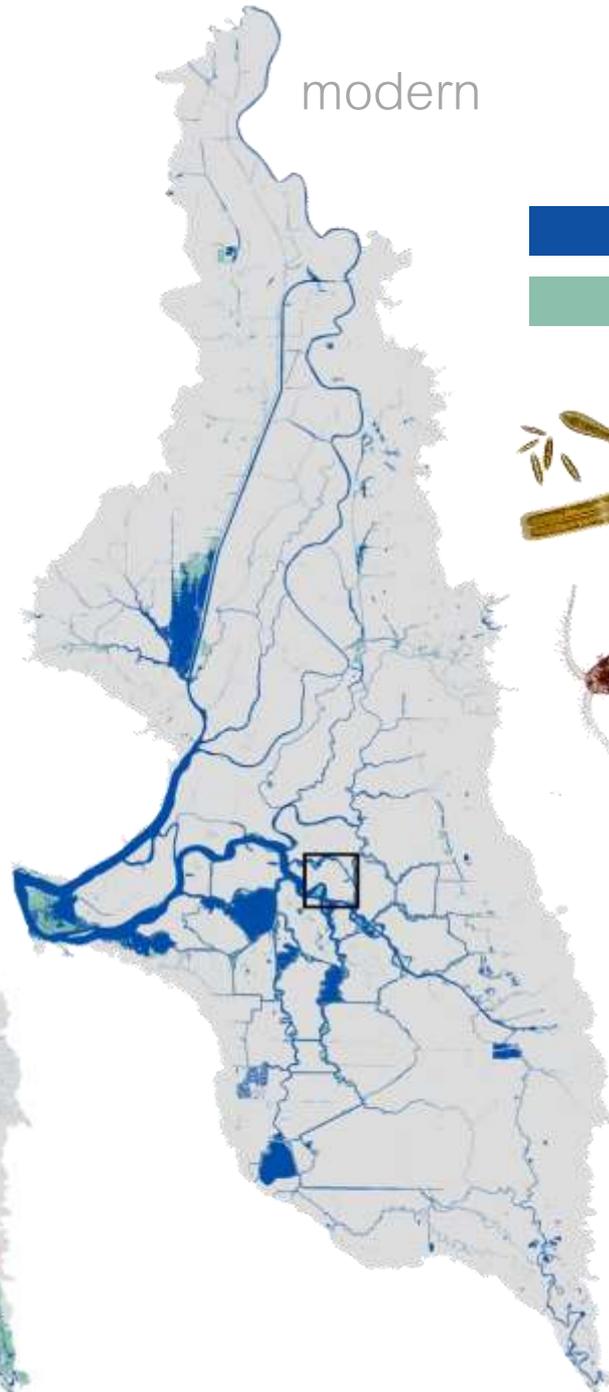
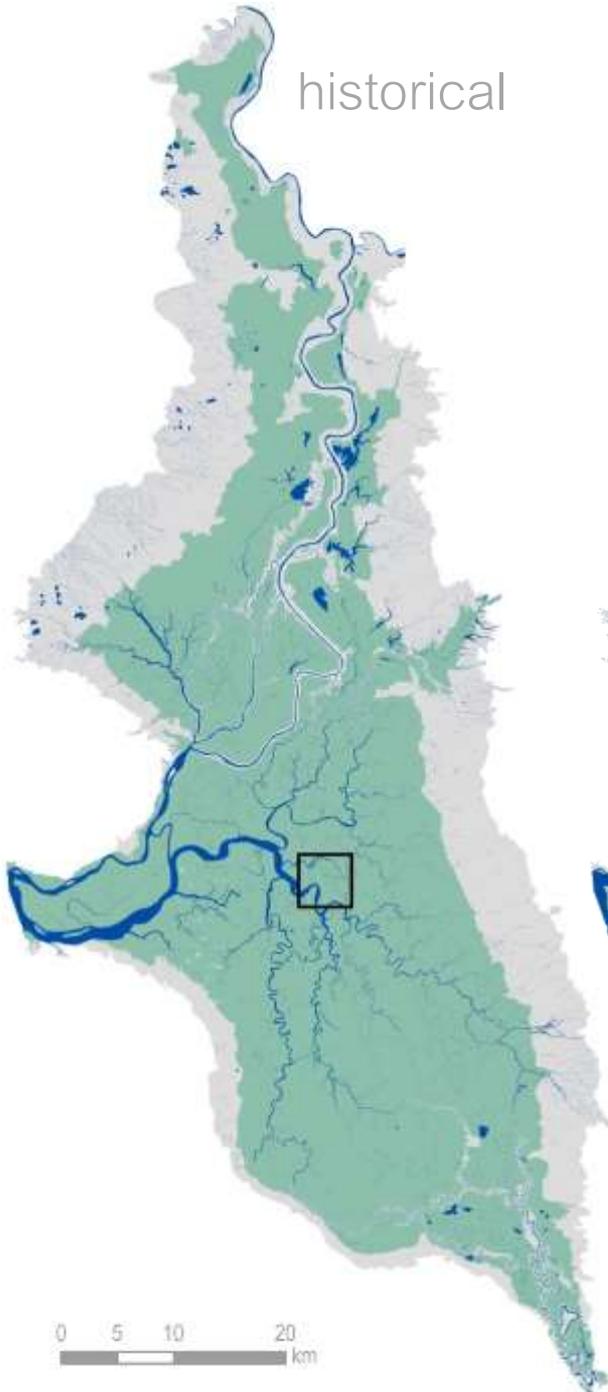
74x decrease in marsh to open water ratio

“channels in marsh” → “marsh in channels”

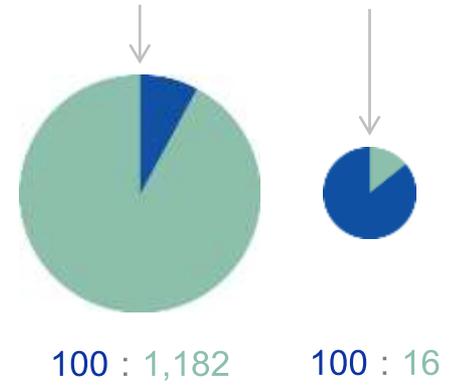


historical

modern



	historical	modern
open water	16,300 ha	26,600 ha
marsh	193,200 ha	4,300 ha

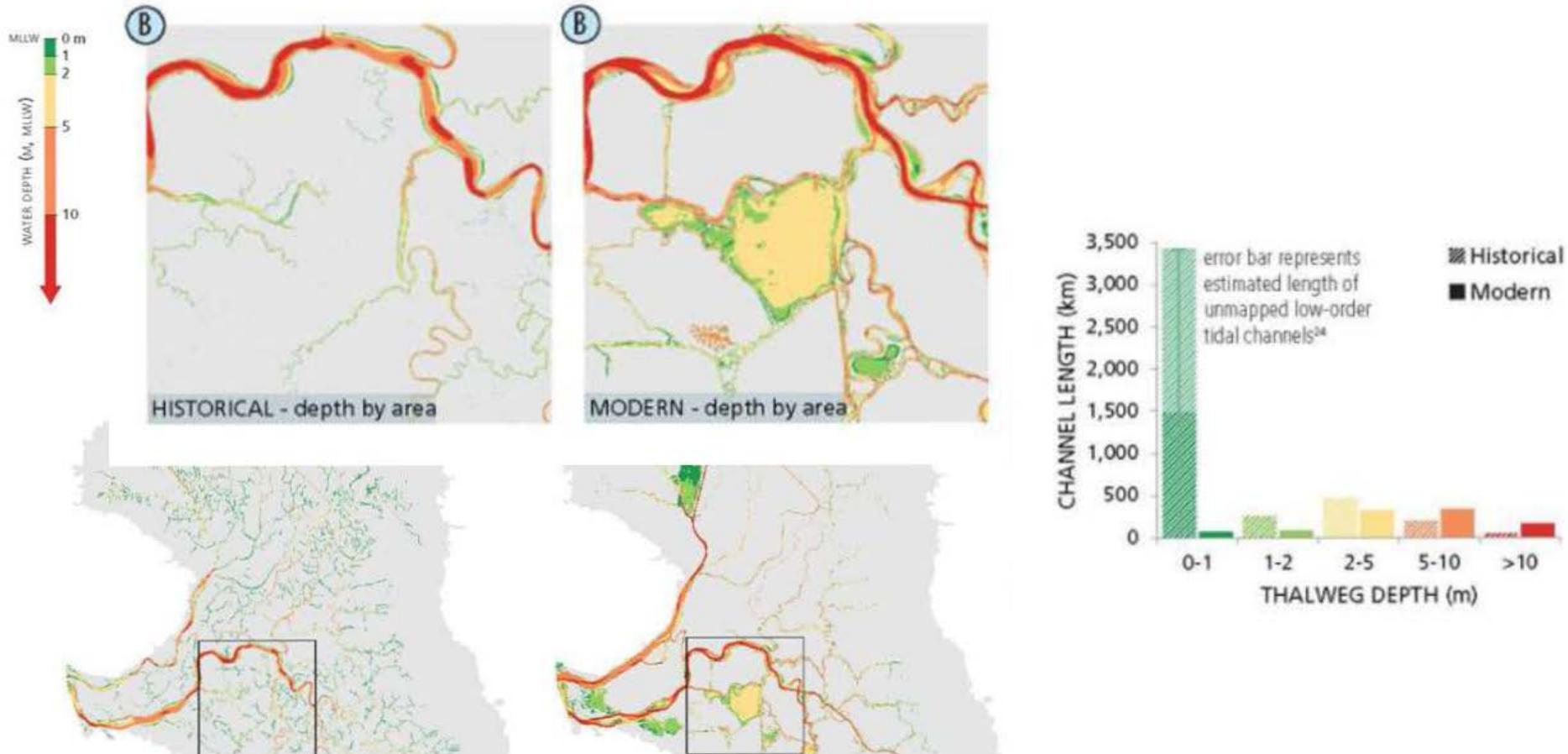


74x decrease in marsh to open water ratio

“channels in marsh” → “marsh in channels”



There is twice as much shallow-water habitat (<2m) in the Delta today as there was historically.



*Historical DEM co-developed with UC Davis CWS (Fleenor, Whipple, Bell, et al.)*

# Complex dendritic channel networks likely provided high productivity habitat for fish.

## Complex dendritic channel networks likely provided high productivity habitat for fish

Most dendritic channels are now gone, especially in the central Delta

As Delta marshes were diked, connections were severed to the channel networks that wove through them. These dendritic (lower-order tidal channels (also known as "dead-end" or "blind channels") that terminated within the wetland were once the capillary exchange system between the wetland and aquatic areas, promoting both food web productivity and spatial complexity in habitat conditions. They provided native fish species with a range of gradients (e.g., temperature, turbidity, and water velocity) at both large and small scales. Dendritic channel networks offered channel complexity and higher turbidities, which provided refuge for certain species. Channels that branched through the marsh may have been particularly important for salmonids because they provided access to and export of invertebrates from the marsh plain,<sup>11</sup> physical cover and turbidity for refuge, and slow moving water for energetic refugia. The larger, looped channels that characterize the Delta today allow water to move through and mix more quickly, with less diversity in residence time and less heterogeneity in channel habitat. The lack of large wetlands connected to channels means that there is little exchange of organic matter, organisms, or sediment between these ecosystems.

Comparing the historical (right) and modern (far right) landscape. While the skeletal framework of looped mainstem channels remains largely similar (red), the branching networks of dendritic channels (green and yellow) are mostly gone.

### Methods: Classifying channel types

Channel reaches were manually classified using the following definitions:

- Dendritic: tidal channel reaches connected to the tidal source by only one non-overlapping path
- Looped: tidal channel reaches connected to the tidal source (the Delta mouth) by two independent and non-overlapping paths
- Fluvial: channel reaches connected to the tidal source, but upstream of the approximate limit of bidirectional tidal flows (during spring tides in times of low river stage) AND tidal reaches between upstream perennial fluvial reaches and downstream flow through reaches
- Detached: channel reaches without a direct connection to the tidal source (through the larger channel network)

Dendritic channels (segmented at 100 m intervals) were classified into those adjacent to marsh and those not adjacent to marsh based on the habitat map.



Channel classification	Channel length (km)	
	Historical	Modern
<span style="color: green;">—</span> Dendritic channels adjacent to marsh	1,151	84
<span style="color: yellow;">—</span> Dendritic channels not adjacent to marsh	153	255
<span style="color: red;">—</span> Looped Channels	754	768
<span style="color: blue;">—</span> Fluvial	2,225	298
<span style="color: grey;">—</span> Detached		
<b>TOTAL</b>	<b>4,283</b>	<b>1,404</b>

Most channels in the Delta today are looped. The length of this kind of channel has slightly increased (due to channel cuts), while the length of dendritic tidal channels has decreased by more than 34%. Where dendritic channels do exist, they are generally not part of marshes—the length of dendritic channels adjacent to marsh has decreased by 92%. These figures and tables do not show or account for the approximately 1,900 km of estimated unmapped, low-order dendritic channels in the historical Delta.



Historically, the complex structure of Delta channels established gradients in residence time, a pattern heavily altered in the modern Delta (after Chris Ertight, Delta Science Program). Historically, small low-order tidal creeks had high residence times, which allowed phytoplankton to accumulate and created net autotrophic conditions. Deeper sloughs, by contrast, had shorter residence times which created net heterotrophic conditions. The increased connectivity of modern channels in the Delta has led to homogenization of residence time across channel networks, increasing the reach of tidal excursion within channel networks and decreasing the occurrence of small channels with high residence time. The relationship between residence time and primary productivity in the modern Delta has been additionally

Most of the temporarily flooded habitat available to fish in the Delta has been lost.

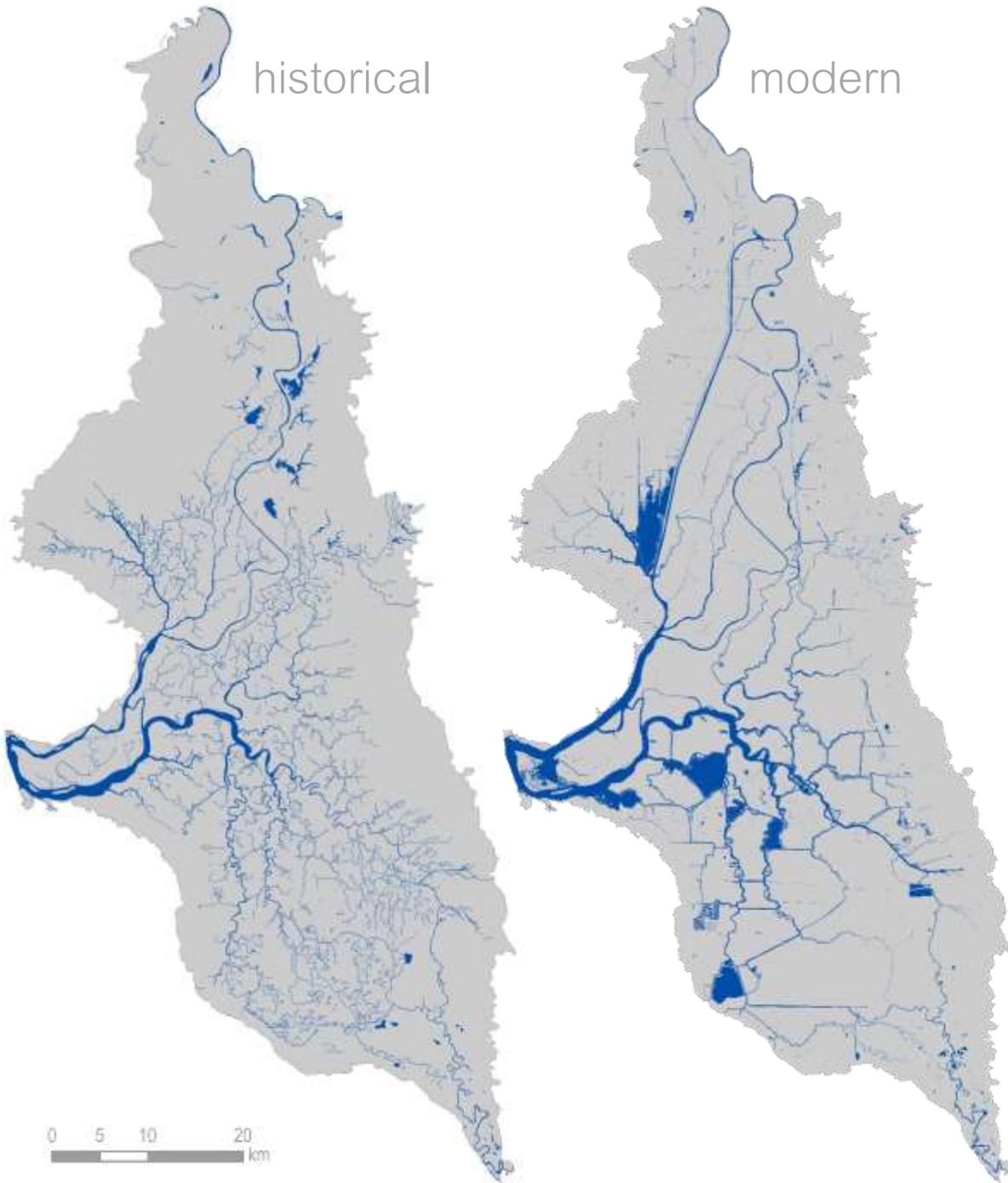
historical

modern

■ PONDS, LAKES, CHANNELS,  
FLOODED ISLANDS

*Mostly perennial open water features*

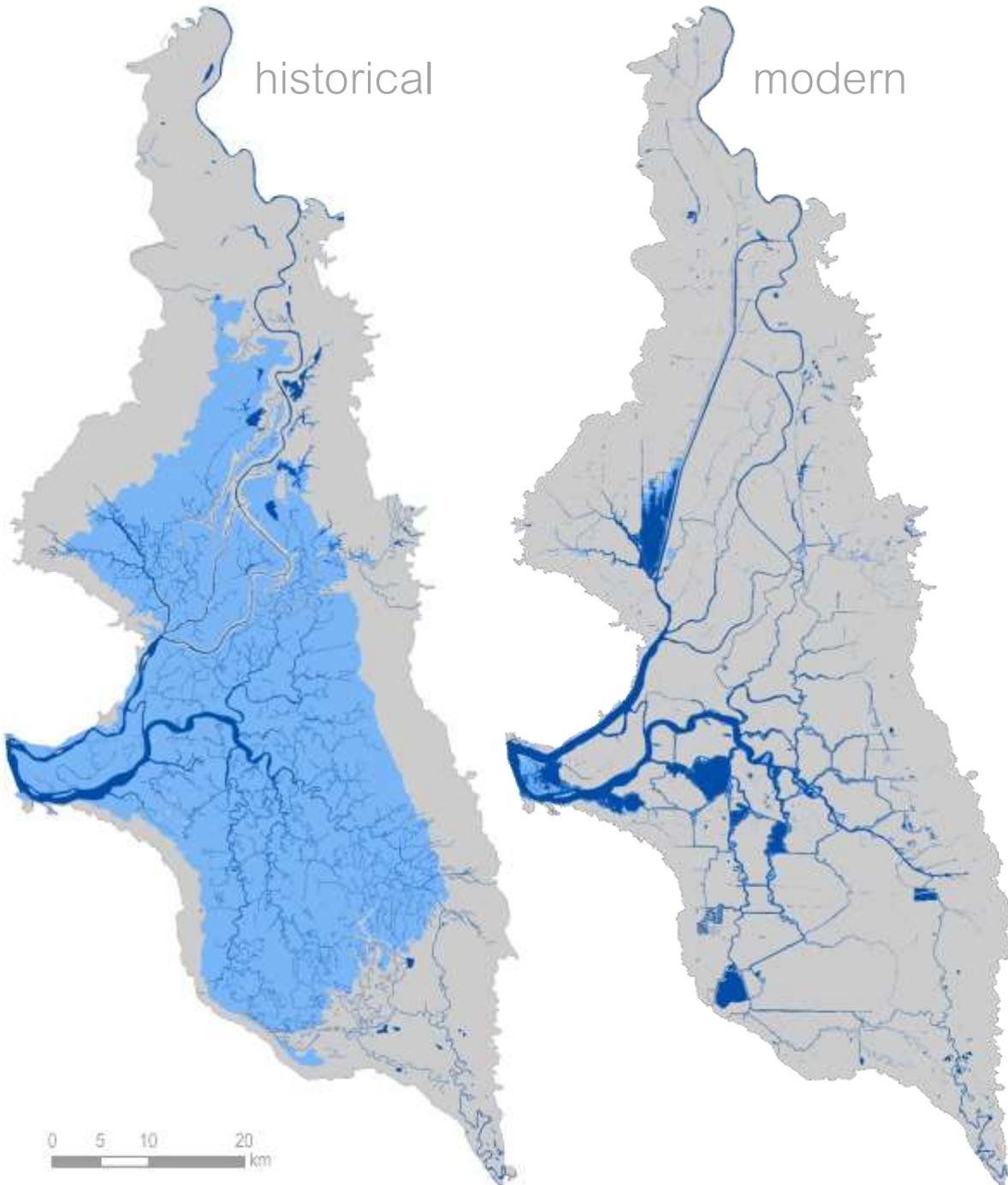
- variable depth



0 5 10 20  
km

historical

modern



■ PONDS, LAKES, CHANNELS,  
FLOODED ISLANDS

*Mostly perennial open water features*

- variable depth

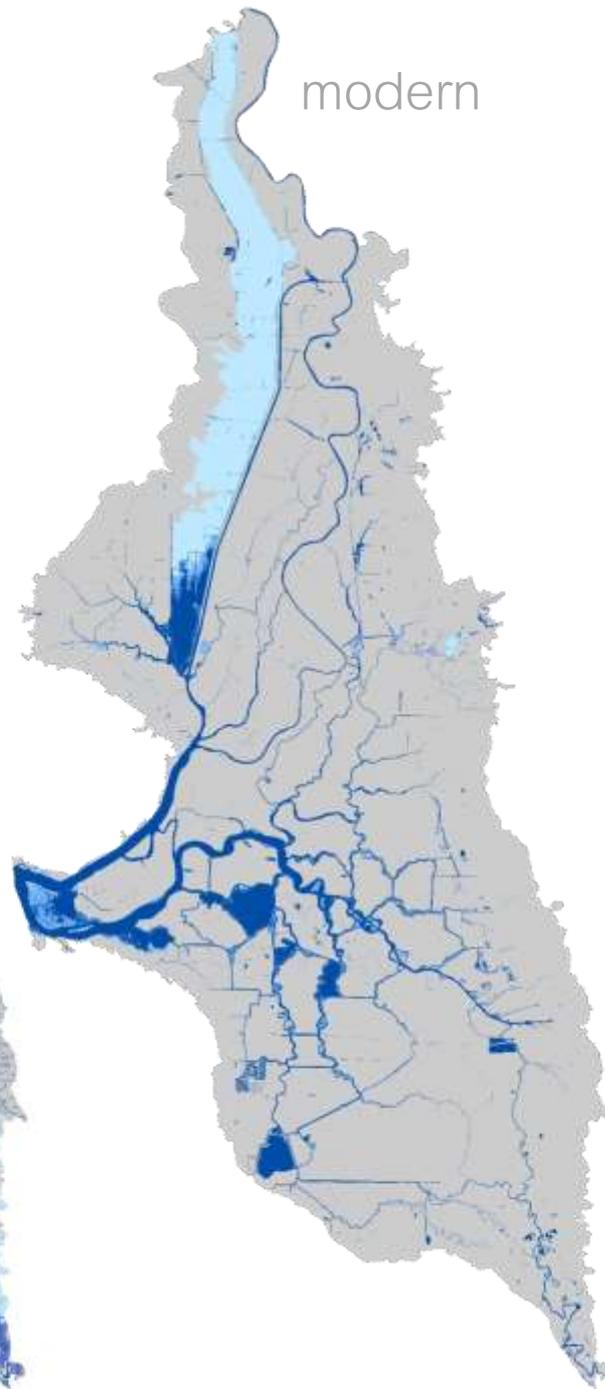
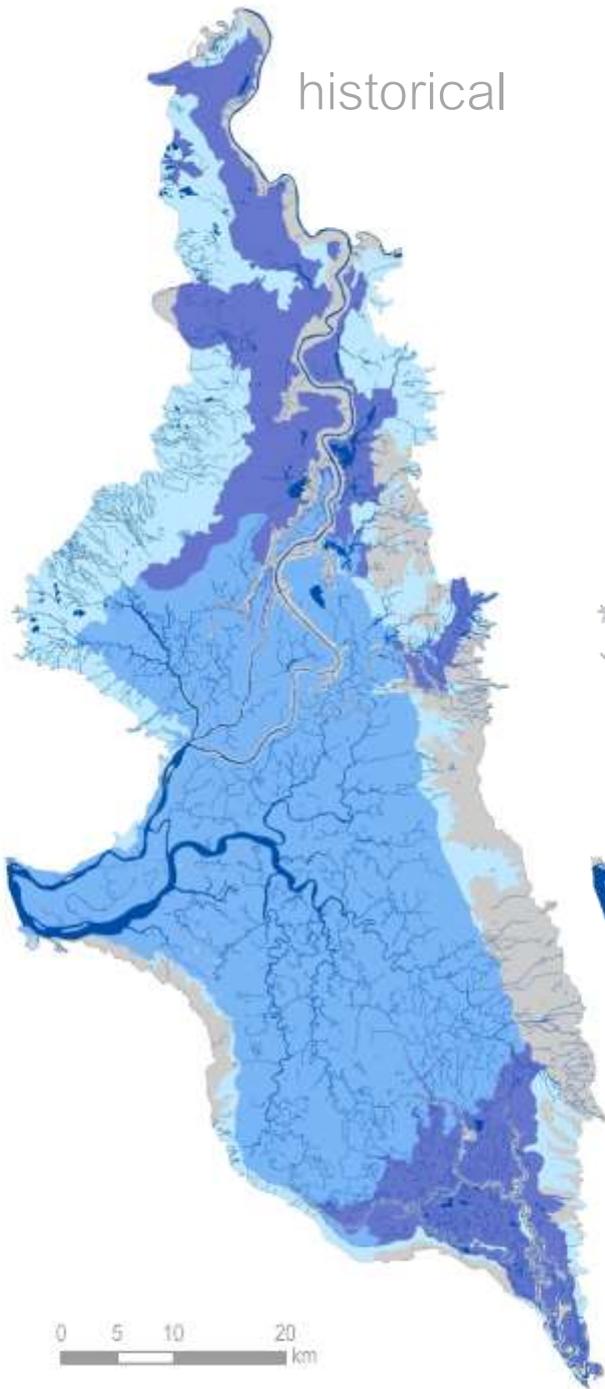
■ TIDAL INUNDATION

*Diurnal overflow of tidal sloughs into  
marshes*

- high recurrence (2x daily to monthly)
- low duration (< 6 hrs per event)
- low depth ("wetted" up to .5 m)

historical

modern



**PONDS, LAKES, CHANNELS, FLOODED ISLANDS**

*Mostly perennial open water features*

- variable depth

**TIDAL INUNDATION**

*Diurnal overflow of tidal sloughs into marshes*

- high recurrence (2x daily to monthly)
- low duration (< 6 hrs per event)
- low depth ("wetted" up to .5 m)

**SEASONAL LONG DURATION FLOODING**

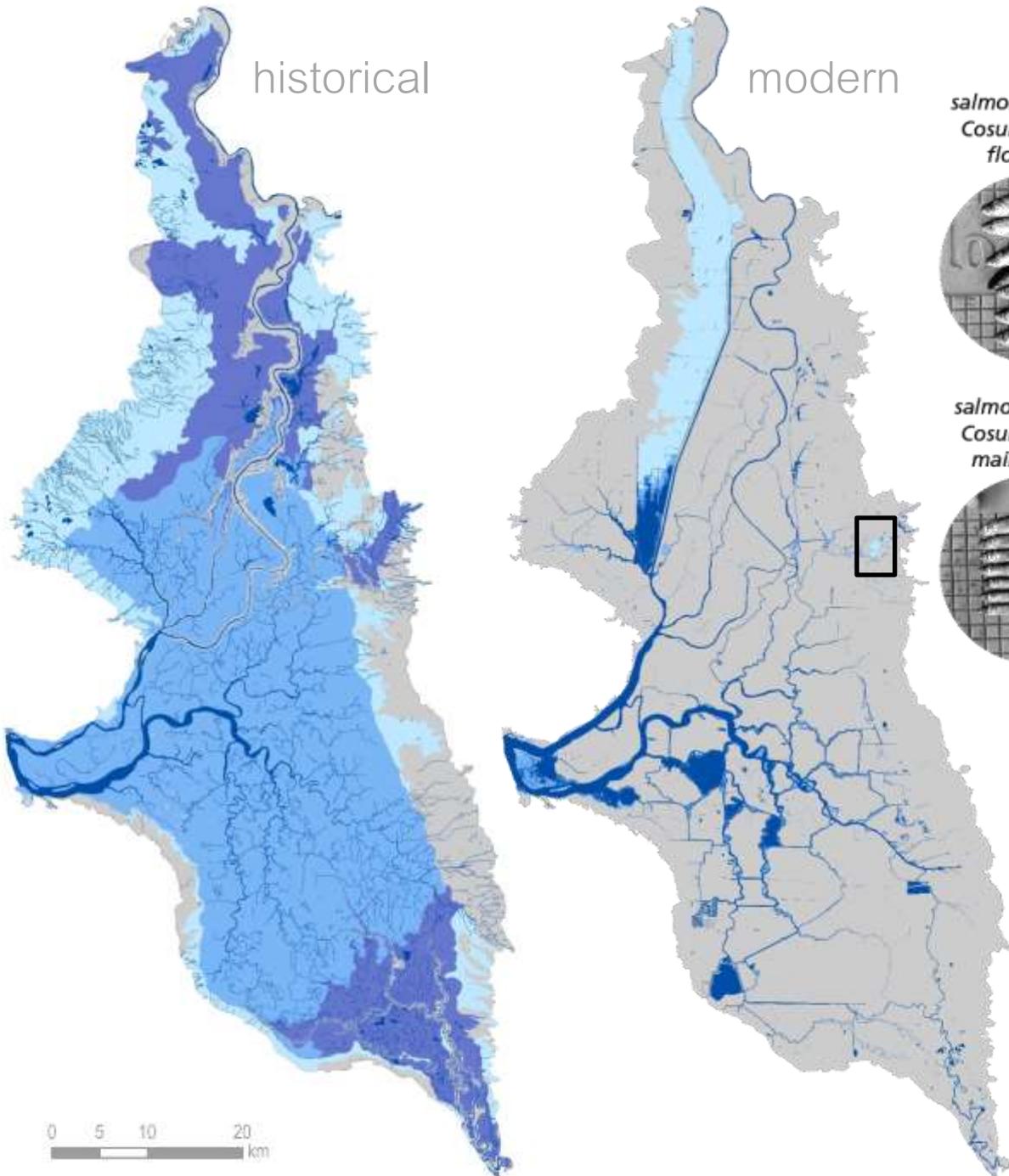
*Prolonged inundation from river overflow into flood basins*

- low recurrence (~1 event per year)
- high duration (persists up to 6 month)
- generally deeper than 'seasonal short-term flooding'

**SEASONAL SHORT-TERM FLOODING**

*Short-term fluvial inundation*

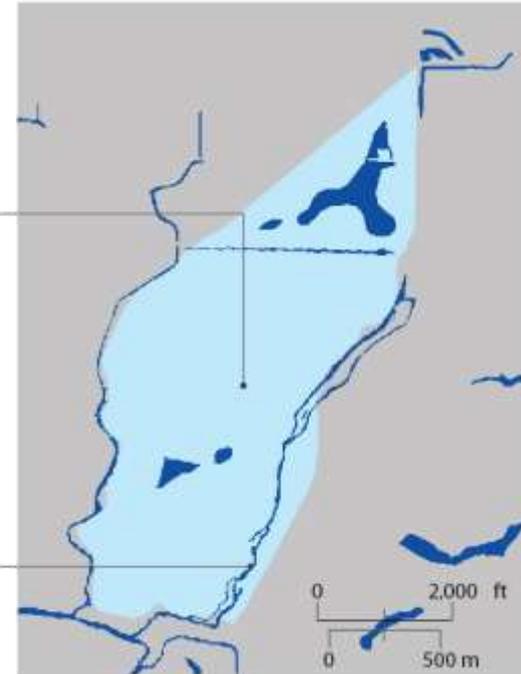
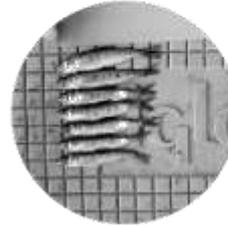
- can be multiple events per year
- low duration (days-weeks per event)
- generally shallower than 'seasonal long duration flooding'



salmon reared on  
Cosumnes River  
floodplain



salmon reared in  
Cosumnes River  
main channel

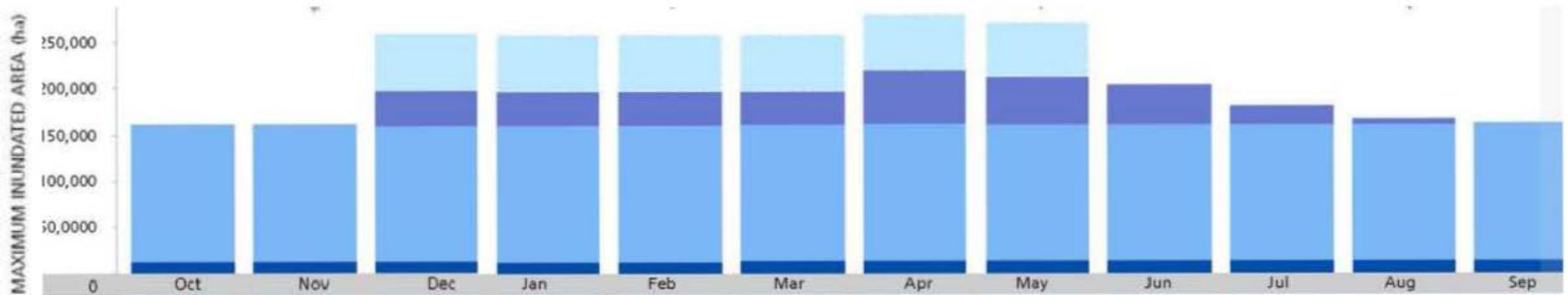


photos by Jeff Opperman, 2006

Juvenile salmon reared in ephemeral floodplain habitats of the Cosumnes River have been found to grow significantly larger than juvenile salmon reared only within the Cosumnes River (Jeffres et al. 2008).

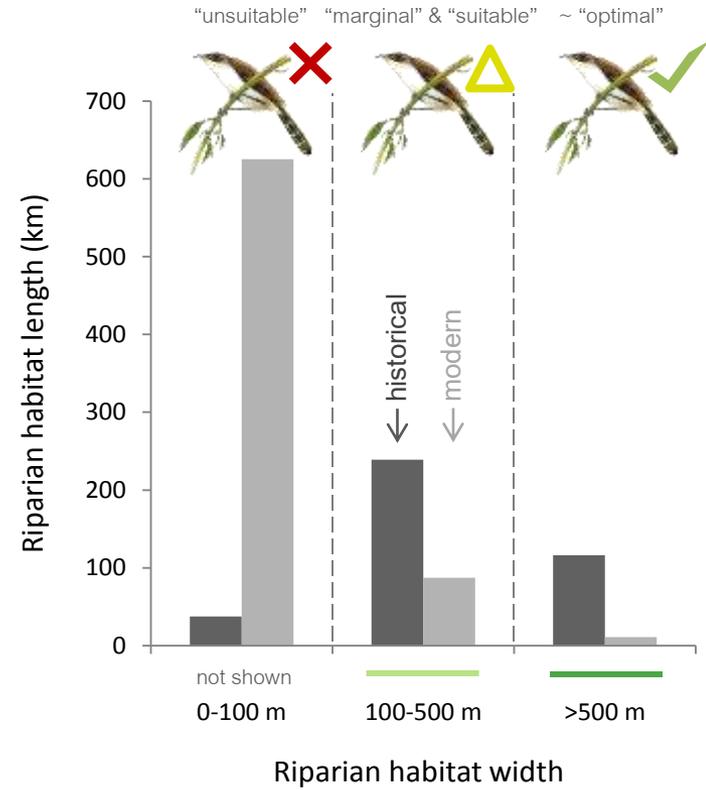
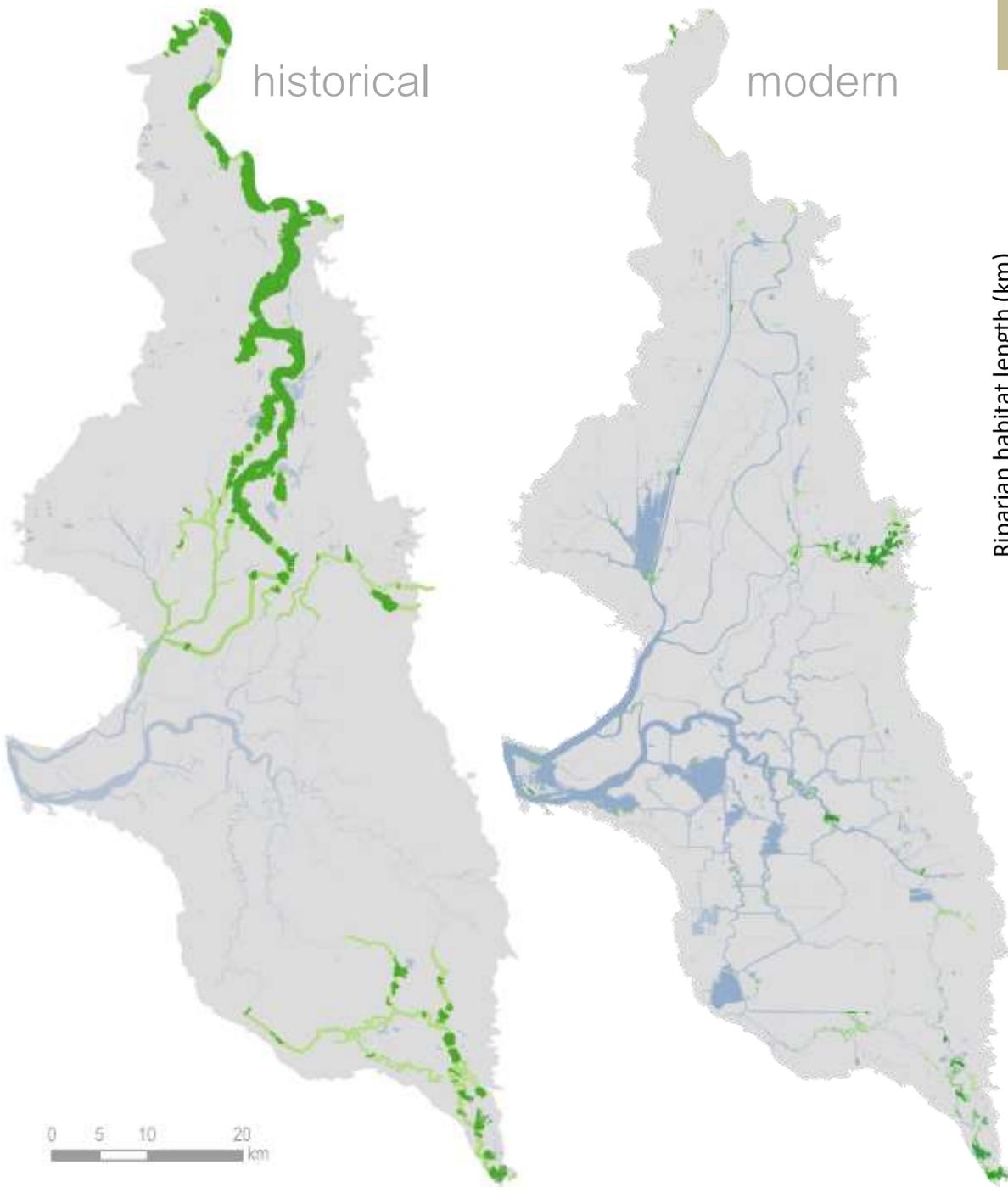
- PONDS, LAKES, CHANNELS, FLOODED ISLANDS
- TIDAL INUNDATION
- SEASONAL LONG DURATION FLOODING
- SEASONAL SHORT-TERM FLOODING

# Native fish are adapted to a complex, variable landscape with extensive aquatic resources throughout the year.



- SEASONAL SHORT-TERM FLOODING**  
*Short-term fluvial inundation*
  - intermediate recurrence (~10 events per year)
  - low duration (days to weeks per event)
  - generally shallower than seasonal long-duration flooding
- SEASONAL LONG-DURATION FLOODING**  
*Prolonged inundation from river overflow into flood basins*
  - low recurrence (~1 event per year)
  - high duration (persists up to 6 months)
  - generally deeper than seasonal short-term flooding
- TIDAL INUNDATION**  
*Diurnal overflow of tidal sloughs into marshes*
  - high recurrence (twice daily)
  - low duration (<6 hrs per event)
  - low depth ("wetted" up to 0.5 m)
- PONDS, LAKES, CHANNELS, & FLOODED ISLANDS**  
*Perennial open water features (with the exception of historical intermittent ponds and streams)*
  - recurrence not applicable (generally perennial features)
  - high duration (generally perennial features)
  - variable depth

There are a number of additional elements to a complete Delta ecosystem.



Majority of riparian habitat today is of "unsuitable" width to support yellow billed cuckoos (Laymon & Halterman 1989). Length of forest of "optimal" width has decreased by 91%

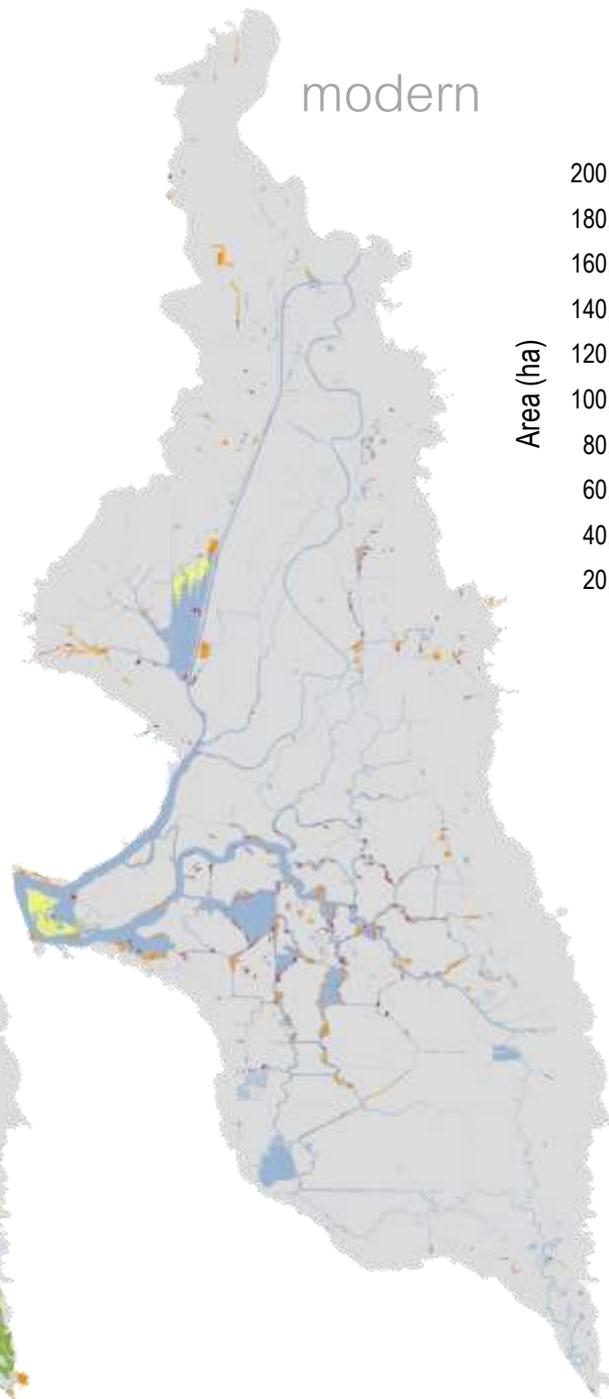
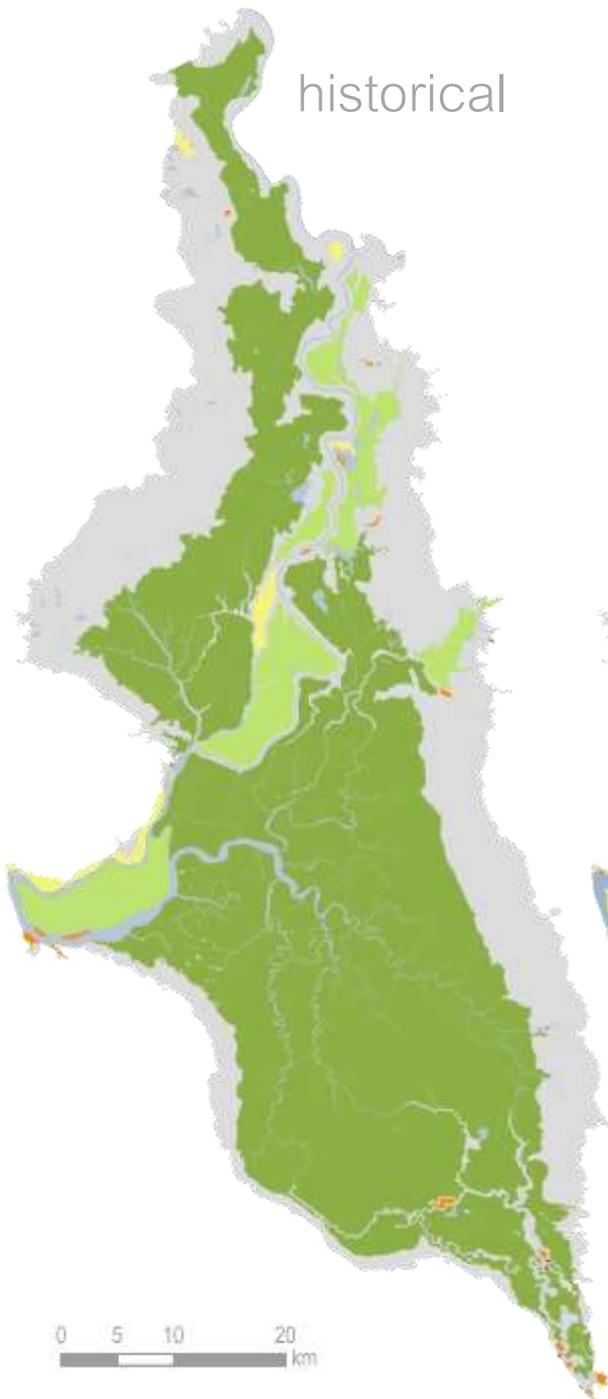
riparian forest width (transects)

- > 100 m wide
- > 500 m wide

riparian forest < 100 m wide not shown

historical

modern



Marsh in patches large enough to fully support rails

(based on Liu et al. 2012, Spautz & Nur 2002):

Historical: 192,000 ha

Modern: 1,000 ha

marsh patch size class (hectares)

- ≤ 10 ha
- 10 - 100
- 100 - 1,000
- 1,000 - 10,000
- > 10,000



# THANKS

**CDFW:** Daniel Burmester, Carl Wilcox, Dave Zezulak

**DSP:** Peter Goodwin, Chris Enright, Anke Mueller-Solger, Cliff Dahm

**Cache Slough Team:** Bruce Orr, Noah Hume (Stillwater); Stuart Siegel (ESA)

**Lower Yolo Team:** Curt Schmutte, Val Connor

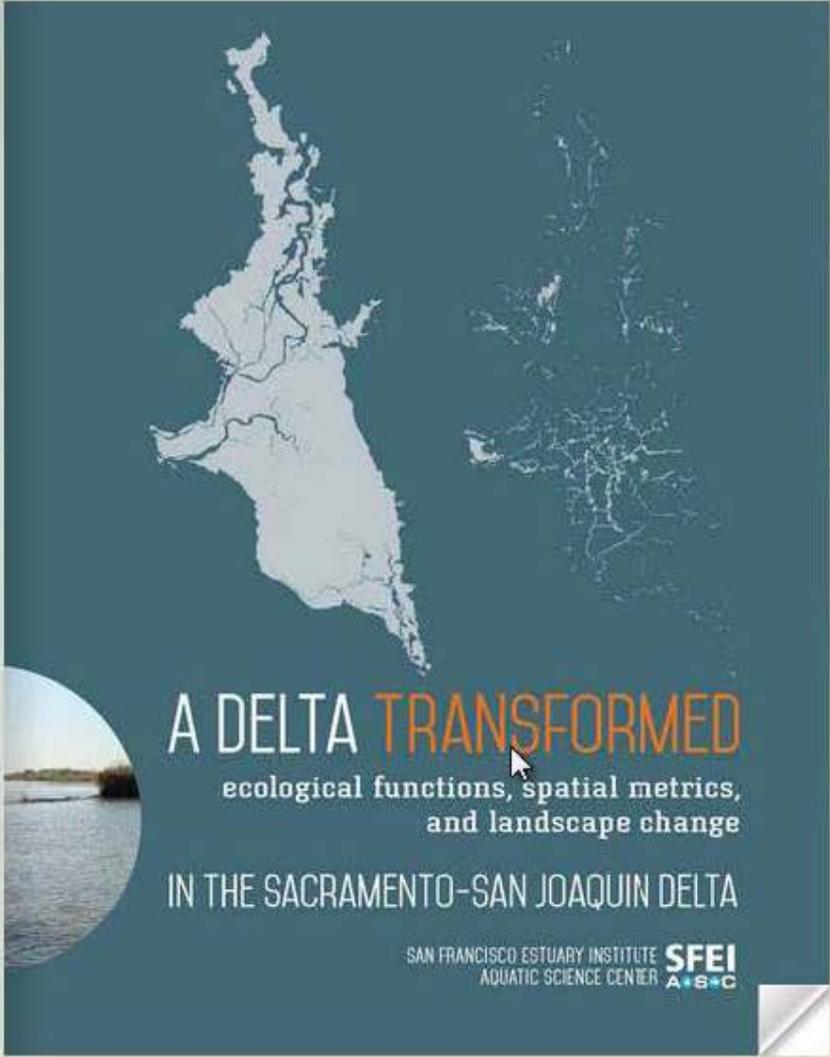
**TNC MWT:** Leo Winternitz, Rodd Kelsey

**The LIT**

**CDFW, ERP, DWR, SFCWA , TNC for funding**

***<http://sfei.li/deltametrics>***





**A DELTA TRANSFORMED**  
ecological functions, spatial metrics,  
and landscape change

IN THE SACRAMENTO-SAN JOAQUIN DELTA

SAN FRANCISCO ESTUARY INSTITUTE **SFEI**  
AQUATIC SCIENCE CENTER **A+S+C**



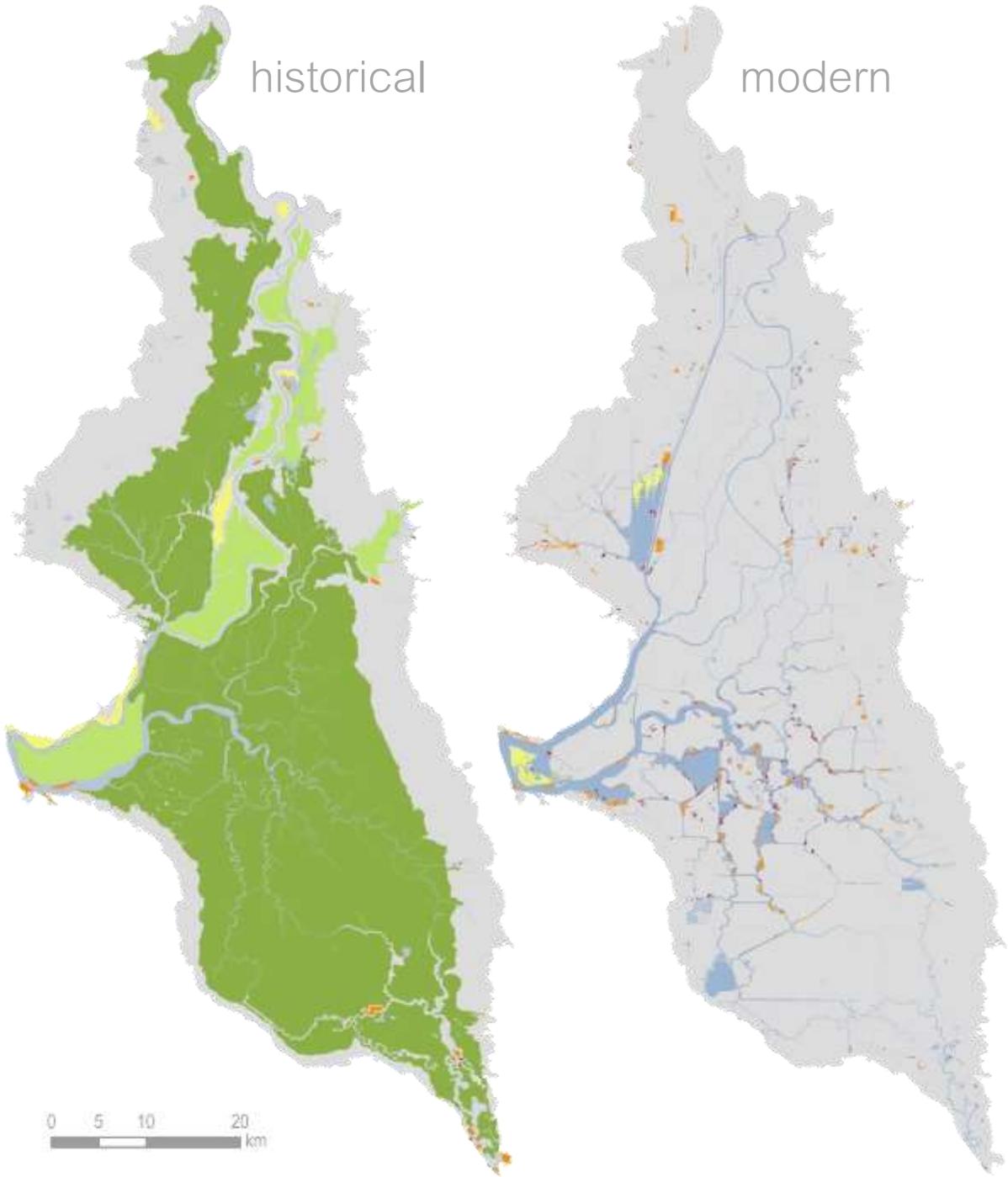


# Support for:

- marsh wildlife
  - marsh patch size
- native fish
  - marsh:open water ratio
  - length of marsh-water edge
  - inundated areas
- riparian wildlife
  - riparian forest width
- edge wildlife
  - marsh-terrestrial transition zone

historical

modern



marsh patch size class (hectares)

- <= 10 ha
- 10 - 100
- 100 - 1,000
- 1,000 - 10,000
- > 10,000

marsh patch size class (hectares)



historical marsh patches

Largest patch:  
Sherman Island  
(749 ha)

modern marsh patches



**4,493 ha**  
average patch size

**1,211 ha**  
average patch size





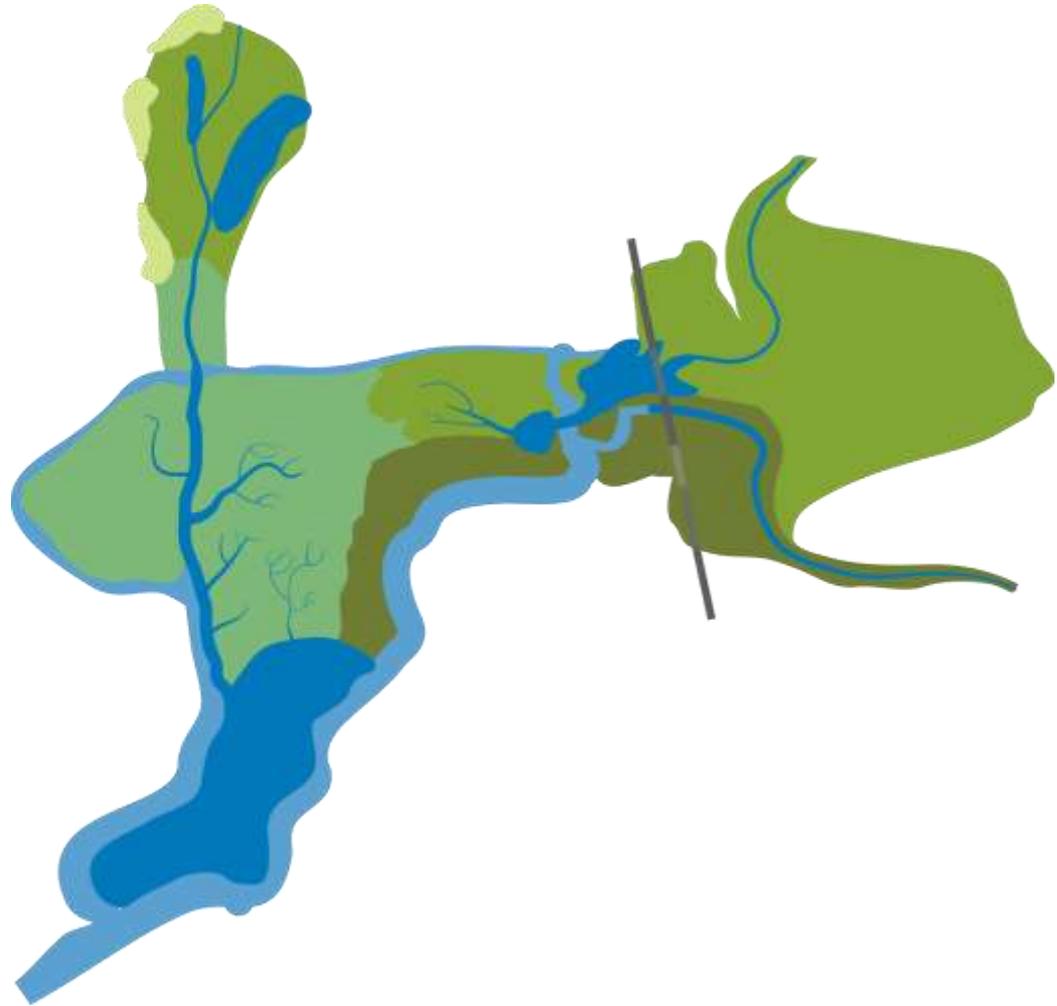
LEVEL	POPULATION					COMMUNITY		
	Life history support					Adaptation potential	Food webs	Biodiversity
THEME								
FUNCTION	Provides habitat and connectivity for fish	Provides habitat and connectivity for marsh wildlife	Provides habitat and connectivity for waterbirds	Provides habitat and connectivity for riparian wildlife	Provides habitat and connectivity for marsh-terrestrial transition zone wildlife	Maintains adaptation potential within wildlife populations	Maintains food supplies and nutrient cycling to support robust food webs	Maintains biodiversity by supporting diverse natural communities
METRICS	Inundation extent, duration, timing, and frequency	Marsh area by patch size (patch size distribution)	Ponded area in summer by depth and duration	Riparian habitat area by patch size	Length of marsh-terrestrial transition zone by terrestrial habitat type	To be addressed with qualitative conceptual models in Task 4.	Expected to be addressed with a related project.	To be addressed with qualitative conceptual models in Task 4.
	Marsh to open water ratio	Marsh area by nearest neighbor distance	Wetted area by type in winter	Riparian habitat length by width class				
	Adjacency of marsh to open water by length and marsh patch size	Marsh core area ratio						
	Ratio of looped to dendritic channels (by length and adjacent habitat type)	Marsh fragmentation index						

LEVEL	POPULATION					COMMUNITY		
	Life history support					Adaptation potential	Food webs	Biodiversity
THEME	Life history support					Adaptation potential	Food webs	Biodiversity
FUNCTION	Provides habitat and connectivity for fish	Provides habitat and connectivity for marsh wildlife	Provides habitat and connectivity for waterbirds	Provides habitat and connectivity for riparian wildlife	Provides habitat and connectivity for marsh-terrestrial transition zone wildlife	Maintains adaptation potential within wildlife populations	Maintains food supplies and nutrient cycling to support robust food webs	Maintains biodiversity by supporting diverse natural communities
METRICS	Inundation extent, duration, timing, and frequency	Marsh area by patch size (patch size distribution)	Ponded area in summer by depth and duration	Riparian habitat area by patch size	Length of marsh-terrestrial transition zone by terrestrial habitat type	To be addressed with qualitative conceptual models in Task 4.	Expected to be addressed with a related project.	To be addressed with qualitative conceptual models in Task 4.
	Marsh to open water ratio	Marsh area by nearest neighbor distance	Wetted area by type in winter	Riparian habitat length by width class				
	Adjacency of marsh to open water by length and marsh patch size	Marsh core area ratio						
	Ratio of looped to dendritic channels (by length and adjacent habitat type)	Marsh fragmentation index						

LEVEL	POPULATION					COMMUNITY		
	Life history support					Adaptation potential	Food webs	Biodiversity
THEME	Life history support					Adaptation potential	Food webs	Biodiversity
FUNCTION	Provides habitat and connectivity for fish	Provides habitat and connectivity for marsh wildlife	Provides habitat and connectivity for waterbirds	Provides habitat and connectivity for riparian wildlife	Provides habitat and connectivity for marsh-terrestrial transition zone wildlife	Maintains adaptation potential within wildlife populations	Maintains food supplies and nutrient cycling to support robust food webs	Maintains biodiversity by supporting diverse natural communities
METRICS	Inundation extent, duration, timing, and frequency	Marsh area by patch size (patch size distribution)	Ponded area in summer by depth and duration	Riparian habitat area by patch size	Length of marsh-terrestrial transition zone by terrestrial habitat type	To be addressed with qualitative conceptual models in Task 4.	Expected to be addressed with a related project.	To be addressed with qualitative conceptual models in Task 4.
	Marsh to open water ratio	Marsh area by nearest neighbor distance	Wetted area by type in winter	Riparian habitat length by width class				
	Adjacency of marsh to open water by length and marsh patch size	Marsh core area ratio						
	Ratio of looped to dendritic channels (by length and adjacent habitat type)	Marsh fragmentation index						

LEVEL	POPULATION					COMMUNITY		
	Life history support					Adaptation potential	Food webs	Biodiversity
THEME								
FUNCTION	Provides habitat and connectivity for fish	Provides habitat and connectivity for marsh wildlife	Provides habitat and connectivity for waterbirds	Provides habitat and connectivity for riparian wildlife	Provides habitat and connectivity for marsh-terrestrial transition zone wildlife	Maintains adaptation potential within wildlife populations	Maintains food supplies and nutrient cycling to support robust food webs	Maintains biodiversity by supporting diverse natural communities
METRICS	Inundation extent, duration, timing, and frequency	Marsh area by patch size (patch size distribution)	Ponded area in summer by depth and duration	Riparian habitat area by patch size	Length of marsh-terrestrial transition zone by terrestrial habitat type	To be addressed with qualitative conceptual models in Task 4.	Expected to be addressed with a related project.	To be addressed with qualitative conceptual models in Task 4.
	Marsh to open water ratio	Marsh area by nearest neighbor distance	Wetted area by type in winter	Riparian habitat length by width class				
	Adjacency of marsh to open water by length and marsh patch size	Marsh core area ratio						
	Ratio of looped to dendritic channels (by length and adjacent habitat type)	Marsh fragmentation index						

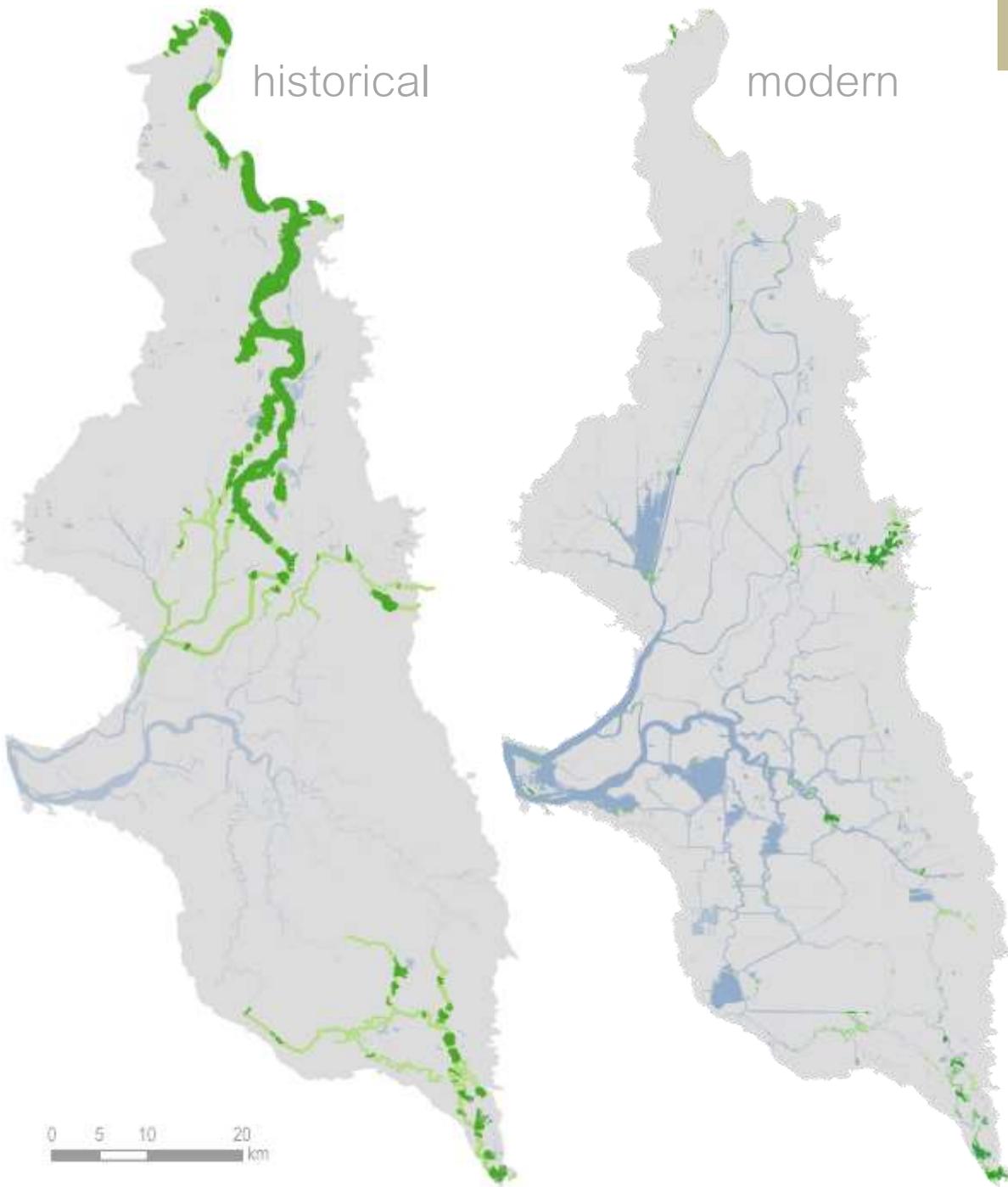
2100



Wide woody riparian habitat has declined by 72%.

historical

modern



riparian forest width (transects)

 > 100 m wide

 > 500 m wide

riparian forest < 100 m wide not shown

