Welcome to the Conservation Lecture Series

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Multi-threaded wetland channels and the implications for salmonids and ecosystem rehabilitation

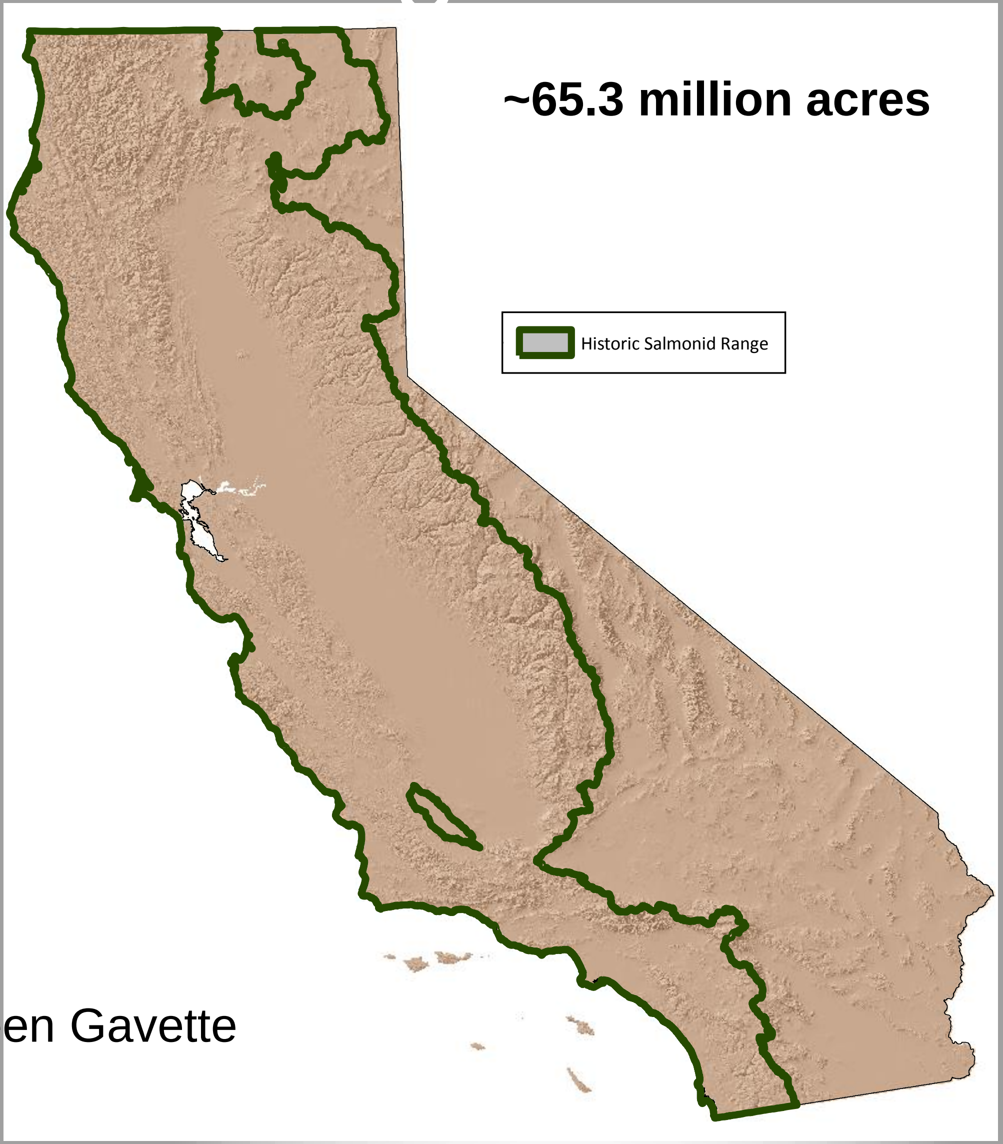

Lauren Hammack
PRUNUSKE CHATHAM, INC.

Brian Cluer, PhD
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

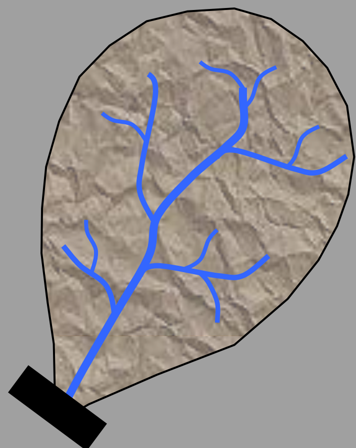
Presentation Agenda

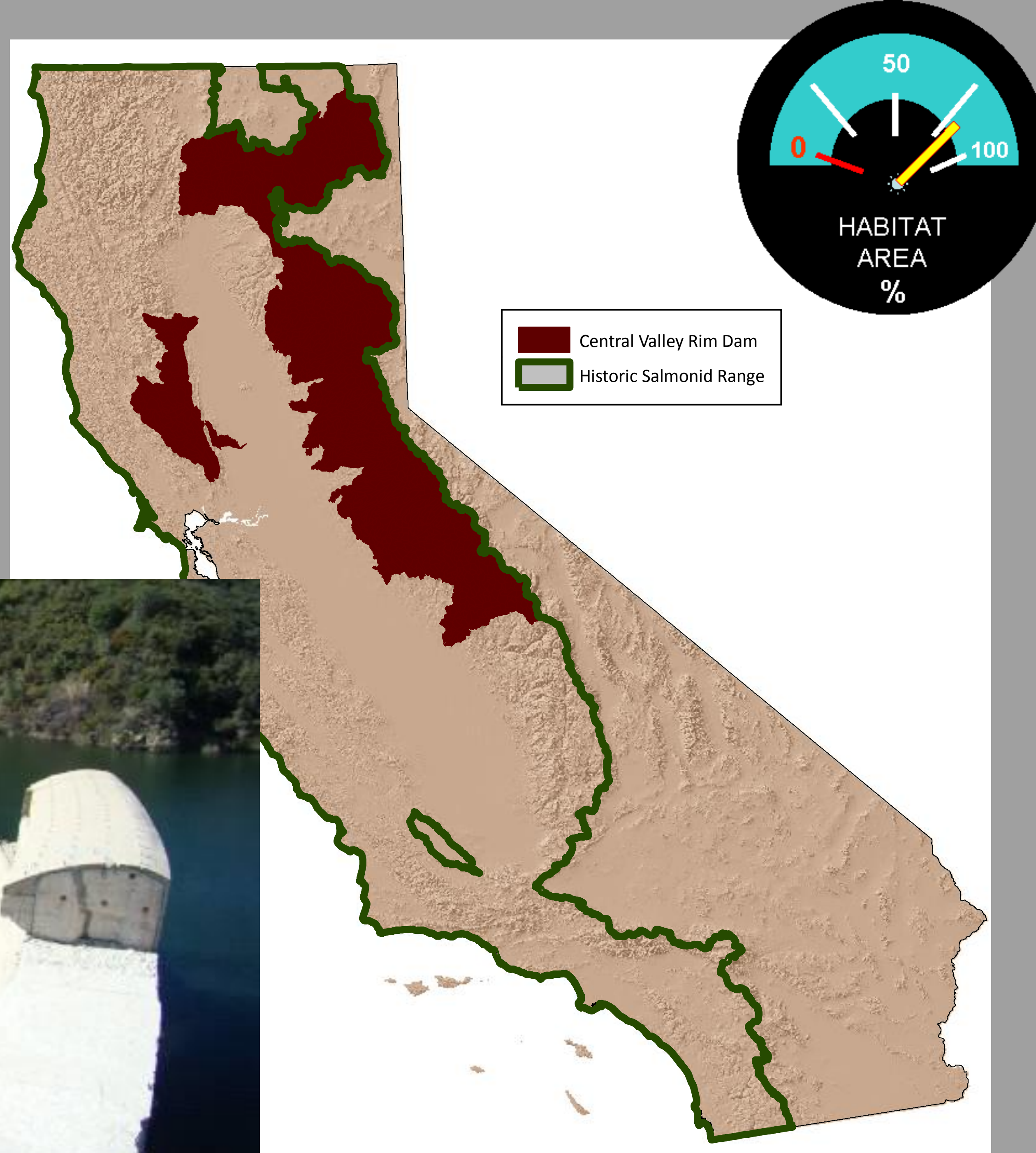
1. Riparian wetland loss in California (Cluer)
2. Overview of channel types (Cluer)
3. Stream Evolution Model and ecosystem value of multi-threaded channels (Cluer)
4. Examples of multi-threaded channel restoration projects and opportunities in the river-estuary ecotone (Hammack)
5. Importance of multi-threaded channels in salmonid life history (Hammack)

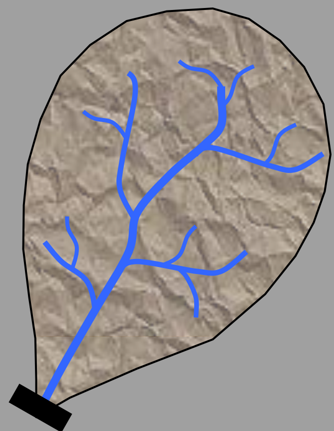
Historic Salmon Range - Drainage Areas

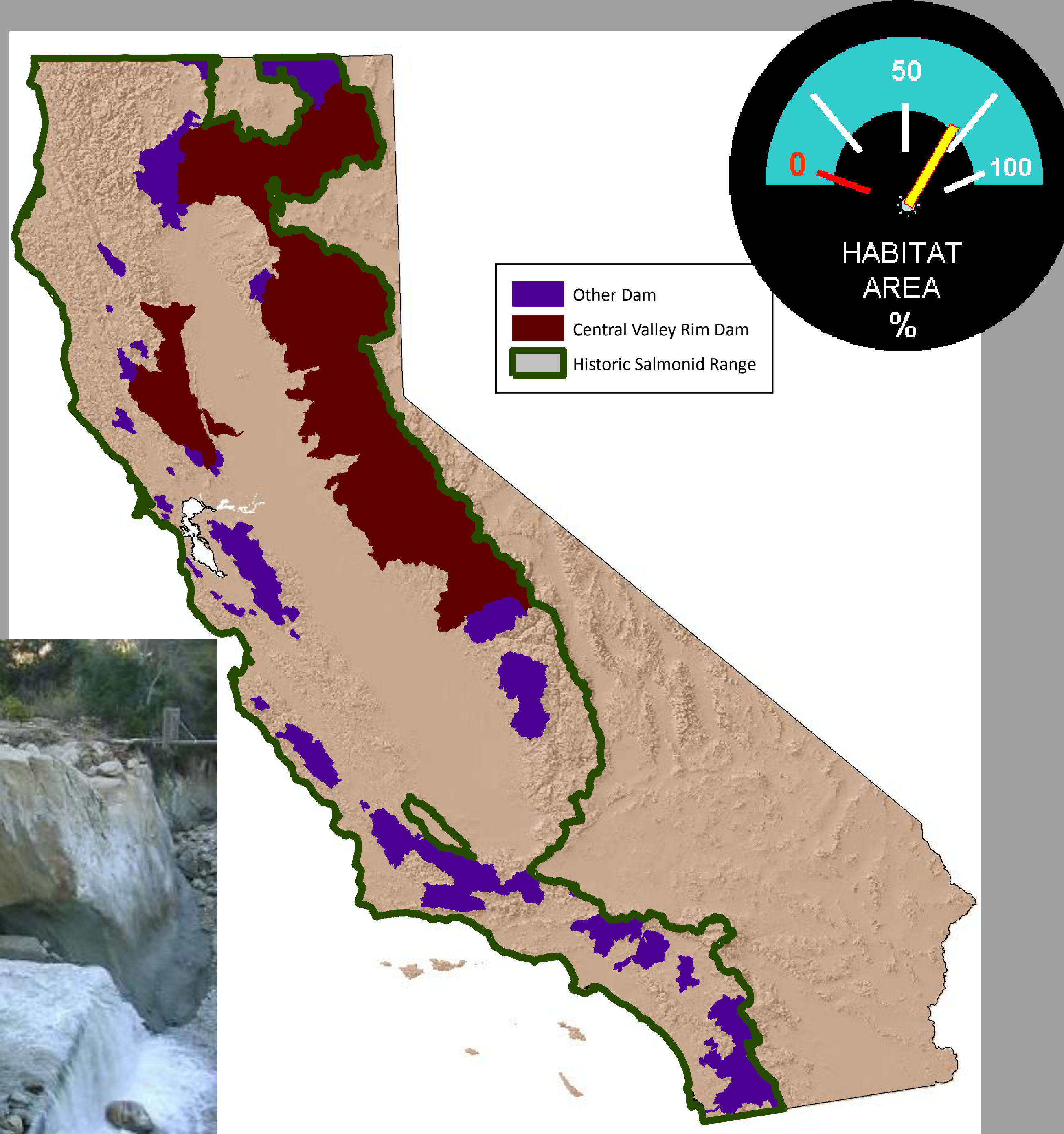


Credit: Charleen Gavette




Central Valley Rim Dam
Historic Salmonid Range
50
0
100
HABITAT
AREA
%




Other Dam
Central Valley Rim Dam
Historic Salmonid Range
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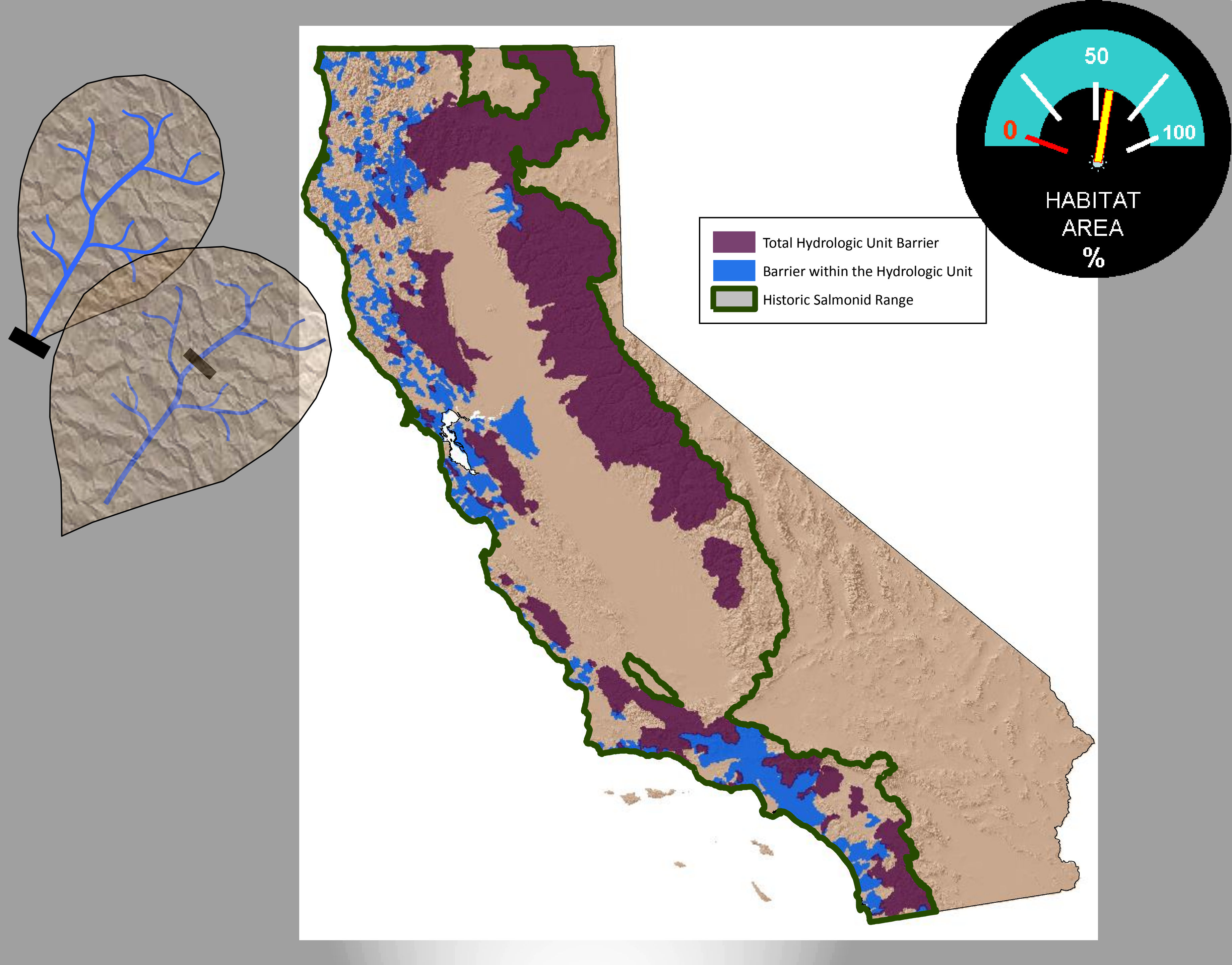
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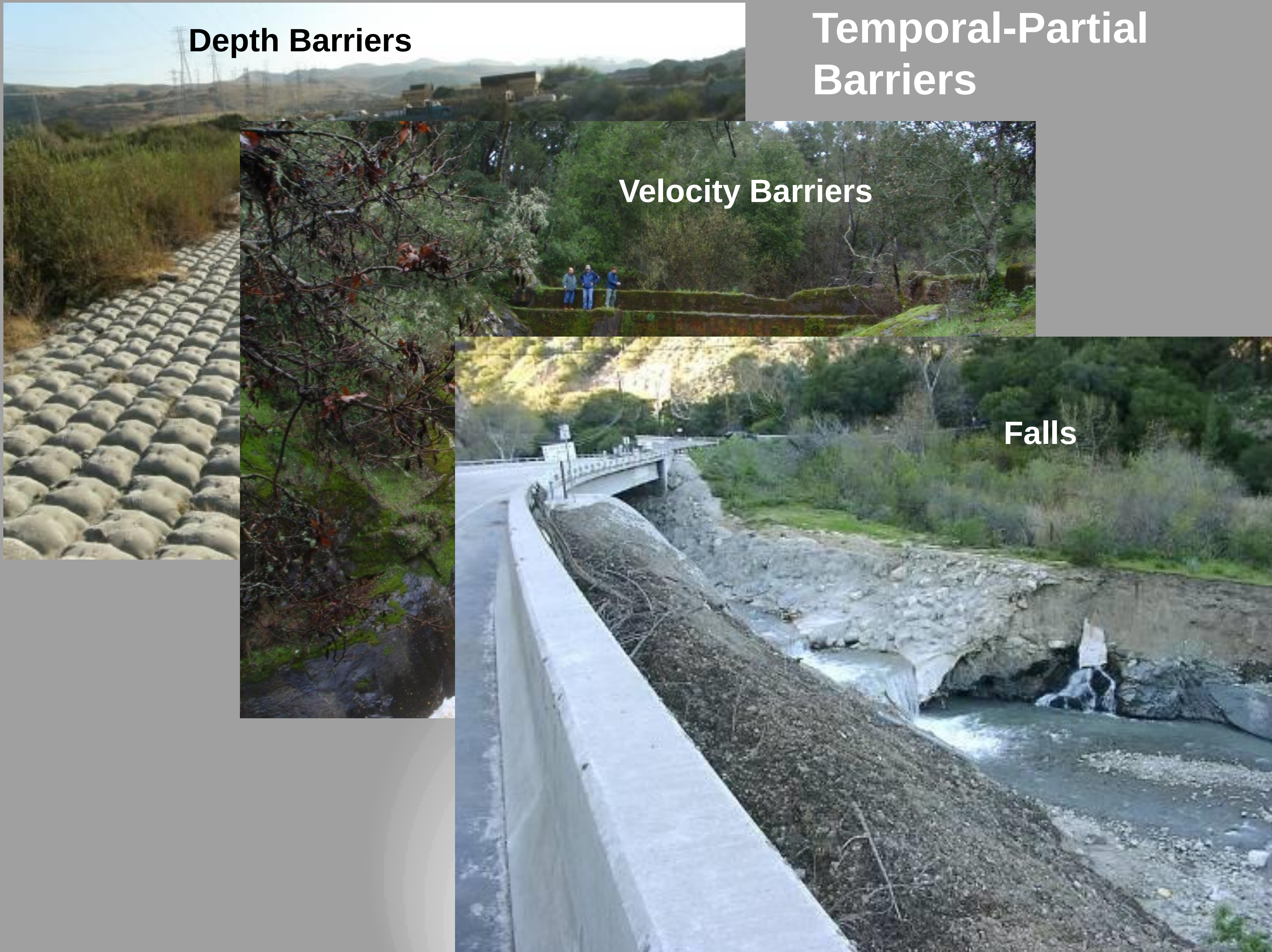
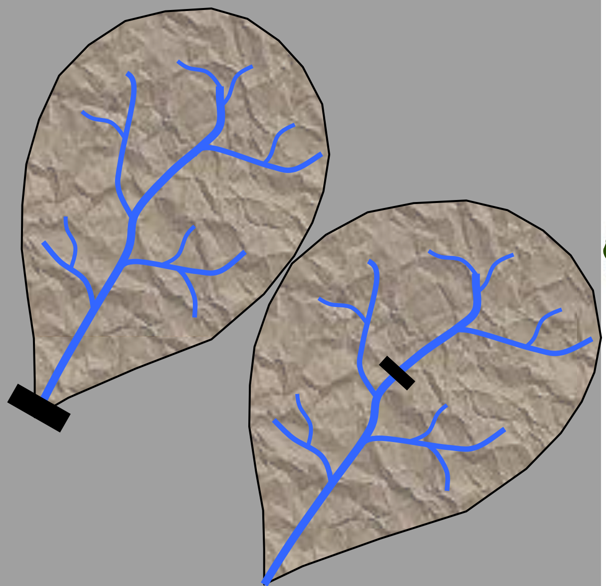
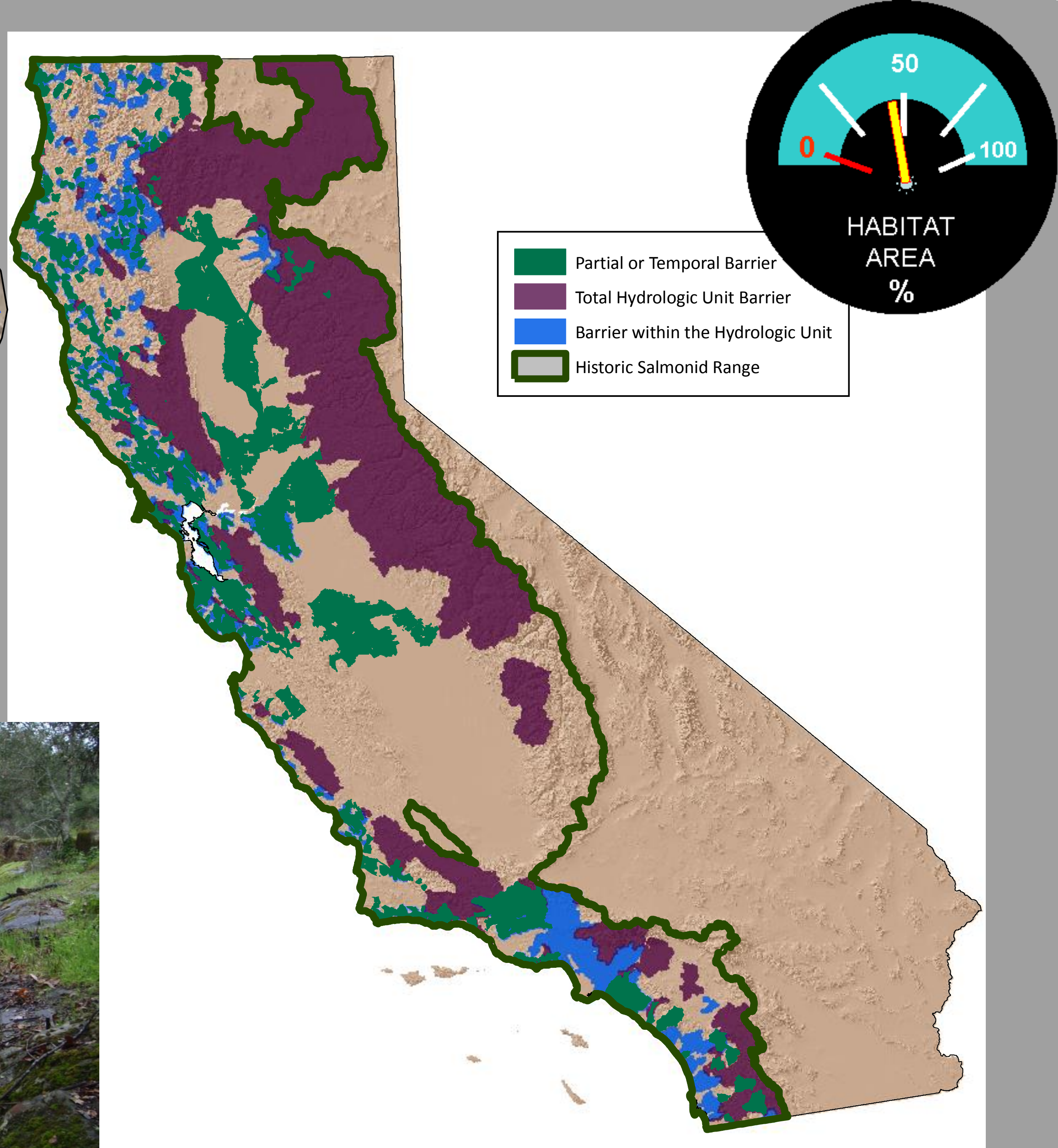
Total Hydrologic Unit Barrier
Barrier within the Hydrologic Unit
Historic Salmonid Range

Temporal-Partial Barriers



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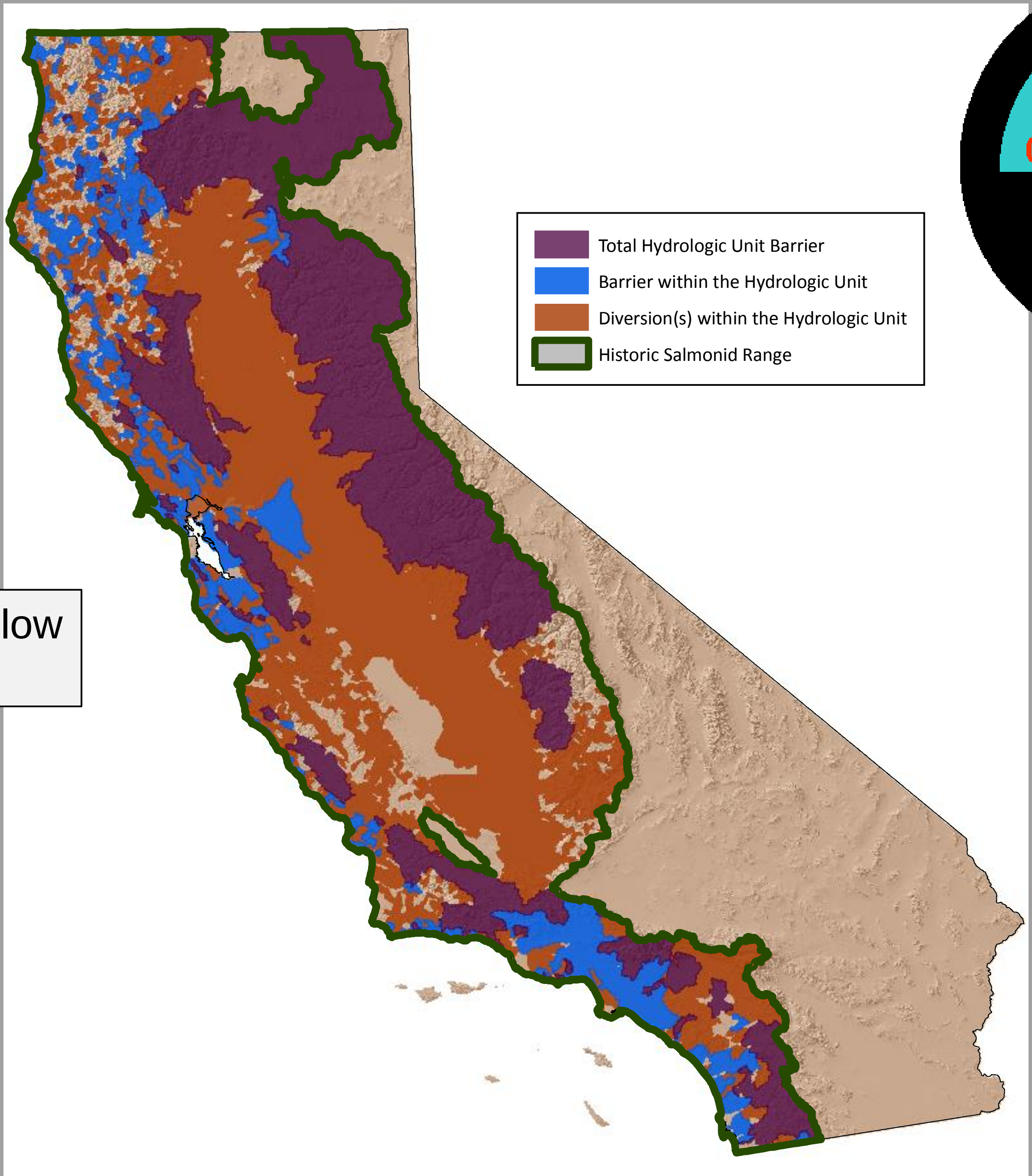
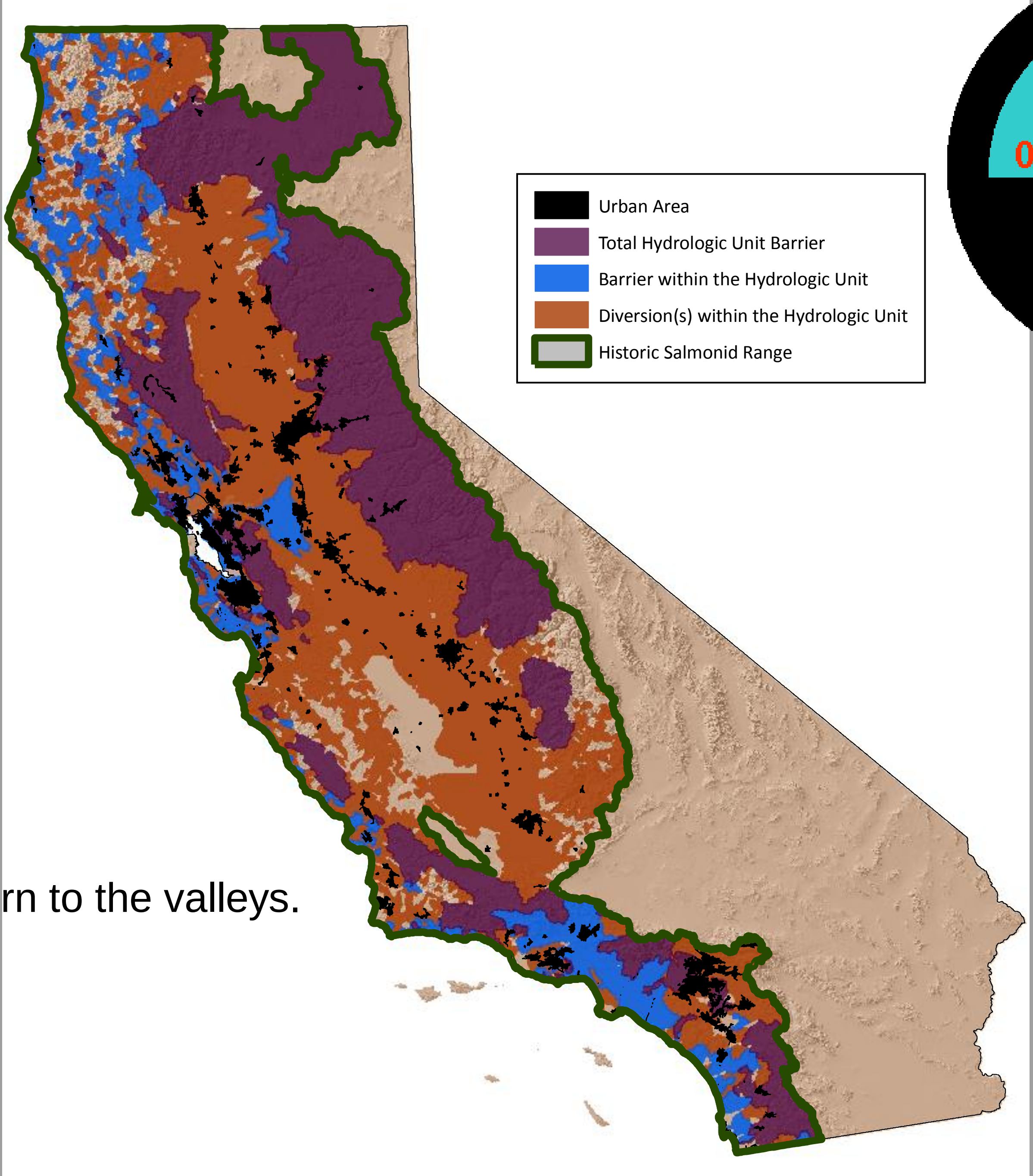
Partial or Temporal Barrier
Total Hydrologic Unit Barrier
Barrier within the Hydrologic Unit
Historic Salmonid Range

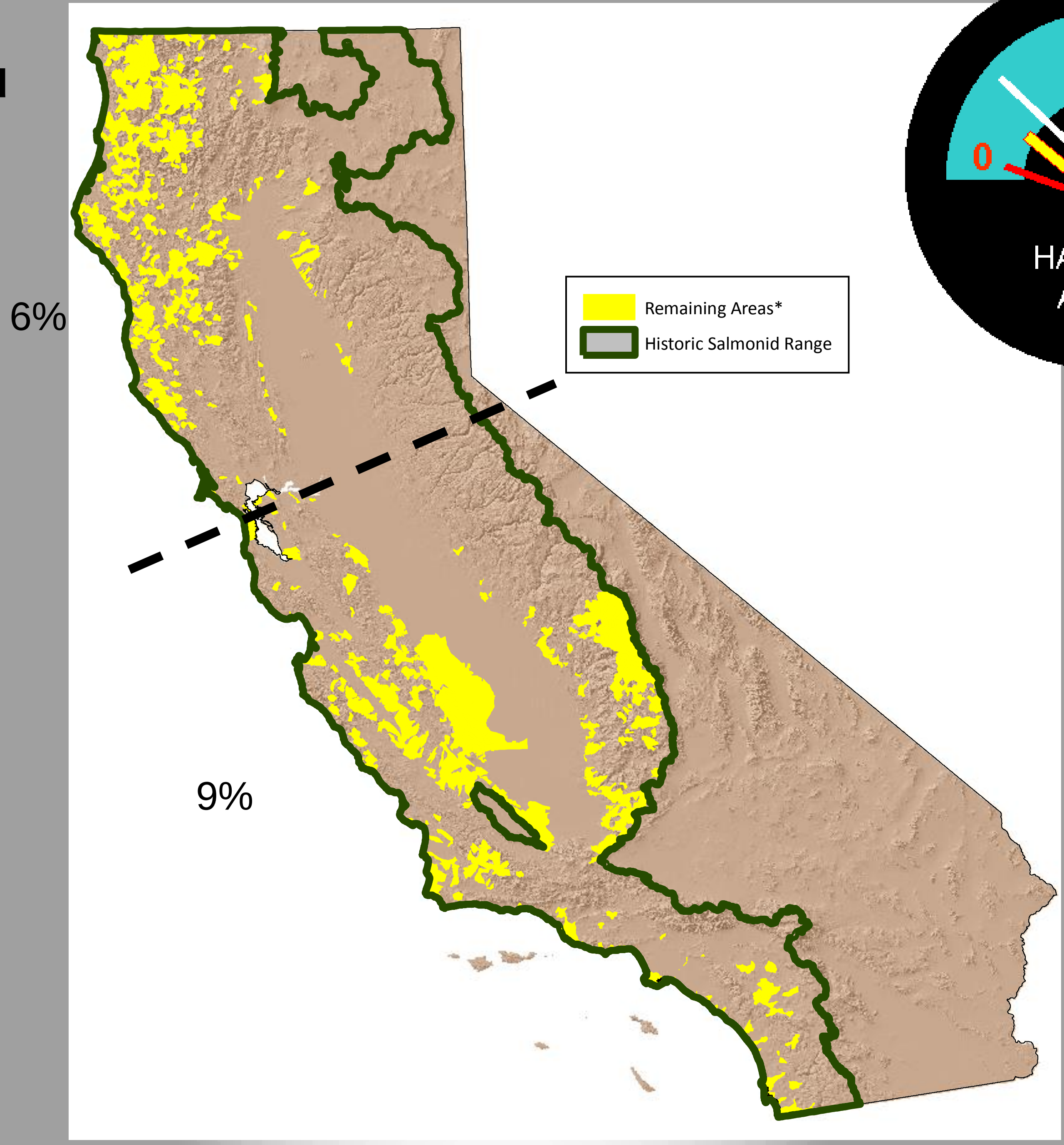
Stream Flow Impacts





We will return to the valleys.

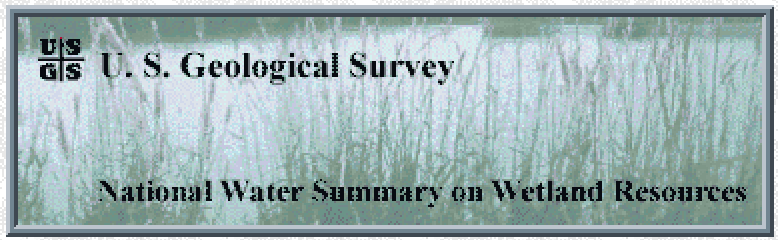
Undisturbed Areas 2010



1900 to 1950--Changing Technology

The first half of the twentieth century was a time of ambitious engineering and drainage operations. Two World Wars, a rapidly growing population, and industrial growth fueled the demand for land as industry and agriculture propelled the United States to the status of a world leader. Technology was increasingly important in manipulation of the Nation's water resources. Two of the most notable projects that affected wetlands were California's Central Valley Project and the lock and dam system on the Mississippi River.

Although draining had begun one-half century earlier, wetland modification in the Central Valley accelerated early in the 20th century. By the 1920's, about 70 percent of the original wetland acreage had been modified by levees, drainage, and water-diversion projects (Frayer and others, 1989). In the 1930's, large-scale flood-control projects, diversion dams, and water-control structures were being built on the tributary rivers entering the valley.



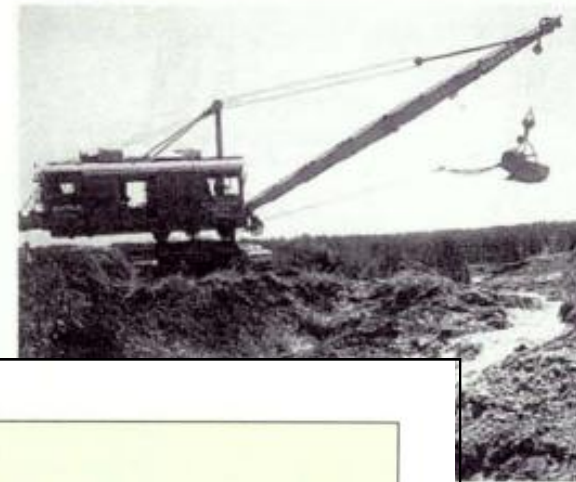
National Water Summary on Wetland Resources
United States Geological Survey Water Supply Paper 2425

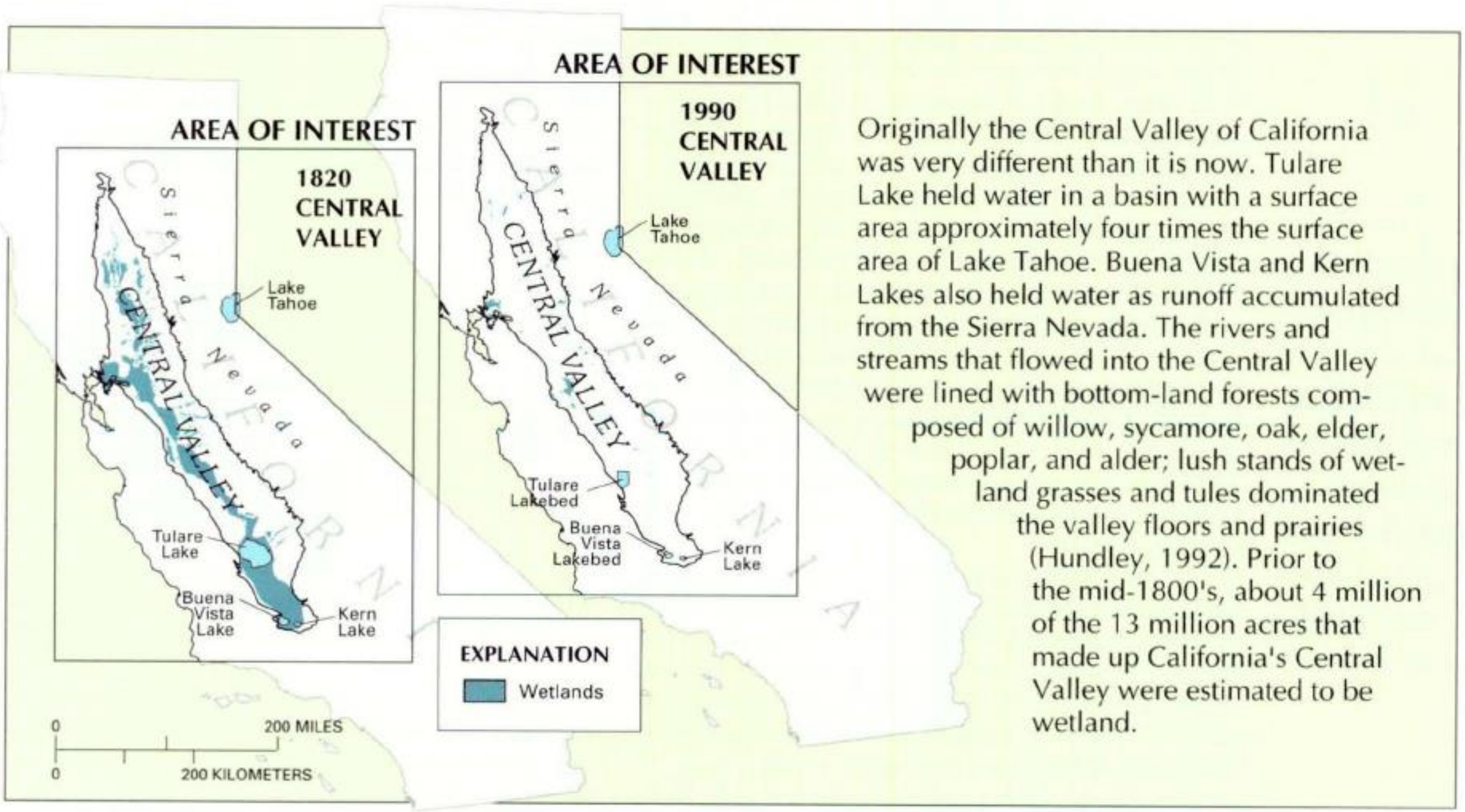
Technical Aspects of Wetlands
History of Wetlands in the Conterminous United States

By

Thomas E. Dahl, ***U.S. Fish and Wildlife Service***
Gregory J. Allord, ***U.S. Geological Survey***

History of Valley Modifications ?





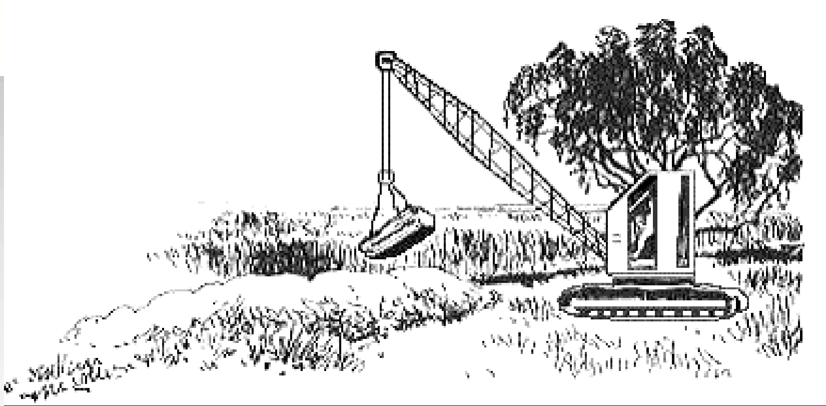
Originally the Central Valley of California was very different than it is now. Tulare Lake held water in a basin with a surface area approximately four times the surface area of Lake Tahoe. Buena Vista and Kern Lakes also held water as runoff accumulated from the Sierra Nevada. The rivers and streams that flowed into the Central Valley were lined with bottom-land forests composed of willow, sycamore, oak, elder, poplar, and alder; lush stands of wetland grasses and tules dominated the valley floors and prairies (Hundley, 1992). Prior to the mid-1800's, about 4 million of the 13 million acres that made up California's Central Valley were estimated to be wetland.

Figure 9. Wetlands of the Central Valley of California, circa 1820 (left) and 1990 (right). *(Source: U.S. Fish and Wildlife Service, Status and Trends, unpub. data, 1994.)*

Figure 2. States with notable wetland loss, 1780's to mid-1980's. *(Source: Modified from Dahl, 1990.)*

U.S. Geological Survey Water-Supply Paper 2425

Scale of hydromodification and habitat elimination is difficult to grasp.



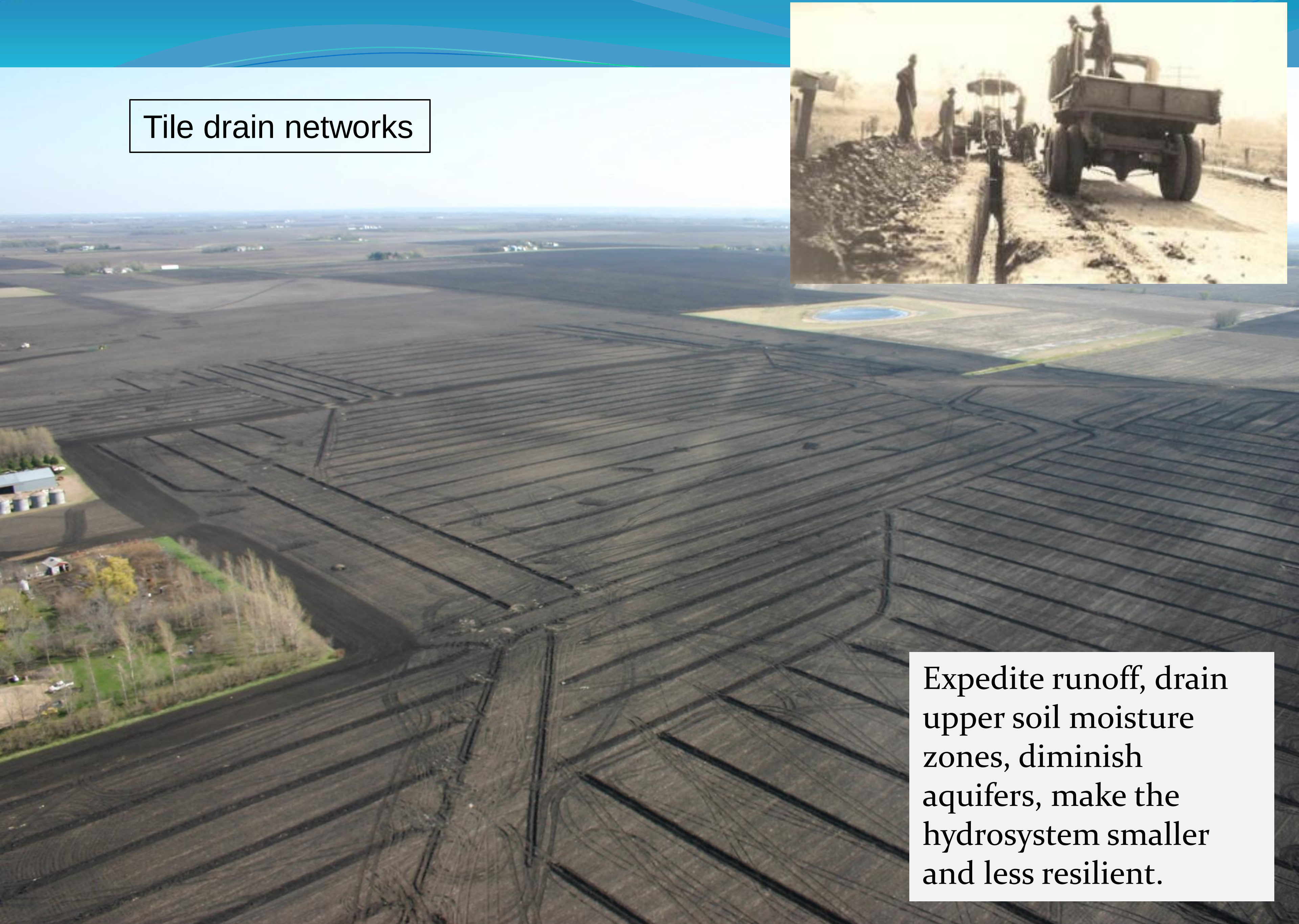

LaGrand River, OR
Eel River, CA

History of landscape hydromodification is poorly documented, and forgotten by many.

LaGrand River, OR

Netherlands

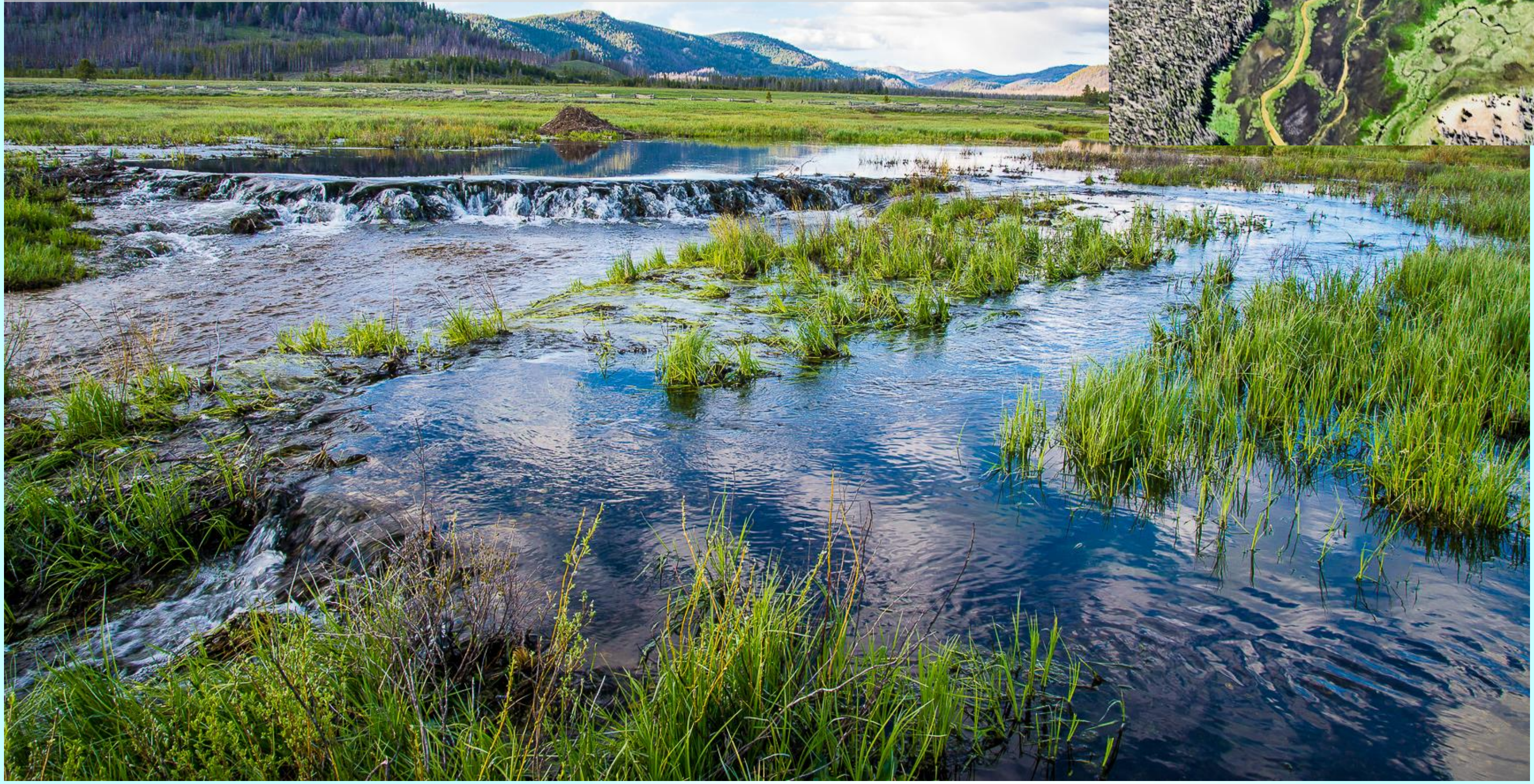
Tile drain networks

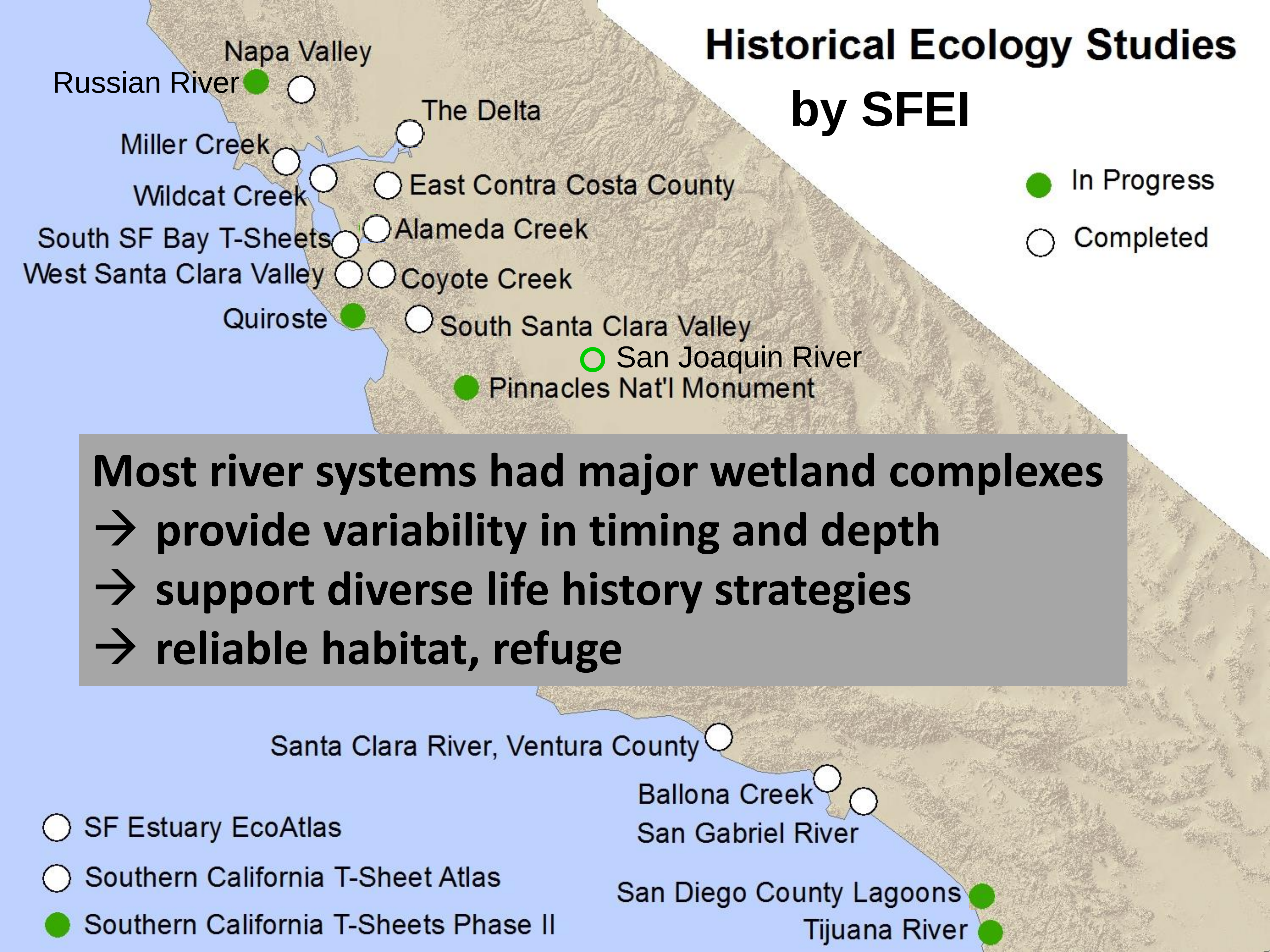


Expedite runoff, drain upper soil moisture zones, diminish aquifers, make the hydrosystem smaller and less resilient.

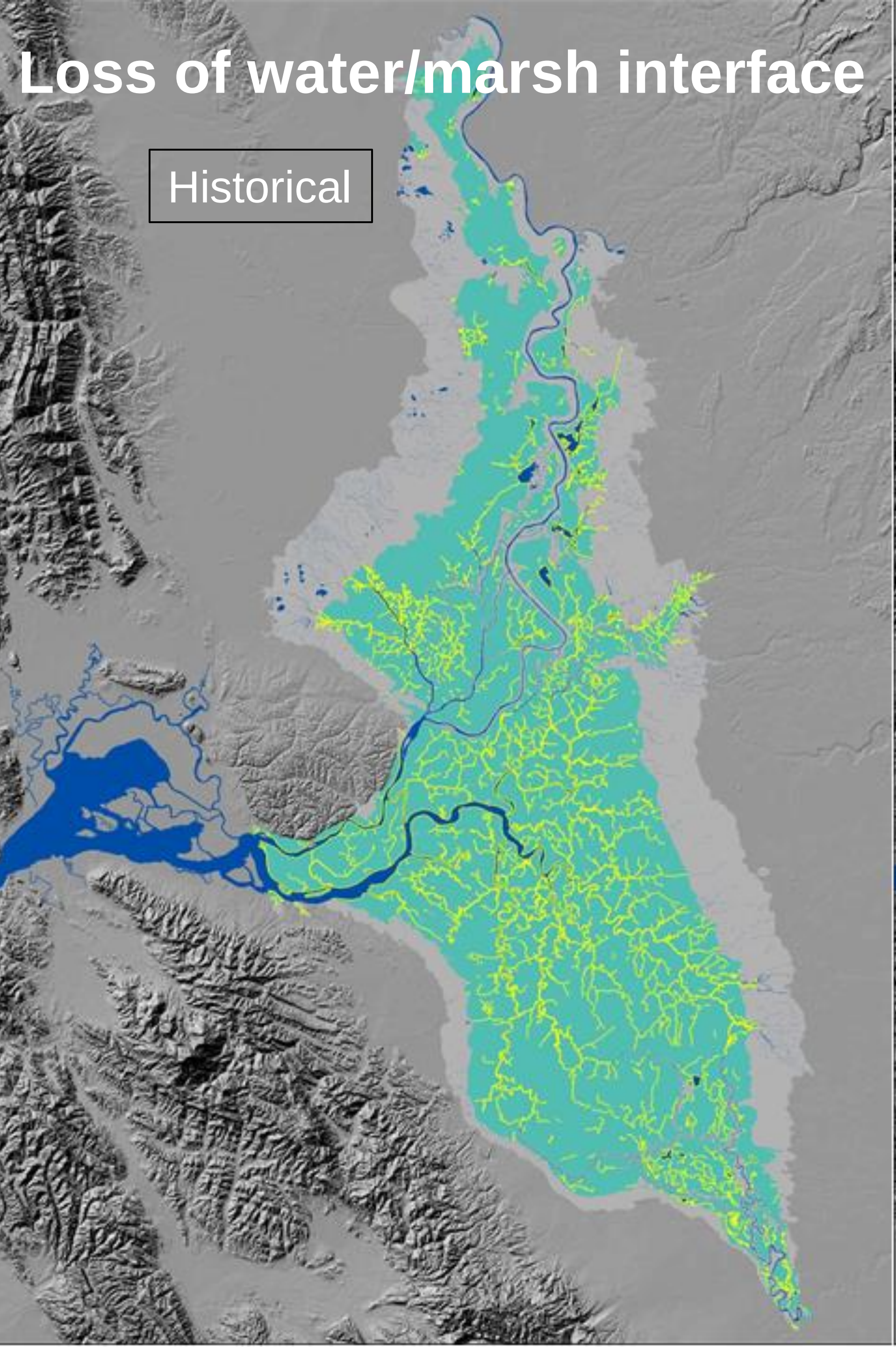

Valleys

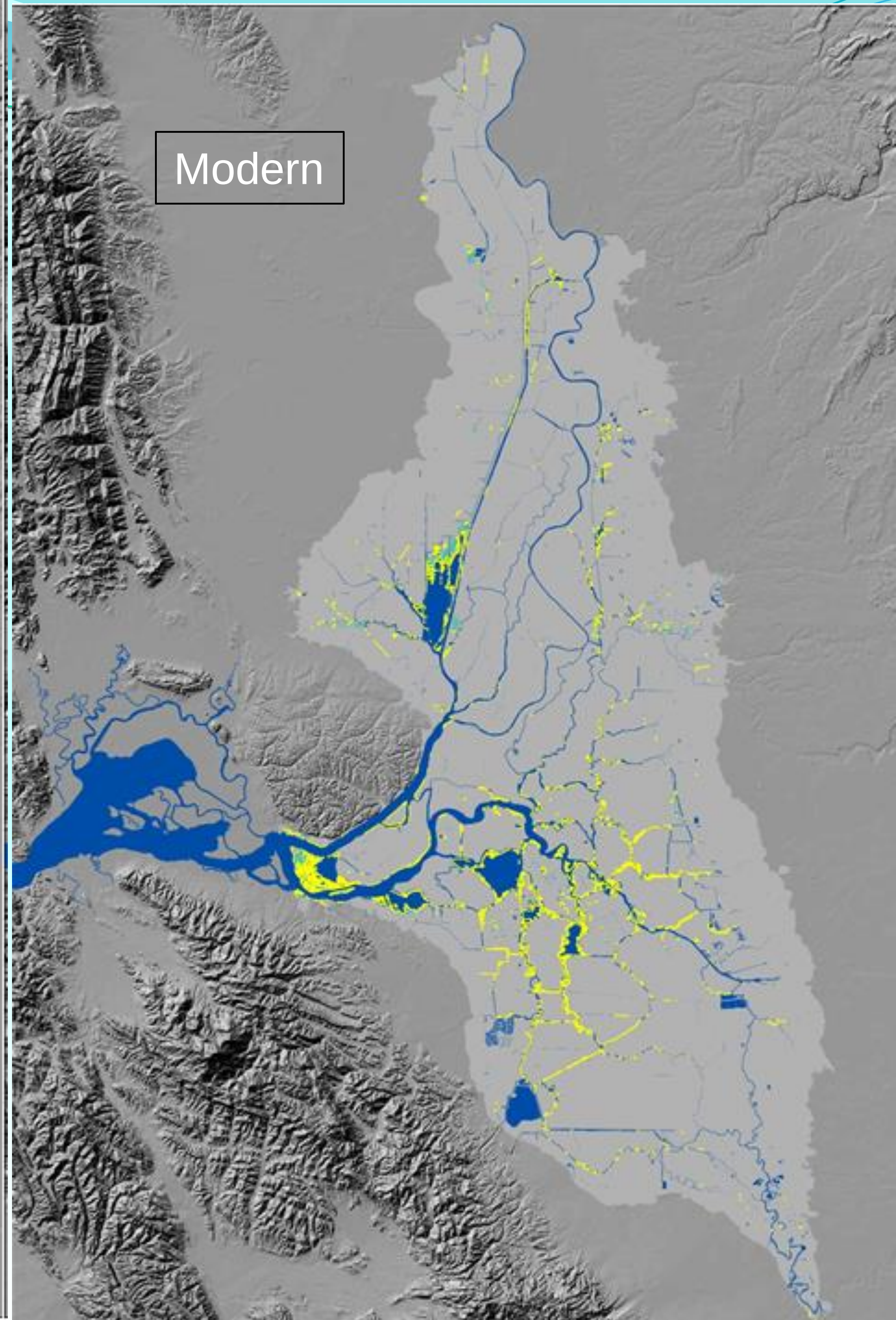
What were pre-settlement habitats like, WRT salmonids ?

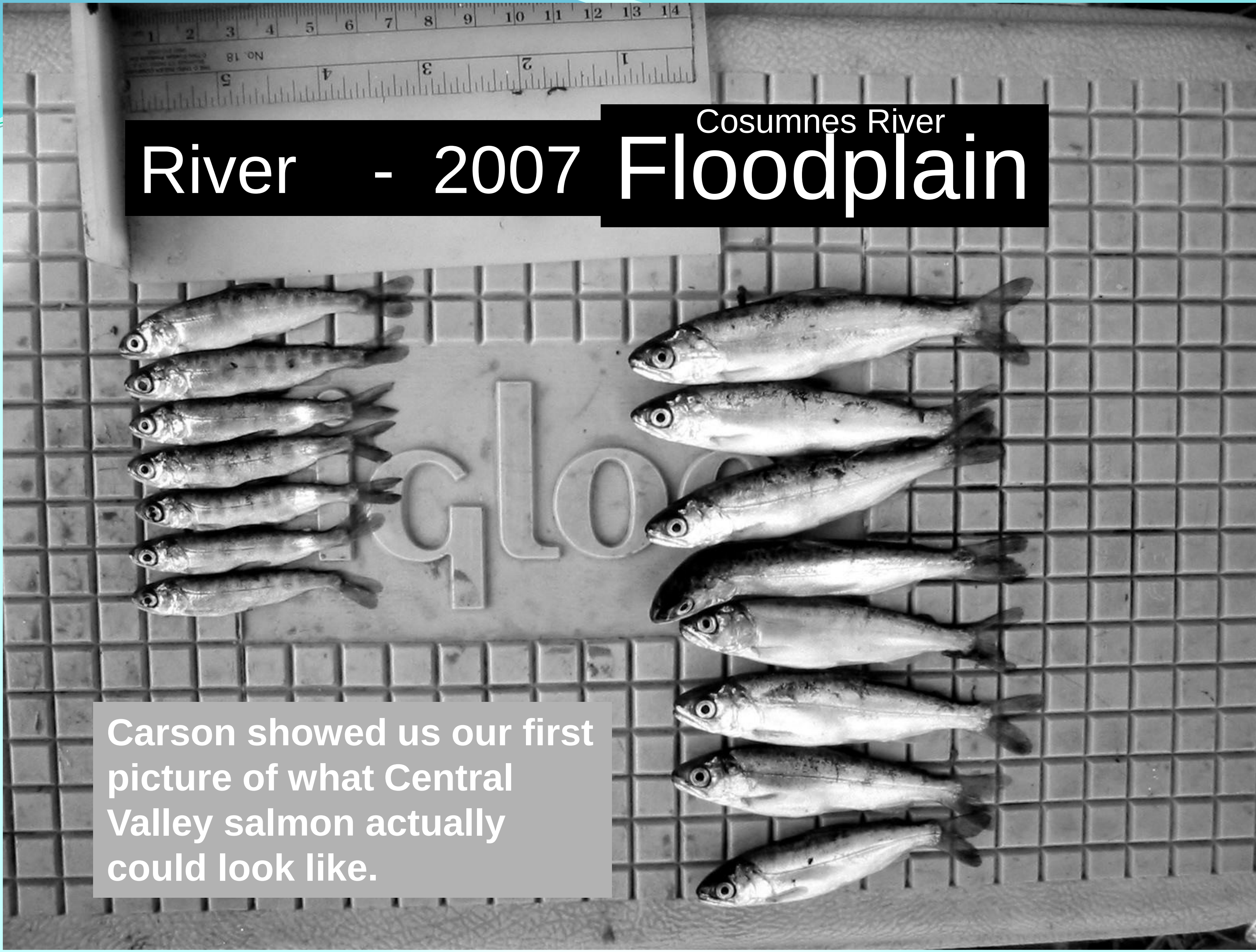



Historical Ecology Studies
by SFEI
In Progress
Completed
Napa Valley
Russian River
The Delta
Miller Creek
Wildcat Creek
East Contra Costa County
Alameda Creek
South SF Bay T-Sheets
West Santa Clara Valley
Coyote Creek
Quiroste
South Santa Clara Valley
San Joaquin River
Pinnacles Nat'l Monument
Most river systems had major wetland complexes
→ provide variability in timing and depth
→ support diverse life history strategies
→ reliable habitat, refuge
Santa Clara River, Ventura County
Ballona Creek
San Gabriel River
SF Estuary EcoAtlas
Southern California T-Sheet Atlas
Southern California T-Sheets Phase II
San Diego County Lagoons
Tijuana River

Loss of water/marsh interface







Jeffres et al. 2008

RIVER RESEARCH AND APPLICATIONS

River Res. Applic. (2013)

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A STREAM EVOLUTION MODEL INTEGRATING HABITAT AND ECOSYSTEM BENEFITS

B. CLUER[a*] and C. THORNE[b]

[a] *Fluvial Geomorphologist, Southwest Region, NOAA's National Marine Fisheries Service, Santa Rosa, California, USA*
[b] *Chair of Physical Geography, University of Nottingham, Nottingham, UK*

ABSTRACT

For decades, Channel Evolution Models have provided useful templates for understanding morphological responses to disturbance associated with lowering base level, channelization or alterations to the flow and/or sediment regimes. In this paper, two well-established Channel Evolution Models are revisited and updated in light of recent research and practical experience. The proposed Stream Evolution Model includes a precursor stage, which recognizes that streams may naturally be multi-threaded prior to disturbance, and represents stream evolution as a cyclical, rather than linear, phenomenon, recognizing an *evolutionary cycle* within which streams advance through the common sequence, skip some stages entirely, recover to a previous stage or even repeat parts of the evolutionary cycle.

The hydrologic, hydraulic, morphological and vegetative attributes of the stream during each evolutionary stage provide varying ranges and qualities of habitat and ecosystem benefits. The authors' personal experience was combined with information gleaned from recent literature to construct a fluvial habitat scoring scheme that distinguishes the relative, and substantial differences in, ecological values of different evolutionary stages. Consideration of the links between stream evolution and ecosystem services leads to improved understanding of the ecological status of contemporary, managed rivers compared with their historical, unmanaged counterparts. The potential utility of the Stream Evolution Model, with its interpretation of habitat and ecosystem benefits includes improved river management decision making with respect to future capital investment not only in aquatic, riparian and floodplain conservation and restoration but also in interventions intended to promote species recovery.

KEY WORDS: Stream Evolution Model (SEM); channel evolution; freshwater ecology; habitat; conservation; river management; restoration; climate resilience

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Paper Outline:

- PART I Geomorphology
  - Channel Evolution Models:
  - Stream Evolution Model:
- PART II Linkages:
  - Hydrogeomorphic Attributes
  - Habitat and Ecosystem Benefits
- Management and Restoration Implications

- Channel patterns reflect the processes that created them. There exists a continuum of patterns because there is a continuum of processes.

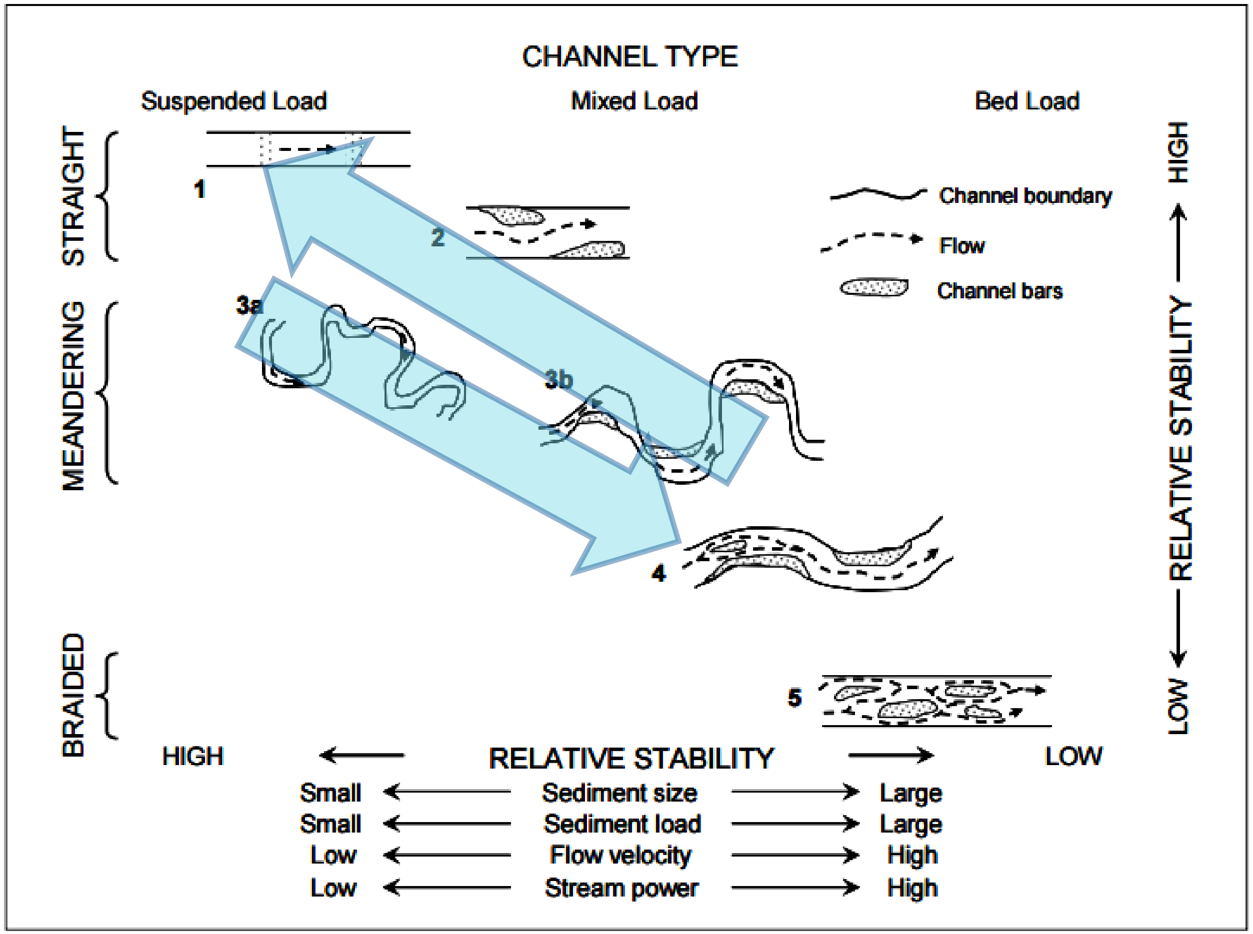
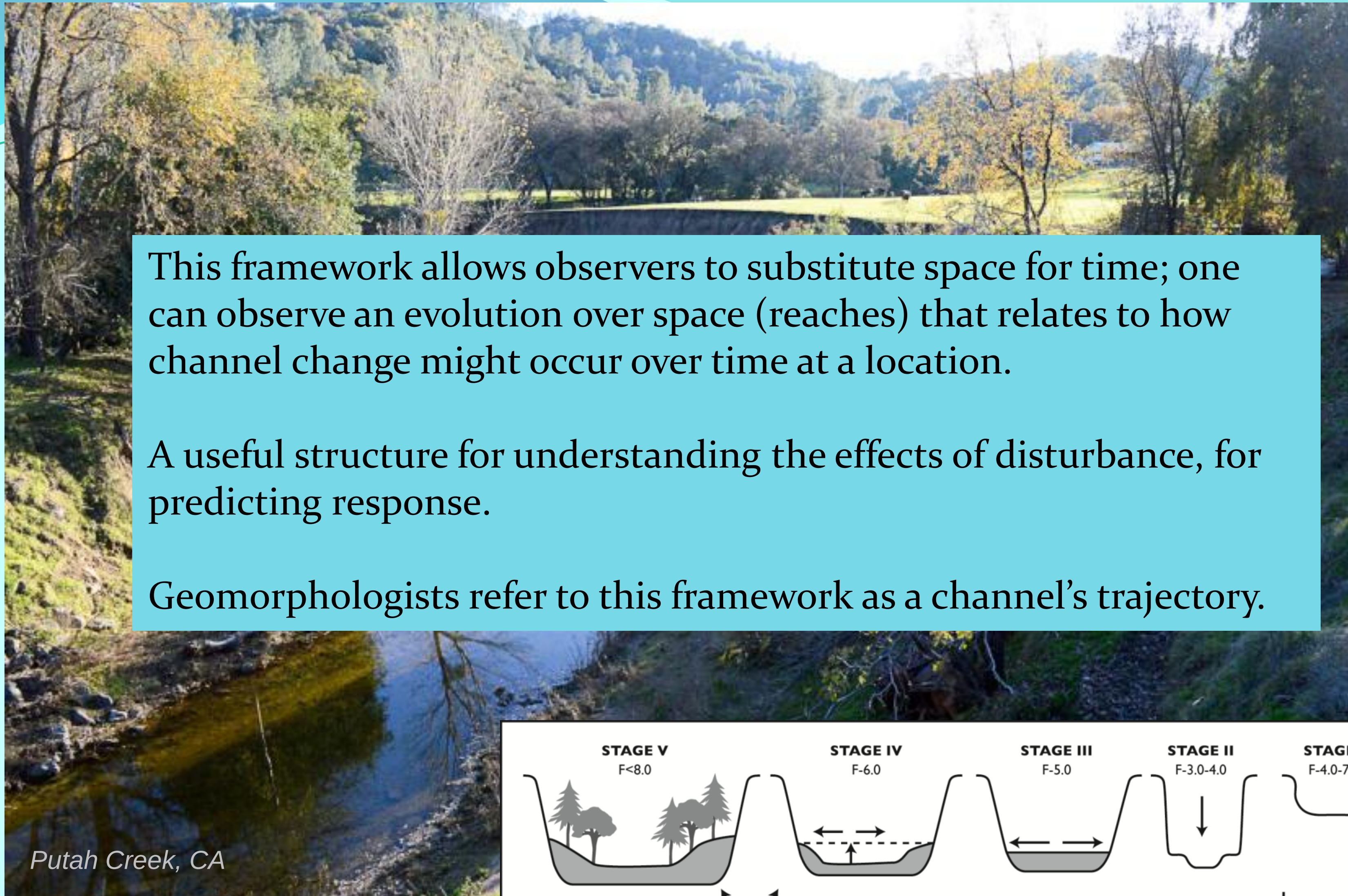


Figure 13. A qualitative classification of stream channels based on pattern (straight, meandering, or braided) and type of sediment load, along with flow and sediment variables and relative stability with regard to average erosional activity. From Schumm (1981).

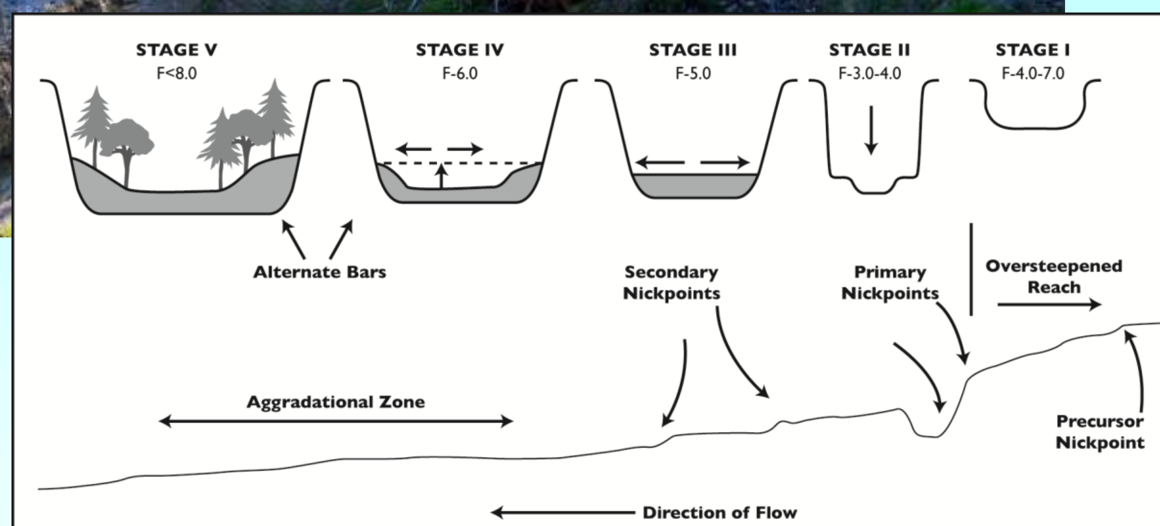


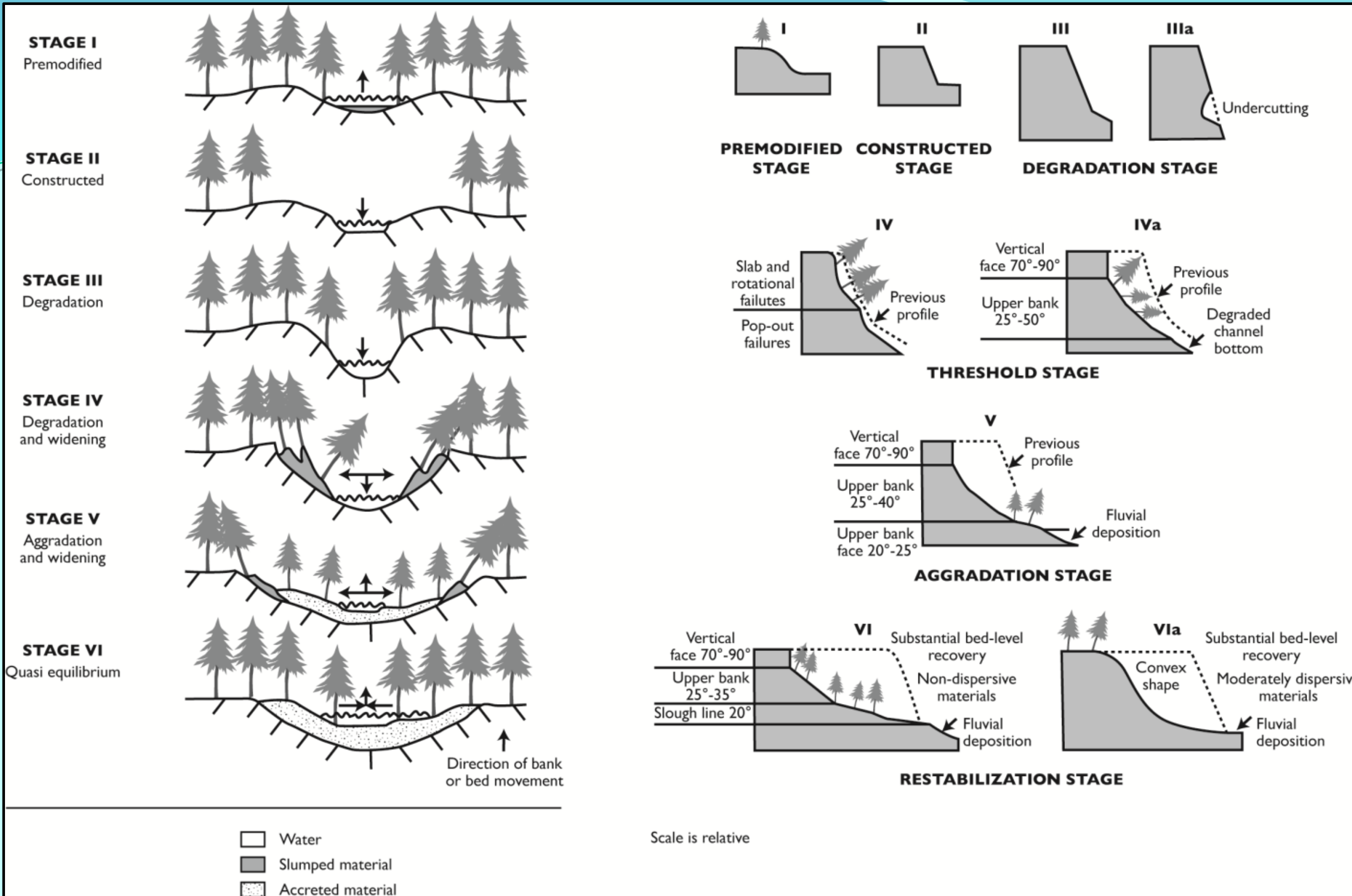
This framework allows observers to substitute space for time; one can observe an evolution over space (reaches) that relates to how channel change might occur over time at a location.

A useful structure for understanding the effects of disturbance, for predicting response.

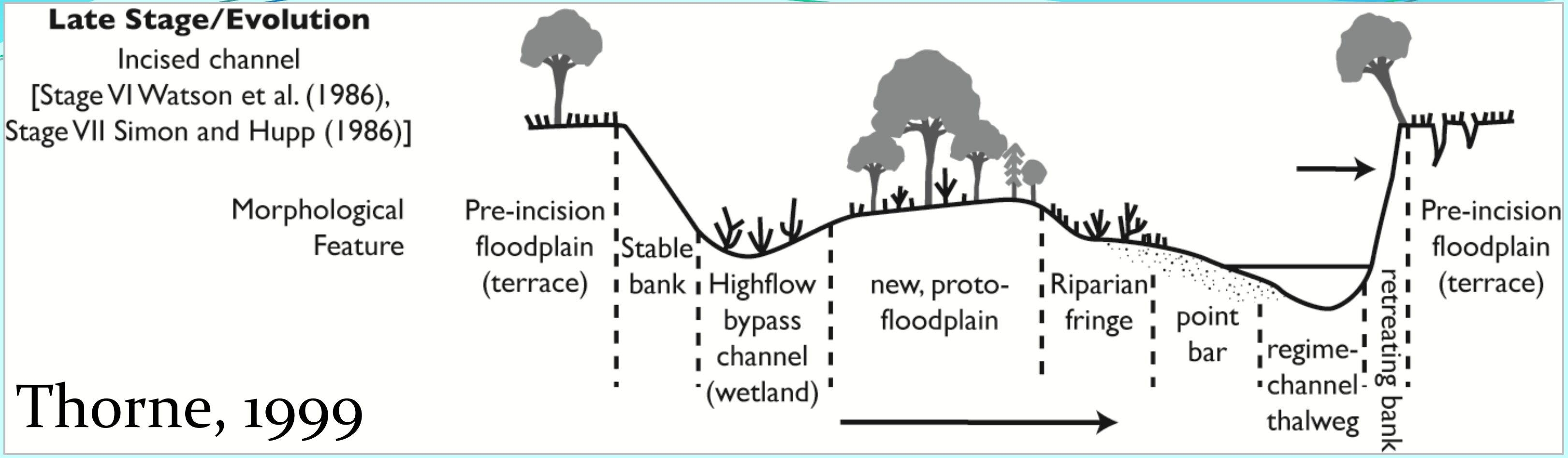
Geomorphologists refer to this framework as a channel's trajectory.

Schumm, Harvey, Watson, 1984





Simon and Hupp, 1986



Thorne, 1999

CEM's:
3 decades of use

The physical processes that form channels occur over a continuum so there must be successional stages, and corresponding attributes.

, LaGrand River, OR

, Salmon River, ID

Recent detailed field research challenges the concept of 'ideal' single-thread channel geometry.

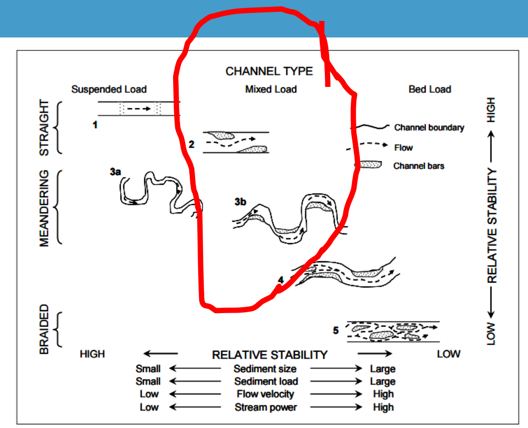
- Sear, Brown : Europe
- Montgomery and Collins : PNW
- Walter and Merrits : E US
- Grossinger et al. : CA

Schumm *et al*., 1984	Simon and Hupp, 1986	SEM		Description
		0. Anastomosing		Pre-disturbance, dynamically meta-stable network of anabranching channels and floodplain with vegetated islands supporting wet woodland or grassland. $Qs_{in} \geq Qs_{out}$, $h << h_c$
I. Undisturbed	I. Pre-modified	Single Thread Channels	1.Sinuous	Dynamically stable and laterally active channel within a floodplain complex. Flood return period 1-5 yr range. $Qs_{in} \geq Qs_{out}$, $h << h_c$
	II. Constructed		2. Channelized	Re-sectioned land drainage, flood control, or navigation channels. $Qs_{in} \leq Qs_{out}$, $h > h_c$
II. Degradation	III. Degradation		3. Degrading	Incising and abandoning its floodplain. Featuring head cuts, knick points or knick zones that incise into the bed, scours away bars and riffles and removes sediments stored at bank toes. Banks stable geotechnically. $Qs_{in} < Qs_{out}$, $h > h_c$
			3s. Arrested degradation	Stabilized, confined or canyon-type channels. Incised channel in which bed lowering and channel evolution have been halted because non-erodible materials (bed rock, tight clays) have been encountered. $Qs_{in} \sim Qs_{out}$, $h > h_c$
III. Rapid Widening	IV. Degradation and widening		4. Degradation and widening	Incising with unstable, retreating banks that collapse by slumping and/or rotational slips. Failed material is scoured away and the enlarged channel becomes disconnected from its former floodplain, which becomes a terrace. $Qs_{in} < Qs_{out}$, $h > h_c$
			4-3. Renewed incision	Further head cutting within Stage 4 channel. $Qs_{in} < Qs_{out}$, $h >> h_c$
IV. Aggradation	V. Aggradation and widening		5. Aggrading and widening	Bed rising, aggrading, widening channel with unstable banks in which excess load from upstream together with slumped bank material build berms and silts bed. banks stablizing & berming. $Qs_{in} > Qs_{out}$, $h \sim h_c$
V. Stabilization	VI. Quasi-equilibrium		6. Quasi-equilibrium	Inset floodplain re-established. quasi-equilibrium channel with two-stage cross-section featuring regime channel inset within larger, degraded channel. Berms stabilize as pioneer vegetation traps fine sediment, seeds and plant propagules. $Qs_{in} \sim Qs_{out}$, $h < h_c$
	VII. [1]Late-stage evolution		7. Laterally active	Channel with frequent floodplain connection develops sinuous course, is laterally active and has asymmetrical cross-section promoting bar accretion at inner margins and toe scour and renewed bank retreat along outer margins of expanding/migrating bends. $Qs_{in} \geq Qs_{out}$, $h << h_c$
		8. Anastomosing		Meta-stable channel network. Post-disturbance channel featuring anastomosed planform connected to a frequently inundated floodplain that supports wet woodland or grassland that is bounded by set-back terraces on one or both margins. $Qs_{in} \geq Qs_{out}$, $h << h_c$

Floodplain

Disconnected

Floodplain



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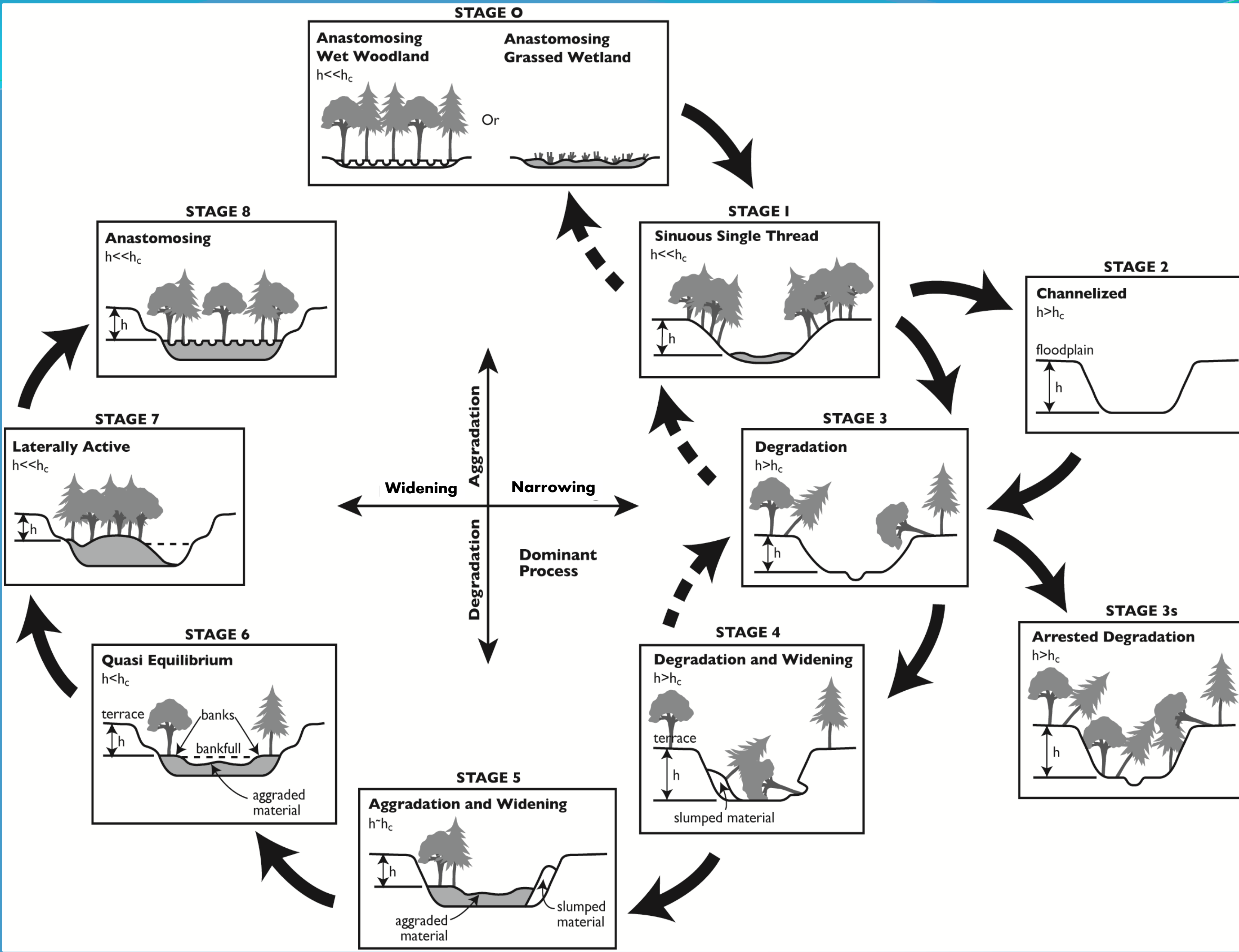
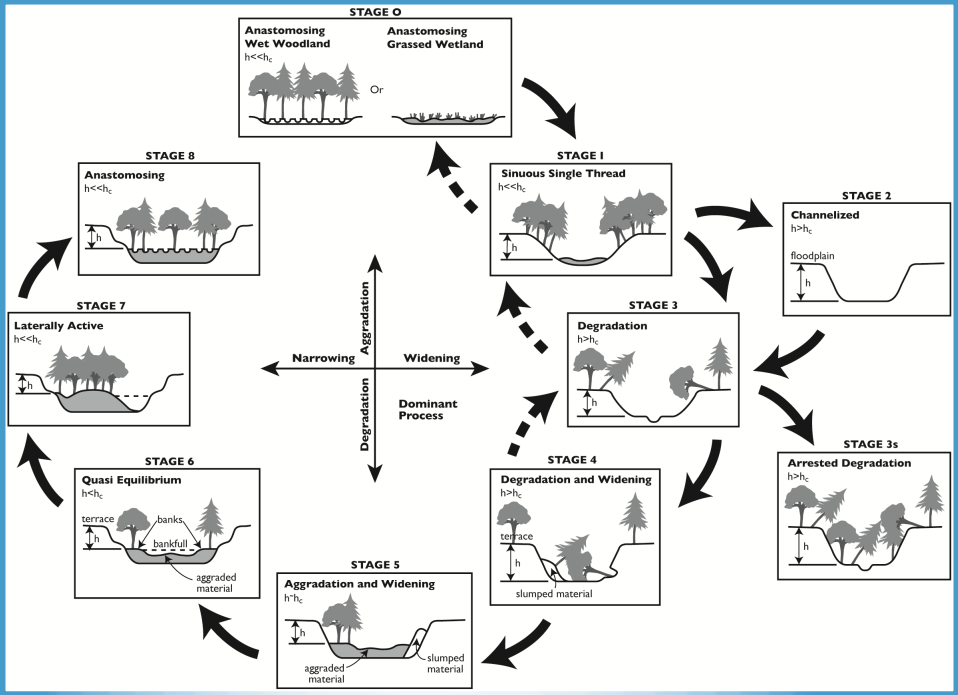


Short circuits
Dead ends

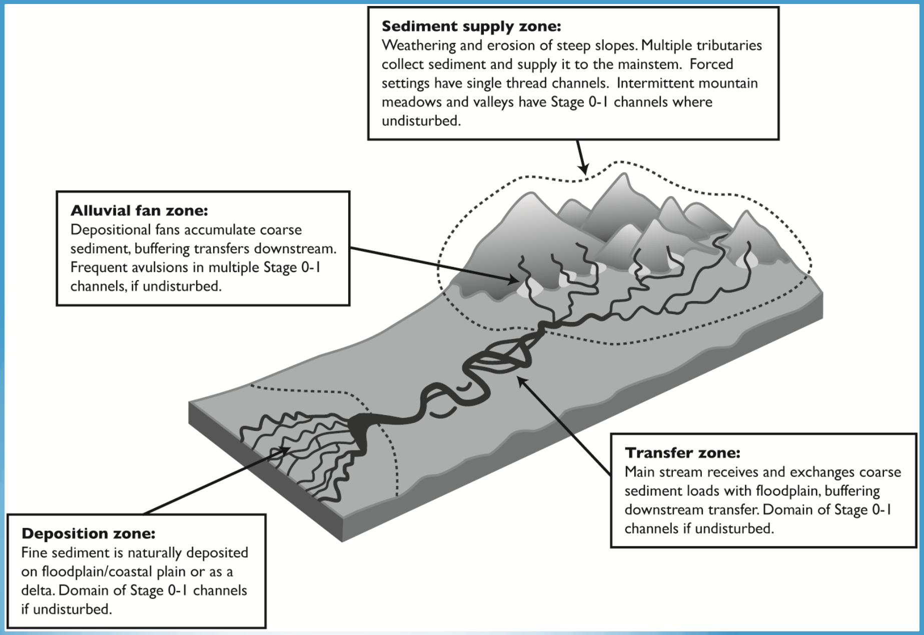
SEM highlights two ideas:

- Stream systems are not represented by their channel; there is a web of bio-geo process interactions upstream, in the past, and nearby resulting in a dynamic stream corridor and a continuum of channel forms.
- There is no "start point" or "end point" to channel evolution.



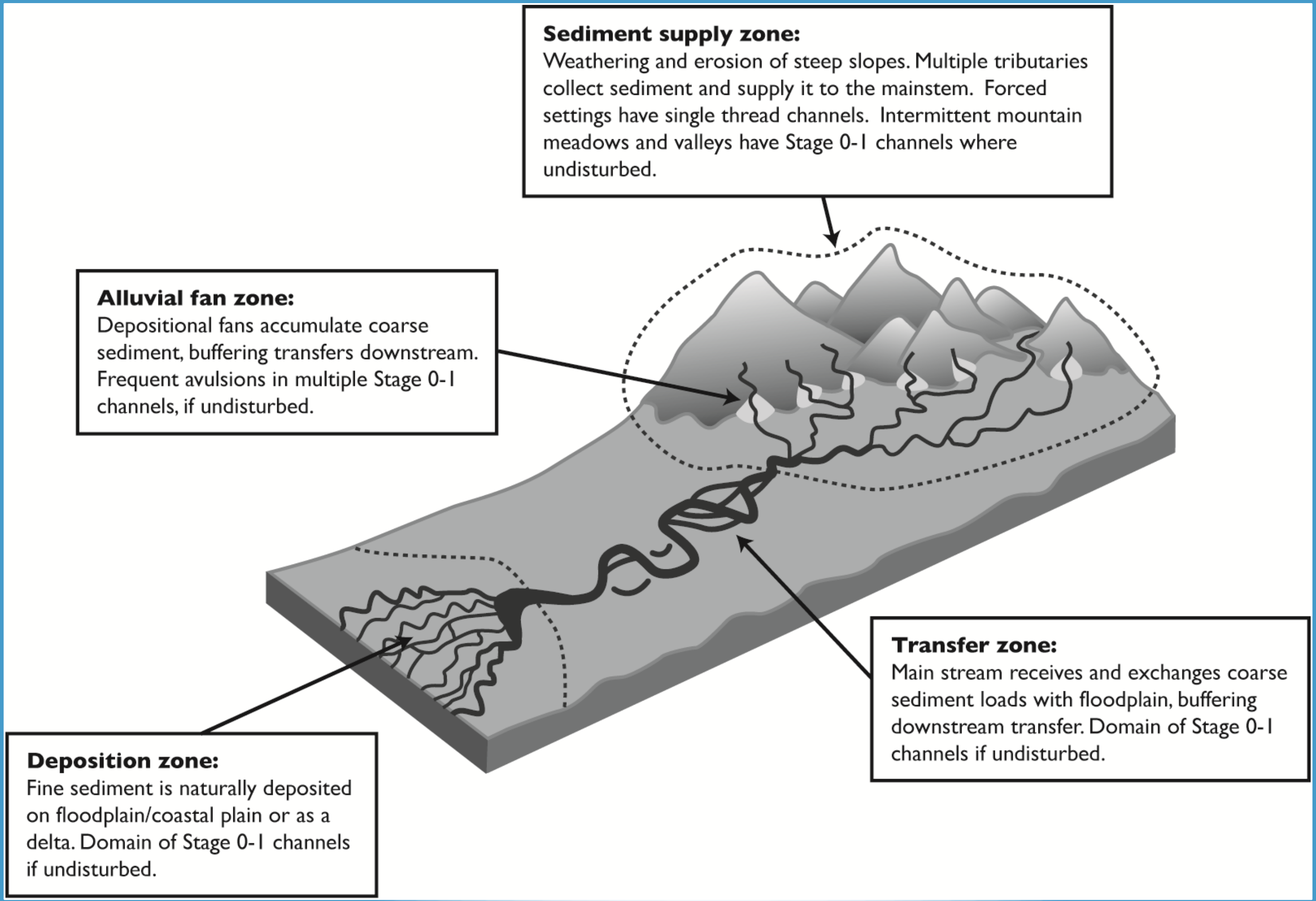
SEM: broader definition and utility than incised channels, emphasis on;

- Watershed scale interconnectedness of sediment, vegetation, and hydrologic regimes.
- Valley-stream system processes & outcomes vs. channel form which is only a snapshot of its past.



Where do Stage 0 streams occur?

- Over a range of scales and locales.
- Where do we find them today?



PART II

Linking Habitat and Ecosystem Benefits to Hydrogeomorphic Attributes

Principles of functional ecology link the SEM Stages to habitat and ecosystem benefits.

- Stream morphology interacts with flow and sediment regimes, channel boundary characteristics, and water quality to produce, maintain and renew habitat.
- The potential for a stream to support resilient and diverse ecosystems increases with morphological diversity.
- Morphological adjustments (SEM Stage) have implications for diversity and richness of habitat and ecosystem services.

Primary literature:

Harper et al 1995, Padmore 1997, Newson and Newson 2000, Thorpe et al 2010]

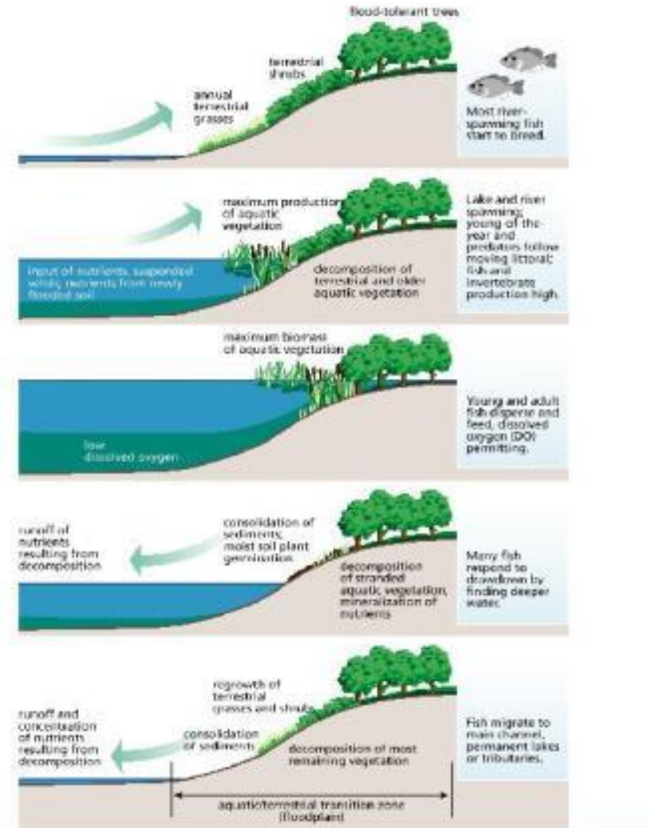
Physical Attributes

Hydrologic regime

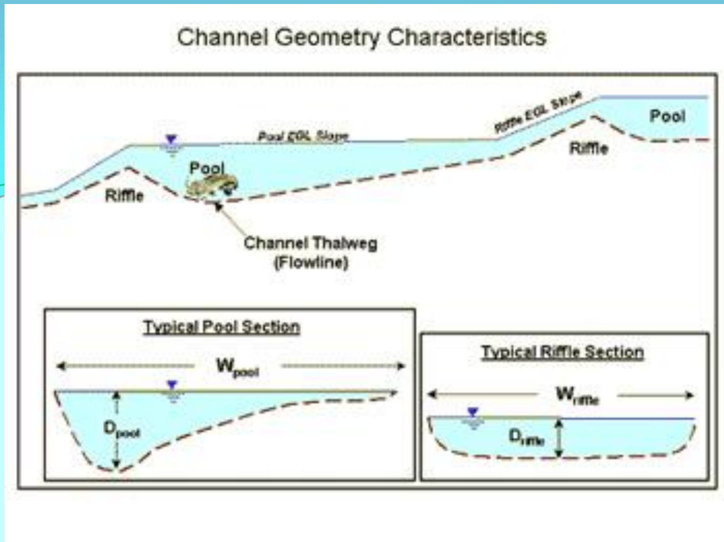
- Base flows
  - Habitability and biodiversity
- Floods and flood pulses - timing
- Floodplain connectivity
  - Hydroperiod, attenuation, recharge

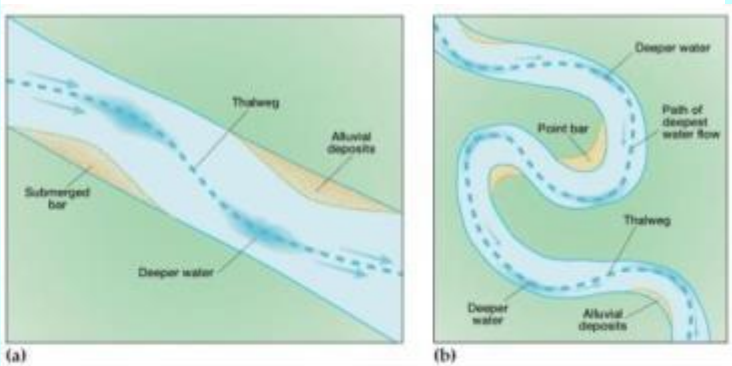
Hydraulics

- Hydraulic diversity
  - Dead water
  - White water



The flood-pulse concept diagrammed in five stages of an annual hydrologic cycle. The left column describes nutrient movement, the right describes typical life history traits of fish.



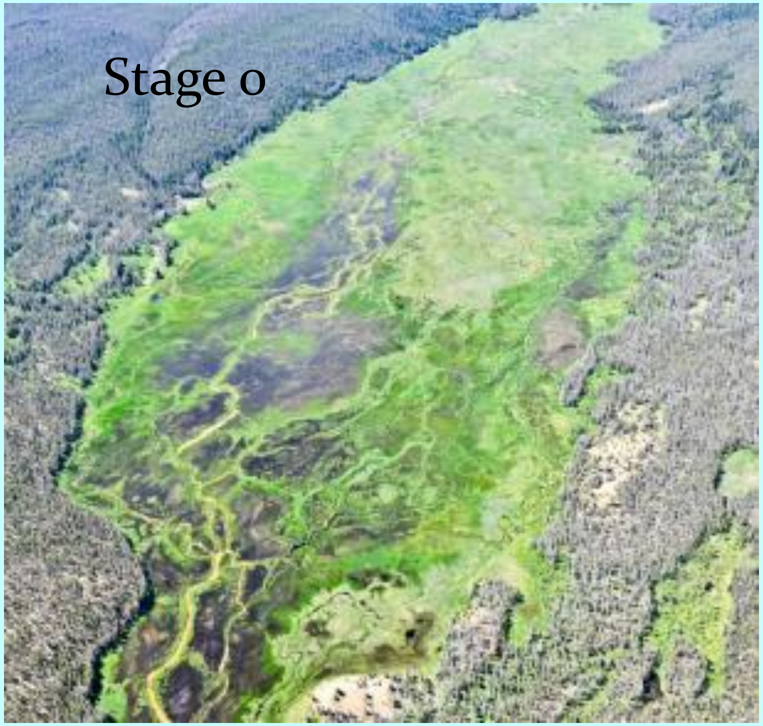


Geomorphic attributes

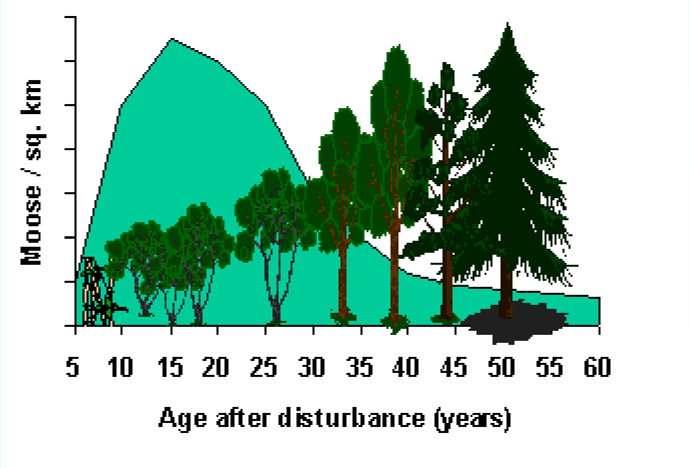
- Channel dimensions and geometry
  - Wetted area
  - Length and complexity of the shoreline
- Channel features
  - Bedforms, bars, islands, riparian margins
- Instream sediment storage
- Proportion of shoreline stable or unstable
- Substrate
  - Size and distribution, sorting, patchiness

Floodplain attributes

- Extent and Connectivity
  - Inundation surfaces
    - Duration, timing
  - Topo features on floodplain
  - Processes
    - Sediment storage
    - Carbon sequestration
    - Nutrient processing



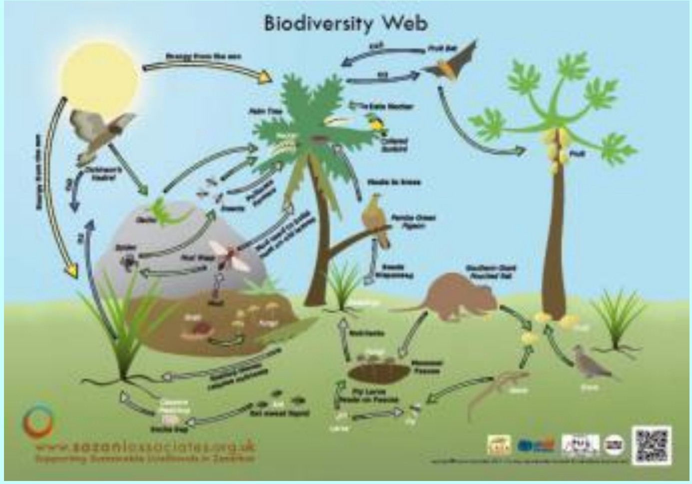
Vegetation attributes

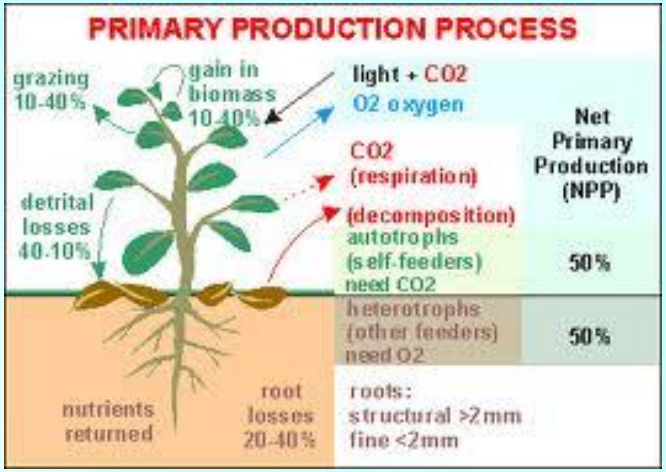


- Presence of plants
  - Aquatic, emergent, riparian, floodplain
- Leaf litter
  - Primary production support
- Tree trunk recruitment
  - Cycling nutrients and carbon
  - Hydraulic and morpho diversity
  - Channel stability
  - Sediment storage
  - Sorting and patchiness
  - Forcing hyporheic flow
- Riparian succession, dynamic landscape

Habitat and ecosystem benefits

- Biota
  - Biodiversity (species richness and trophic diversity) varies in relation to morphologic diversity of the channel and the extent and frequency of floodplain connectivity
  - Proportion of native plants
  - 1° and 2° productivity; in proportion to the hydrologic, hydraulic, morphologic and vegetative diversity





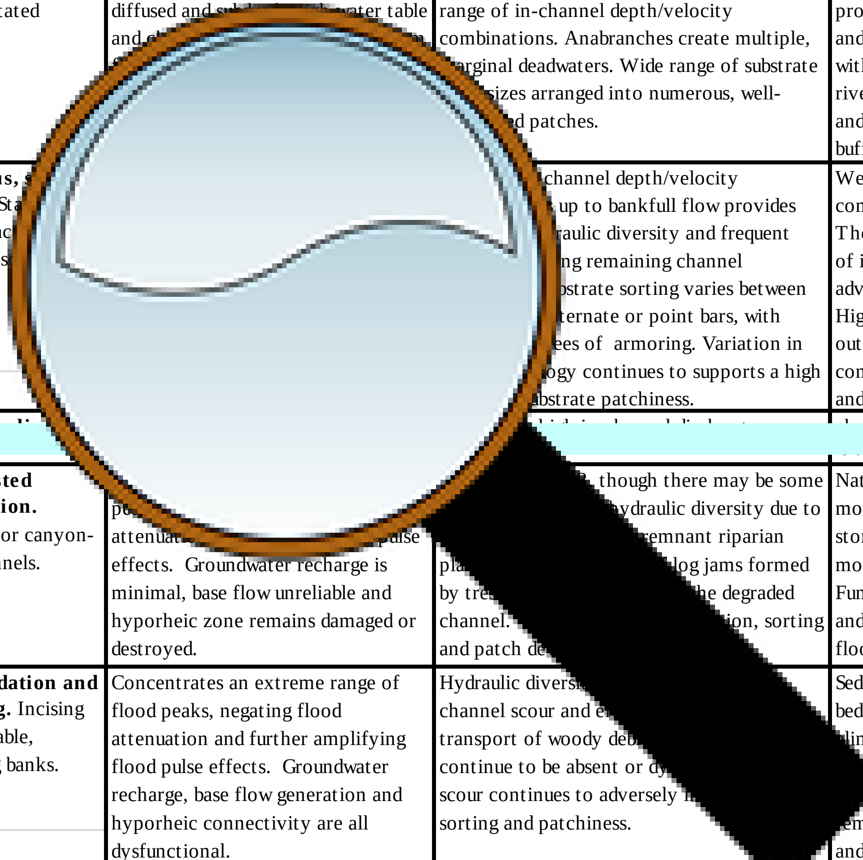
- Resilience
  - Floods
    - Stage resilient edges
    - Floodplain
  - Droughts
    - Water table connection
    - Availability of deep pools
- Able to withstand disturbances

Each stream Stage is associated with a gradient of hydrogeomorphic processes, attributes, and ranges and qualities of habitat and ecosystem benefits.

- Assessment per stage:
  - Interpretation of processes and resulting physical attributes,
  - Informed by published relationships between stream attributes, functional habitats, and freshwater ecology.

Table II Physical and Vegetation Attributes

SEM Stage		Physical Attributes			Vegetation Attributes
		Hydrologic Regime	Hydraulics and Substrate	Dimensions and Morphology	
0. Anastomosing. Dynamically meta-stable network of anabranching channels with vegetated islands.		Floods diffused over the full width of the floodplain so flood peaks are maximally attenuated. Flood pulses diffused and subdued. High water table and close connection between stream flow and ground water ensures reliable base flows and continuous hyporhesis, though flow in smaller anabranches may be ephemeral.	Multiple channels provide maximum in-channel hydraulic diversity through partition of discharge between branches that widens range of in-channel depth/velocity combinations. Anabranches create multiple, marginal deadwaters. Wide range of substrate grain sizes arranged into numerous, well-sorted bed patches.	Multiple anabranches, islands and side channels maximize. Morphological features abound in-channel and on the extensive and fully connected floodplain, providing a high capacity to store sediment and wood and supporting diverse wetlands. Bank heights are low with stability enhanced by riparian margins, but some river cliffs are generated by localised erosion. Network and floodplain are highly resilient to disturbance, buffering the system.	Frequent, small channel adjustments and high, reliable water table create ubiquitous settings for proliferation and succession of aquatic, emergent, riparian and floodplain plants. Wet woodlands on islands and floodplain supply and retain wood, and widespread vegetation proximal to channels produces abundant leaf litter.
Single Thread Channels	**1.Sinuous, single-thread .** Stable and laterally active. Sediment sorting and transfer.	Floods up to bankfull discharge retained in-channel reducing attenuation. Larger floods still spill to floodplain, attenuating their peaks. Close connection between groundwater and stream flow [illegible] reliable base flows and good [illegible] hyporhesis.	Range of in-channel [illegible] combinati[illegible] mo[illegible]	Wetted area relative to flow, shoreline length and [illegible]xity decrease due to switch to single channel. [illegible]rms and bars remain widespread, frequency [illegible]ces and diffluences is greatly reduced, [illegible]acity to store sediment and wood. [illegible] with river cliffs found along [illegible]dplain extent and [illegible]number of side channels [illegible]tlands reduced.	Decreases in hydraulic and morphological diversity trigger reductions in quantity and quality of aquatic, riparian and, especially, emergent plants. Floodplain communities remain diverse, but transition from wetland to more terrestrial assemblages. Reductions in extent of woodlands due to switch from multiple to a single channel decrease recruitment of wood and leaf litter.
	2. Channelized. Re-sectioned land drainage, flood control, or navigation channels.	Flood flows retained [illegible] design discharge, en[illegible] pulses. Flood atten[illegible] Efficient drainage [illegible] recession and lo[illegible] base flows and h[illegible] impaired.	[illegible]	[illegible] shoreline length and [illegible]dforms and bars [illegible] Capacity to store [illegible]d by channel [illegible]with river cliffs [illegible]ctionality of	Aquatic and emergent plants destroyed during construction with recovery limited to patches and narrow belts. Riparian plants only contribute wood and leaf litter if some of riparian corridor is left in place. Floodplain vegetation communities disconnected from channel may transition
	3. Degrading. Incising and abandoning its floodplain. Banks stable geotechnically.	Concentrates p[illegible] flood peaks in-[illegible] amplifying floo[illegible] attenuation ine[illegible] recharge is mini[illegible] flow unreliable. [illegible] damaged or destro[illegible] and bank toes.	[illegible]	[illegible]e length and [illegible] Stage 1. [illegible]e channels, [illegible]acity to store [illegible]nks mostly stable [illegible] the riparian zone [illegible]vity with channel.	Aquatic and most emergent plants destroyed by incision; only seasonal and annual species remain. Riparian vegetation undercut and increasingly unstable leading to artificially elevated inputs of wood. Input of leaf litter, seeds and propagules continues, but retention reduced. Floodplain vegetation stressed due to lower water table.
	3s. Arrested degradation. Confined or canyon-type channels.	Concentrates a wide [illegible] peaks, providing no e[illegible] attenuation and maxima[illegible] effects. Groundwater rech[illegible] minimal, base flow unreliable [illegible] hyporheic zone remains damage[illegible] destroyed.	[illegible]	[illegible]ks in dimensions and [illegible] Limited capacity to [illegible]ation ceases. Banks [illegible]ay increase. [illegible]diminished [illegible]its	Relative stability allows for early succession in emergent and riparian plant communities, improving supply of leaf litter. Wood recruitment continues, limited by the proximity, width and contiguity of woodlands on surrounding floodplain and terrace surfaces.
	4. Degradation and widening. Incising with unstable, retreating banks.	Concentrates an extreme range of flood peaks, negating flood attenuation and further amplifying flood pulse effects. Groundwater recharge, base flow generation and hyporheic connectivity are all dysfunctional.	Hy[illegible] channel s[illegible] transport of wood[illegible] continue to be absent or dysfunctional. Bed scour continues to adversely impact substrate sorting and patchiness.	[illegible] and ba[illegible] eliminate stable ba[illegible] cliffs that destroy rip[illegible] shoreline length and co[illegible] remain low. No recovery o[illegible] and wood, and floodplain still d[illegible]	Aquatic plant community remains dysfunctional due to on-going bed [illegible]gradation and riparian plants are destroyed [illegible]id widening. Wood recruitment may [illegible]if banks are forested, though [illegible]pends on trees being large [illegible]asing channel width.
	4-3. Renewed incision. Further head cutting within Stage 4 channel.	Increased range of floods retained in-bank continues to amplify flood pulse effects. Flood attenuation, groundwater recharge, base flow generation and hyporheic connectivity all remain dysfunctional.	Renewed incision maintains limited range of depth/velocity, combinations and so hydraulic diversity remains low. No new marginal deadwaters are created. Channel scour effectively eliminates functionality of substrate sorting and patchiness in providing habitat and ecosystem benefits.	Renewed scour removes embryonic [illegible] formed in Stage 4. Degree of disconne[illegible] channels, floodplain and wetlands due to c[illegible] incision increases. Any stored sediment or w[illegible] flushed downstream. Continued bank retreat for[illegible] cliffs that erode any remaining riparian fringe.	[illegible]iparian and floodplain [illegible]depleted and [illegible]y of leaf litter but [illegible]until proximal [illegible]depends on [illegible]g
	5. Aggrading and widening. Bed rising, banks stablising & berming.	No significant improvement in flood attenuation but flood pulse effects not quite as marked. Groundwater recharge remains dysfunctional, and base flows are still unreliable, but some hyporheic connectivity is recovered.	Aggradation renews depth/velocity variability that to improve hydraulic diversity. Small marginal deadwaters may develop, but these are not yet functional in providing habitat and ecosystem benefits. Bars and log jams begin to improve sediment sorting and patchiness.	Wetted area, shoreline length and complexity relative to flow all remain low. Aggradation generates some bedforms and bars but channel remains dysfunctional with regard to effective storage of sediment and wood. Bank stability improves marginally compared to Stage 4 allowing some recovery in riparian fringe. Floodplain connectivity begins to recover due to aggradation at bed and berm formation at banks.	[illegible] ber[illegible] and rip[illegible] communit[illegible] physically an[illegible] may continue to [illegible]e proximal trees and [illegible]er may be renewed as well.
	6. Quasi-equilibrium. Regime channel and proto-floodplain re-established.	Remains disconnected from former floodplain, but increased boundary roughness and emergent riparian stands damp flood pulse effects and reintroduce some flood attenuation. Groundwater recharge and base flow functions begin to recover and hyporhesis continues to improve.	Developing regime channel interacts with proto-floodplain surfaces to dissipate energy and increase hydraulic diversity. Accumulation of sediment and colonization of bars and berms by emergent and riparian vegetation increases number and functionality of marginal deadwaters. Patches of contrasting substrate size and sorting develop accordingly.	Wetted area, shoreline length and complexity relative to flow all remain low. Bedforms and bars recover to pre-disturbance levels restoring some capacity to storage of sediment and wood. Bank stability continues to improve at expense of river cliffs, allowing further recovery in riparian fringe. Floodplain connectivity continues to recover and new side channels may be created, though wetlands remain disconnected.	Relatively stable channel margins and inset features provide sites for development of aquatic, emergent and riparian plant communities. Aggradation improves connectivity with and functionality of floodplain plants, maintaining wood recruitment and enhancing supply of leaf litter.
	7. Laterally active. Regime channel develops sinuous course.	Increases in flow resistance due to development of channel and inset floodplain roughness further damp flood pulse effects while returning groundwater recharge, base flow and hyporheic functionality back close to Stage 1 level.	Development of planform sinuosity and interaction with maturing floodplain enhance hydraulic diversity and make marginal deadwaters fully functional. Substrate sorting enhanced and patchiness becomes fully functional. Hydraulic and substrate attributes recover to Stage 1 levels.	Growth of sinuous channel increases wetted area, shoreline length and complexity. Bedforms and bars persist and new islands, confluences and diffluences develop, increasing capacity to storage of sediment and wood. Renewed bank erosion at bends broadens range of bank morphologies. Extent of new side channels increases with some wetlands created.	Extent of riparian and floodplain plant communities increases at expense of opportunities for emergent plants. Stabilisation of banks reduces wood recruitment but extension and maturing of riparian and floodplain communities maintain supply of leaf litter.
8. Anastomosing. Meta-stable anabranching network.		Hydrologic attributes and functions similar to Stage 0 but network inset within the channel created in Stage 4 as modified in Stage 7.	Hydraulic and substrate attributes and functions similar to Stage 0, but network inset within the channel created in Stage 4 as modified in Stage 7.	Morphological attributes and functions similar to Stage 0, but wetted area, shoreline length, and extent of floodplain and its features diminished because network is inset within the valley created in Stage 4.	Hydrological, hydraulic and morphological attributes and functions similar to those of Stage 0 allow vegetation attributes to recover to pre-disturbance levels.



SEM Stage		Physical Attributes			Vegetation Attributes
		Hydrologic Regime	Hydraulics and Substrate	Dimensions and Morphology	
0. Anastomosing. Dynamically meta-stable network of anabranching channels with vegetated islands.		Floods diffused over the full width of the floodplain so flood peaks are maximally attenuated. Flood pulses diffused and su… …ater table and e…	Multiple channels provide maximum in-channel hydraulic diversity through partition of discharge between branches that widens range of in-channel depth/velocity combinations. Anabranches create multiple, …arginal deadwaters. Wide range of substrate …sizes arranged into numerous, well-…d patches.	Multiple anabranches, islands and side channels maximize. Morphological features abound in-channel and on the extensive and fully connected floodplain, providing a high capacity to store sediment and wood and supporting diverse wetlands. Bank heights are low with stability enhanced by riparian margins, but some river cliffs are generated by localised erosion. Network and floodplain are highly resilient to disturbance, buffering the system.	Frequent, small channel adjustments and high, reliable water table create ubiquitous settings for proliferation and succession of aquatic, emergent, riparian and floodplain plants. Wet woodlands on islands and floodplain supply and retain wood, and widespread vegetation proximal to channels produces abundant leaf litter.
…ngle Thread Channels	**1.Sinuous, s… thread .** Sta… laterally ac… Sediment s… transfer.		…channel depth/velocity …s up to bankfull flow provides …raulic diversity and frequent …ng remaining channel …bstrate sorting varies between …ternate or point bars, with …ees of armoring. Variation in …ogy continues to supports a high …bstrate patchiness.	Wetted area relative to flow, shoreline length and complexity decrease due to switch to single channel. Though bedforms and bars remain widespread, frequency of islands, confluences and diffluences is greatly reduced, adversely affecting capacity to store sediment and wood. Higher banks are less stable with river cliffs found along outer margins of bends. Floodplain extent and connectivity undiminished, but number of side channels and functionality of connected wetlands reduced.	Decreases in hydraulic and morphological diversity trigger reductions in quantity and quality of aquatic, riparian and, especially, emergent plants. Floodplain communities remain diverse, but transition from wetland to more terrestrial assemblages. Reductions in extent of woodlands due to switch from multiple to a single channel decrease recruitment of wood and leaf litter.
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	3s. Arrested degradation. Confined or canyon-type channels.	pe… attenuat… …ulse effects. Groundwater recharge is minimal, base flow unreliable and hyporheic zone remains damaged or destroyed.	…3, though there may be some …hydraulic diversity due to …remnant riparian pla… …log jams formed by tre… …he degraded channel. …ion, sorting and patch de…	Natural or artificial stabilization locks in dimensions and morphology developed in Stage 3. Limited capacity to store sediment and wood once degradation ceases. Banks mostly stable but extent of river cliffs may increase. Functionality of the riparian zone remains diminished and channel is permanently disconnected from its floodplain and wetlands.	Relative stability allows for early succession in emergent and riparian plant communities, improving supply of leaf litter. Wood recruitment continues, limited by the proximity, width and contiguity of woodlands on surrounding floodplain and terrace surfaces.
	4. Degradation and widening. Incising with unstable, retreating banks.	Concentrates an extreme range of flood peaks, negating flood attenuation and further amplifying flood pulse effects. Groundwater recharge, base flow generation and hyporheic connectivity are all dysfunctional.	Hydraulic divers… channel scour and e… transport of woody deb… continue to be absent or dy… scour continues to adversely i… sorting and patchiness.	Sediment inputs from bank retreat initiates limited bedform and bar development, but mass failures …liminate stable banks and increase the extent of river …fs that destroy riparian margins. Wetted area, …reline length and complexity relative to flow all …emain low. No recovery of capacity to store sediment and wood, and floodplain still disconnected.	Aquatic plant community remains dysfunctional due to on-going bed degradation and riparian plants are destroyed by rapid widening. Wood recruitment may increase if banks are forested, though retention depends on trees being large relative to increasing channel width.

SEM Stage		Hydrologic Regime	
0. Anastomosing. Dynamically meta-stable network of anabranching channels with vegetated islands.		Floods diffused over the full width of the floodplain so flood peaks are maximally attenuated. Flood pulses diffused and subdued. High water table and close connection between stream flow and ground water ensures reliable base flows and continuous hyporhesis, though flow in smaller anabranches may be ephemeral.	M ch of ra co m gr so
ngle Thread Channels	**1.Sinuous, single-thread .** Stable and laterally active. Sediment sorting and transfer.	Floods up to bankfull discharge retained in-channel reducing attenuation. Larger floods still spill to floodplain, attenuating their peaks. Close connection between groundwater and stream flow ensures reliable base flows and good hyporhesis.	Ra co m de bo th di be de
	[illegible]	[illegible]	[illegible]
	3s. Arrested degradation. Confined or canyon-type channels.	Concentrates a wide range of flood peaks, providing no effective flood attenuation and maximal flood pulse effects. Groundwater recharge is minimal, base flow unreliable and hyporheic zone remains damaged or destroyed.	Si lin pr pl by ch an
	4. Degradation and widening. Incising with unstable, retreating banks.	Concentrates an extreme range of flood peaks, negating flood attenuation and further amplifying flood pulse effects. Groundwater recharge, base flow generation and hyporheic connectivity are all dysfunctional.	Hy ch tr co sc so

Table III Habitat & Ecosystem Benefits

SEM		Habitat and Ecosystem Benefits			
		Habitat	Biota (see Thorpe et al., 2010)	Resilience and Persistence	Water Quality
0. Anastomosing. Dynamically meta-stable network of anabranching channels with vegetated islands.		Multiple channels, islands and broad floodplain provide access to rich palette of diverse habitats in close proximity and refugia across a wide range of flood events. High water table, deep pools and continuous hyporhesis provide drought refugia in the multiple channels. Channel margins evolve semi-continuously to expose tree roots.	Multiple, complex, dynamic channels that are connected to an extensive floodplain and which interact with groundwater and hyporhesis support large numbers of different species. This provides for the highest possible biodiversity (species richness and trophic diversity), proportion of native species, and 1st and 2nd order productivity [illegible]	Physical and vegetative attributes and functions stemming from their complexity, connectivity and diversity act to attenuate floods and sediment pulses, making habitat and biota persistent and highly resistant to natural and anthropogenic disturbances including flood, drought, and wild fire.	High capacity of multi-channel network to store sediment and cycle nutrients and other suspended solids produces exceptional water clarity. Dense, diverse proximal vegetation provides abundant shade which, together with efficient hyporhesis, is highly effective in ameliorating temperatures.
- Single Thread Channels -	**1.Sinuous, single-thread .** Stable and laterally active. Sediment sorting and transfer.	Palette of habitats somewhat reduced and range of flood refugia decreased though still high. Continued hyporhesis coupled with deeper scour pools in the single-thread channel provide excellent drought refugia. Reduction in length of shoreline decreases extent of exposed roots.	Single-thread channel connected t[illegible] floodplain. Channel still pro[illegible] range of valuable habitat [illegible] margins, though redu[illegible] complexity and ba[illegible] biodiversity and [illegible] productivity a[illegible]	[illegible] nectivity [illegible] eic [illegible]	Sediment storage and nutrient cycling capabilities slightly reduced but clarity still good in single channel/floodplain configuration. Temperature amelioration [illegible]ntained due to effective shade and [illegible]hesis in channel/floodplain system.
	2. Channelized. Re-sectioned land drainage, flood control, or navigation channels.	Construction of trapezoidal cross-section, imposition of uniform morphology and isolation from floodplain destroys most habitat and disables functionality with respect to provision of flood and drought refugia. Exposed tree roots are removed during construction.	Disturbance [illegible] rapid to a[illegible] native sp[illegible] conditio[illegible] richness[illegible] 1st and [illegible] marked[illegible]	[illegible]	[illegible] of flows concentrated into [illegible]annel without floodplain [illegible]sults in low water clarity and [illegible]nt cycling. Poor temperature [illegible]ue to lack of riparian shading [illegible]e hyporheic exchange.
	3. Degrading. Incising and abandoning its floodplain. Banks stable geotechnically.	Degradation destroys benthos, removes features that provide in-channel habitat and isolates channel from floodplain habitat. Channel scour and disconnection from floodplain mean that flood and drought refugia are destroyed or dis-functional. Tree roots exposed by bank scour.	Disturba[illegible] althoug[illegible] with this [illegible] naturally a[illegible] anthropoge[illegible] trophic densi[illegible] impacts on [illegible]	[illegible]	[illegible]ponsible for water clarity and [illegible]ng further weakened due to bed [illegible]tion destruction loss and reduced [illegible] interaction. Effective [illegible]e amelioration impaired by lack of [illegible] poor hyporheic exchange.
	3s. Arrested degradation. Confined or canyon-type channels.	Loss of habitat and/or disabling of functions incurred in Stage 3 are perpetuated in the confined, incised channel that results from arrested development when a degrading channel encounters highly erosion-resistan[illegible] materials.	Suitably [illegible] confi[illegible] sta[illegible]	[illegible]lience.	[illegible]tions responsible for water clarity and [illegible]trient cycling remain ineffective. Temperature amelioration may recover if stable banks support riparian vegetation sufficiently tall to provide effective shade.
	4. Degradation and widening. Incising with unstable, retreating banks.	Continued degradation further dama[illegible] benthos, bedform and bar feature[illegible] preventing recover of in-cha[illegible] and increasing isolation fr[illegible] Bank instability destro[illegible] does expose some t[illegible]	[illegible] bed degradation [illegible]at destroy habitat [illegible] biodiversity, and 1st and [illegible]ivity being sustained in [illegible] proportion of native biota [illegible]ver.	Deg[illegible]pid bank retreat exposes remaining habitat and ecosystem benefits to disturbance and negates their flood and drought resilience.	Physical attributes responsible for providing water clarity and nutrient cycling remain dysfunctional. Bank instability and rapid widening removes riparian shade, negating capability for temperature amelioration.
	4-3. Renewed incision. Further head cutting within Stage 4 channel.	Continued bed s[illegible] that no reco[illegible] connectiv[illegible] furthe[illegible] its[illegible]	[illegible]of incision and rapid bank retreat [illegible]ent recovery of habitat, perpetuating [illegible]ow levels of biodiversity, and leading to collapse of 1st and 2nd order productivity The proportion of native biota remains low.	Renewed incision and bank instability maintains the heightened sensitivity of residual habitat and ecosystem benefits to disturbance and prevents any recovery of flood and drought resilience.	Renewed incision, bank instability and widening reduce remaining capacity of the physical and vegetative attributes of the channel to provide habitat and ecosystem benefits with respect to water quality.
	5. Aggrading and widening. Bed rising, banks stablising & berming.	[illegible] respect [illegible] habitat d[illegible]o drought refuge. Crea[illegible] bars at the aggradi[illegible]ovide limited refuge during floods.	Reinstatement of some benthic sediments and in-channel features is reflected in some recovery in 1st and 2nd order productivity. However, at this stage biodiversity and the proportion of native biota have yet to respond.	Return of benthic sediments and in-channel features allow channel to absorb at least small disturbances without destroying habitat. Enlarged channel dimensions and conveyance tend to increase resilience to floods though not droughts.	Re-creation of bedforms, bars and berms together with return of aquatic, emergent and riparian vegetation re-activate sediment storage and nutrient cycling functions, though water clarity and capacity for temperature amelioration remain limited.
	6. Quasi-equilibrium. Regime channel and proto-floodplain re-established.	Some improvement in palette of accessible habitat, matched by provision of limited flood refuge and exposed roots from recovery of some in-channel features and vegetation. Reconnection of channel to groundwater and hyporheic zones result in some drought refugia.	Quasi-equilibrium, coupled with recovery of floodplain and hyporheic connectivity supports limited improvements in species richness and trophic diversity and allows some native biota to return. 1st and 2nd order productivity continues to increase as a result.	Quasi-equilibrium channel increasingly able to absorb moderate disturbances to flow and sediment regimes without loss of habitat and ecosystem benefits. In-channel features, vegetation, and floodplain connectivity and hyporhesis afford moderate flood and drought resilience.	Increases in the extent of the inset floodplain and riparian zones, vegetation re-growth and re-establishment of hyporheic connectivity provide moderate functionality for clarity and temperature amelioration, though nutrient cycling remains weak.
	7. Laterally active. Regime channel develops sinuous course.	Further improvement in range, quality and accessibility of habitat, coupled with improved functionality in terms of flood and drought refugia. Habitat benefits similar to Stage 1 channel, though habitat palette somewhat smaller.	The wider range of habitat in the increasingly diverse channel supports further improvement in biodiversity, while native species colonise and use the sinuous channel and developing floodplain. Productivity remains moderate.	Disturbances to channel increasingly ameliorated by flow and sediment storage on developing floodplain, though sensitivity remains higher than in Stage 1 due to its smaller extent. Flood and drought resilience similarly limited.	Plant succession and maturing floodplain and riparian zones increase efficiency of nutrient cycling and provision of shade. Water clarity remains moderate but temperature amelioration further improved.
8. Anastomosing. Meta-stable anabranching network.		Multi-channel complexity produces further improvement in habitat palette. Longer banklines provide more extensive areas with exposed roots, but loss of deepest pools reduces performance of flood refugia during the most extreme events.	Renewed habitat diversity, richness and connectivity allow native biota to re-occupy the area, with levels of biodiversity and productivity recovering to pre-disturbance levels, albeit on the somewhat smaller palette provided in Stage 8.	Physical and vegetative attributes and functions of Stage 8 channel make habitat and biota persistent and highly resistant to natural and anthropogenic disturbances, though levels cannot match those of Stage 0 due to restricted size of inset floodplain.	Multi-channel network with connected floodplain, hyporheic exchange and mature plant communities supports excellent water clarity, temperature amelioration, and optimal nutrient cycling.

SEM	Habitat and Ecosystem Benefits			
	Habitat	Biota (see Thorpe et al., 2010)	Resilience and Persistence	Water Quality
0. Anastomosing. Dynamically meta-stable network of anabranching channels with vegetated islands.	Multiple channels, islands and broad floodplain provide access to rich palette of diverse habitats in close proximity and refugia across a ... of flood events. High ... inuous h...	Multiple, complex, dynamic channels that are connected to an extensive floodplain and which interact with groundwater and hyporhesis support large numbers of different species. This provides for the highest possible biodiversity (species richness and trophic diversity), proportion of native ...ecies, and 1st and 2nd order productivity.	Physical and vegetative attributes and functions stemming from their complexity, connectivity and diversity act to attenuate floods and sediment pulses, making habitat and biota persistent and highly resistant to natural and anthropogenic disturbances including flood, drought, and wild fire.	High capacity of multi-channel network to store sediment and cycle nutrients and other suspended solids produces exceptional water clarity. Dense, diverse proximal vegetation provides abundant shade which, together with efficient hyporhesis, is highly effective in ameliorating temperatures.
1.Sinuous, si... thread . Stabl... laterally acti... Sediment so... transfer.		...le-thread channel connected to its ...plain. Channel still provides a good ...f valuable habitat primarily at its ..., though reductions in morphological ...ity and bankline length impact ...sity and mean that biodiversity and ...ivity are moderate rather than high.	Sinuous channel form and close connectivity with floodplain, groundwater and hyporheic zones maintains high resilience to disturbance. Flood and drought resilience slightly reduced compared to that provided by the multi-channel system in Stage 0 due to some loss of effectiveness in attenuating floods.	Sediment storage and nutrient cycling capabilities slightly reduced but clarity still good in single channel/floodplain configuration. Temperature amelioration maintained due to effective shade and hyporhesis in channel/floodplain system.
3. Degrading... Incising and abandoning its floodplain. Banks stable geotechnically.	... flo... refugia ar... ...nal. roots exposed by bank scour.	...rbance due to degradation is severe ...ugh some species have adapted to cope ...s fluvial phenomenon, which occurs ... being generated ...ally. Species richness and ...ll decrease with adverse ...nd order productivity.	Degradation makes remaining habitat and ecosystem benefits highly sensitive to disturbance in response to alterations to the flow and sediment regimes associated with, for example, climate or land-use changes. Resilience to flood and drought is negligible.	Functions responsible for water clarity and nutrient cycling further weakened due to bed scour, vegetation destruction loss and reduced groundwater interaction. Effective temperature amelioration impaired by lack of shade and poor hyporheic exchange.
3s. Arrested degradation. Confined or canyon-type channels.	Loss of habitat and/or disabling of functions incurred in Stage 3 are perpetuated in the confined, incised channel that results from arrested development when a degrading channel encounters highly erosion-resistant materials.	...ill colonise the co... ...ovided it remains stable, ...er productiv... ...phic density and p... ...es will, however, remai...	Erosion-resistant bed and bank materials stabilize the boundaries of a confined, incised channel this marginally reduces habitat and ecosystem sensitivity to disturbance and provides limited flood and drought resilience.	Functions responsible for water clarity and nutrient cycling remain ineffective. Temperature amelioration may recover if stable banks support riparian vegetation sufficiently tall to provide effective shade.

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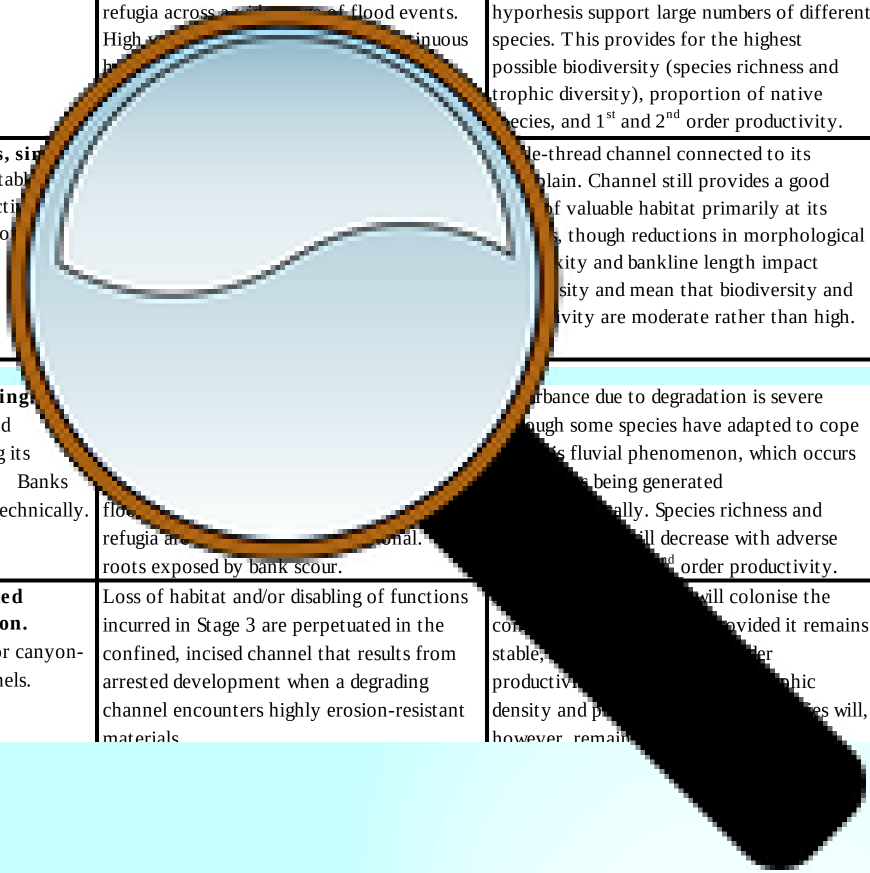


SEM		Habitat	
0. Anastomosing. Dynamically meta-stable network of anabranching channels with vegetated islands.		Multiple channels, islands and broad floodplain provide access to rich palette of diverse habitats in close proximity and refugia across a wide range of flood events. High water table, deep pools and continuous hyporhesis provide drought refugia in the multiple channels. Channel margins evolve semi-continuously to expose tree roots.	Mu are wh hy spe po tro spe
	1.Sinuous, single-thread . Stable and laterally active. Sediment sorting and transfer.	Palette of habitats somewhat reduced and range of flood refugia decreased though still high. Continued hyporhesis coupled with deeper scour pools in the single-thread channel provide excellent drought refugia. Reduction in length of shoreline decreases extent of exposed roots.	Sin flo rar ma cor bio prc
		construction.	ma
	3. Degrading. Incising and abandoning its floodplain. Banks stable geotechnically.	Degradation destroys benthos, removes features that provide in-channel habitat and isolates channel from floodplain habitat. Channel scour and disconnection from floodplain mean that flood and drought refugia are destroyed or dis-functional. Tree roots exposed by bank scour.	Dis alt wit nat ant tro im

Attributes and Benefits, scoring scheme:

- Hydrogeomorphic attributes (26)
  - Hydraulic complexity
  - Physical channel dimensions, #
  - Hydrologic regime, floodplain
  - Channel and floodplain features
  - Substrate – sorting/patchiness
  - Vegetation – sediment interaction

Ordinal Score:
0 = absent
1 = scarce/partly functional
2 = present and functional
3 = abundant/fully functional

- Habitat and Ecosystem Benefit attributes (11)
  - Refugia from extremes – flood/drought
  - Water quality – clarity/temperature/nutrient cycling
  - Biota – diversity/natives/1° & 2° productivity
  - Resilience to disturbance

, Valley Creek, ID

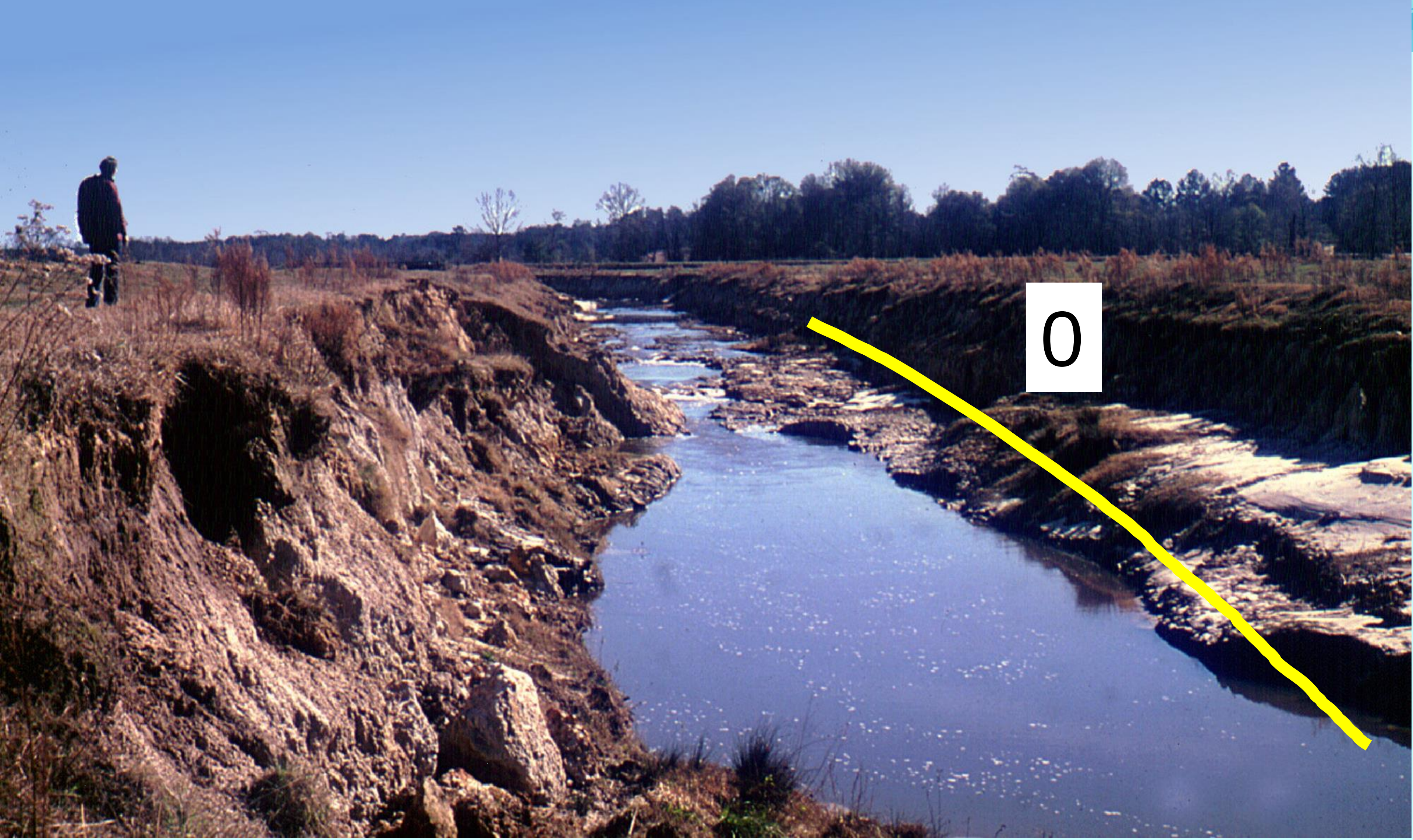
Hydrogeomorphic Attributes Table

Stage	0	1	2	3	3s	4	4-3	5	6	7	8
Physical Channel Dimensions											
Wetted Area Relative to Flow	3	2	1	1	1	0	0	1	1	2	2
Shoreline Length and Complexity	3	2	1	1	1	0	0	1	1	2	2
Channel and Floodplain Features											
Bedforms and bars	2	3	1	0	0	1	0	2	3	3	2
Islands	3	1	0	0	0	0	0	0	0	1	3
Local Confluence/Diffluences	3	1	0	0	0	0	0	0	0	1	3
Stable banks	3	2	2	2	2	0	0	1	2	2	3
River cliffs	2	2	0	1	2	2	2	2	1	2	2
Riparian Margins	3	2	1	1	1	0	0	1	2	2	3
Floodplain Extent and Connectivity	3	3	1	0	0	0	0	1	2	2	2
Side channels	3	2	0	0	0	0	0	0	1	2	2
sediment storage	3	2	1	0	0	0	0	0	1	2	3
Connected Wetlands	3	2	1	0	0	0	0	0	0	1	2
Substrate											
Substrate Sorting	2	3	0	0	1	0	0	1	1	2	2
Substrate Patchiness	3	3	0	0	1	0	0	1	2	3	3
Hydraulics											
Hydraulic Diversity	3	2	0	0	1	0	0	1	1	2	3
Marginal Deadwater	3	2	0	0	0	0	0	0	1	2	3
Vegetation											
Aquatic plants	3	2	1	0	0	0	0	1	2	2	3
Emergent Plants	3	1	1	1	1	1	0	2	2	1	3
Riparian plants	3	2	0	0	1	0	0	1	1	2	3
Floodplain plants	3	3	2	0	0	0	0	0	1	2	3
Woody debris	3	1	0	1	1	2	1	2	2	1	3
Leaf litter	3	2	0	1	2	0	0	1	2	2	3
Hydrological Regime											
Flood pulse	1	1	2	3	3	3	3	2	2	1	1
Flood attenuation	3	2	1	0	0	0	0	0	1	2	3
Base flow	2	3	1	0	0	0	0	0	1	3	2
Hyporheic connectivity	3	3	2	0	0	0	0	1	2	3	3
Results											
possible	78	78	78	78	78	78	78	78	78	78	78
sum	72	54	19	12	18	9	6	22	35	50	67
ratio	92%	69%	24%	15%	23%	12%	8%	28%	45%	64%	86%

Table IV

Shoreline Length and Complexity

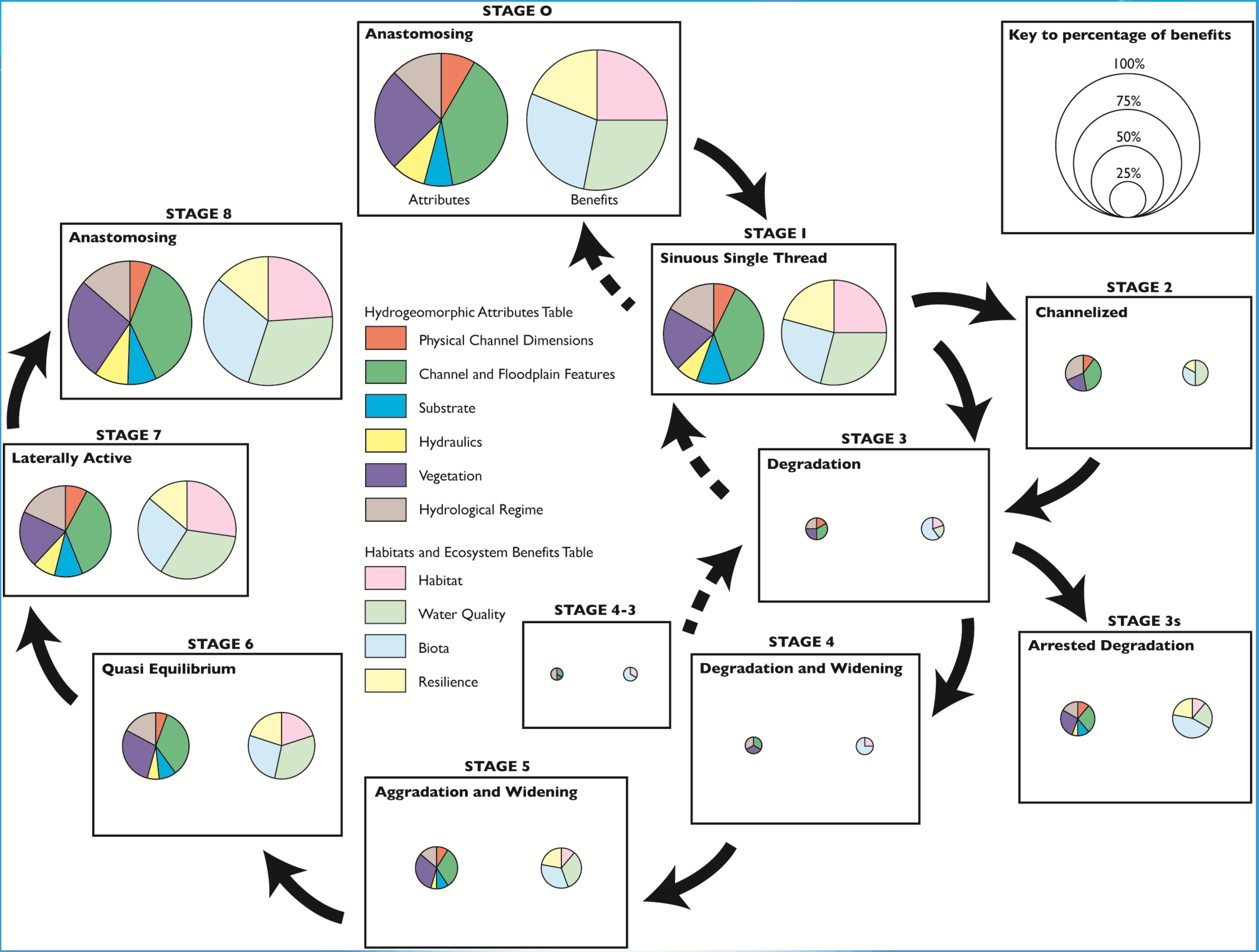

1


0

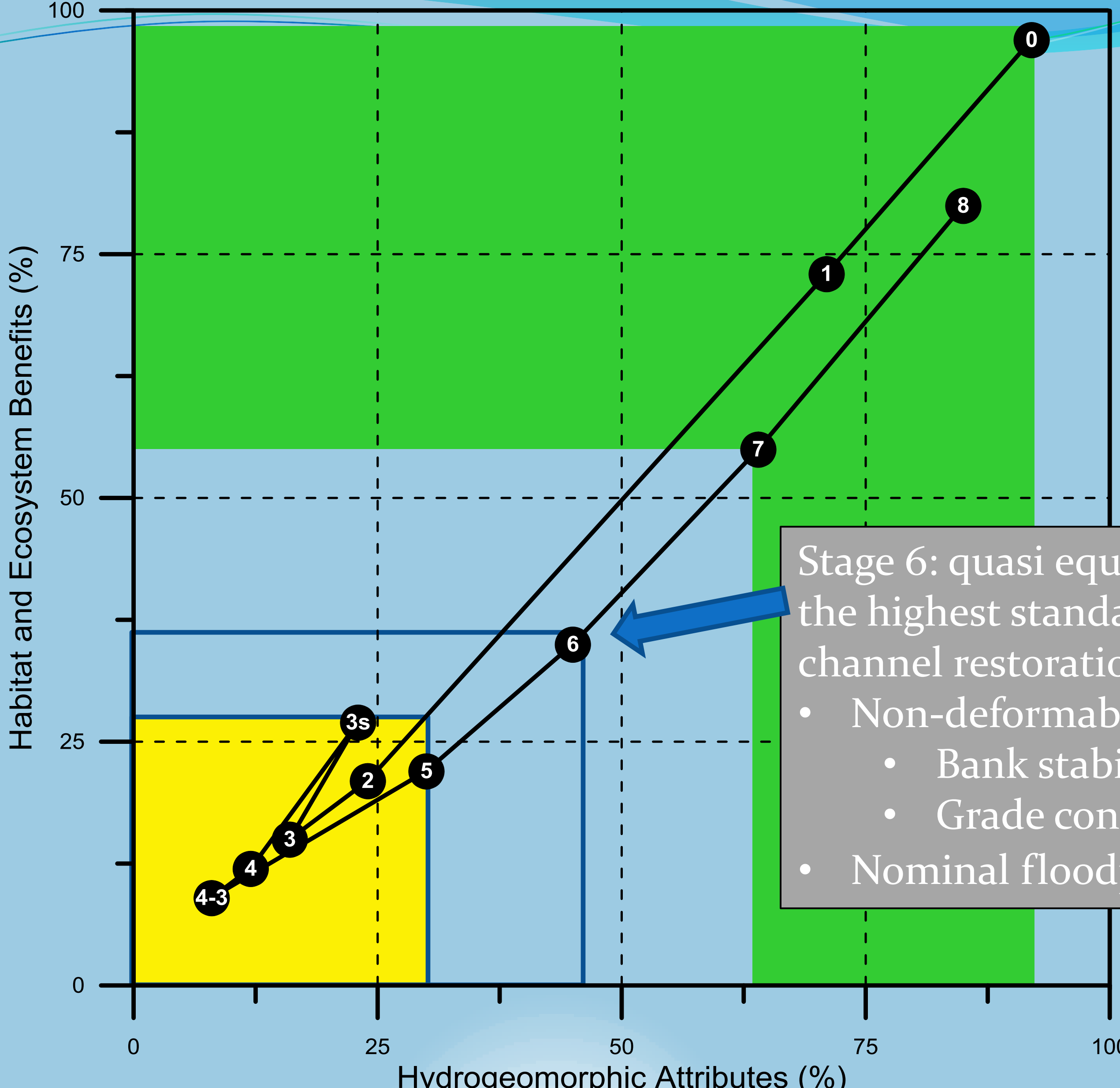
Habitat and Ecosystem Benefits Table

Stage	0	1	2	3	3s	4	4-3	5	6	7	8
Habitat											
Flood Refugia	3	2	0	0	0	0	1	1	1	2	2
Drought Refugia	2	3	0	0	0	0	0	0	1	3	2
Exposed tree roots	3	1	0	1	1	1	0	0	1	1	3
Water Quality											
Clarity	3	2	1	0	0	0	0	1	2	2	3
Temperature amelioration (shade and hyporheic flow)	3	3	1	1	2	0	0	1	2	3	3
nutrient cycling	3	2	1	0	0	0	0	1	1	2	3
Biota											
Biodiversity (species richness and trophic diversity)	3	2	0	1	1	1	1	1	1	2	3
Proportion of Native Biota	3	2	1	1	1	1	1	1	1	2	3
1st and 2nd Order Productivity	3	2	1	1	2	1	0	1	2	2	3
Resilience											
Disturbance	3	3	1	0	1	0	0	1	1	2	2
Flood and Drought	3	2	0	0	1	0	0	1	2	1	2
Results											
possible	33	33	33	33	33	33	33	33	33	33	33
sum	32	24	6	5	9	4	3	9	15	22	29
ratio	97%	73%	18%	15%	27%	12%	9%	27%	45%	67%	88%

Table V



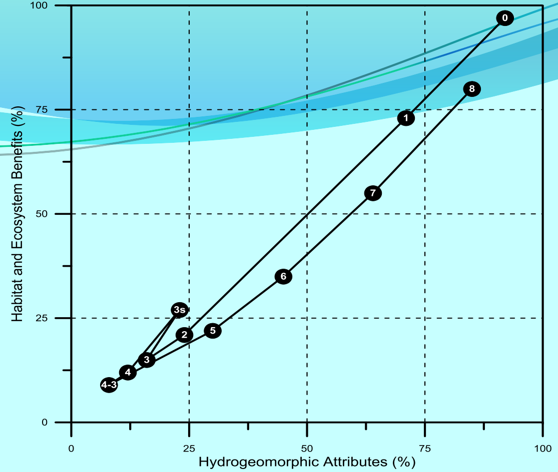
STAGE 0
Anastomosing
Attributes
Benefits
Key to percentage of benefits
100%
75%
50%
25%
STAGE 1
Sinuous Single Thread
STAGE 2
Channelized
STAGE 3
Degradation
STAGE 3s
Arrested Degradation
STAGE 4-3
STAGE 4
Degradation and Widening
STAGE 5
Aggradation and Widening
STAGE 6
Quasi Equilibrium
STAGE 7
Laterally Active
STAGE 8
Anastomosing
Hydrogeomorphic Attributes Table
Physical Channel Dimensions
Channel and Floodplain Features
Substrate
Hydraulics
Vegetation
Hydrological Regime
Habitats and Ecosystem Benefits Table
Habitat
Water Quality
Biota
Resilience



Stage 6: quasi equilibrium, the highest standard of channel restoration.

- Non-deformable
    - Bank stabilization
    - Grade control
- Nominal floodplain *

Conclusions:



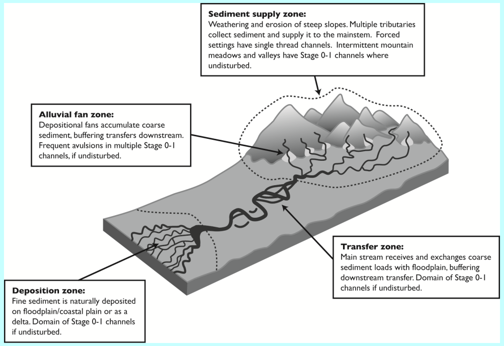
- Level of habitat and benefits - irreplaceable by channel enhancement, only floodplain processes provide the high levels of benefits.
- Low benefit streams can evolve, given space and time, or encouragement.
- Seasonal and perennial wetland floodplain complexes were historically common features in alluvial valleys.
  - Stage O streams are resilient to climate extremes.

Observations:

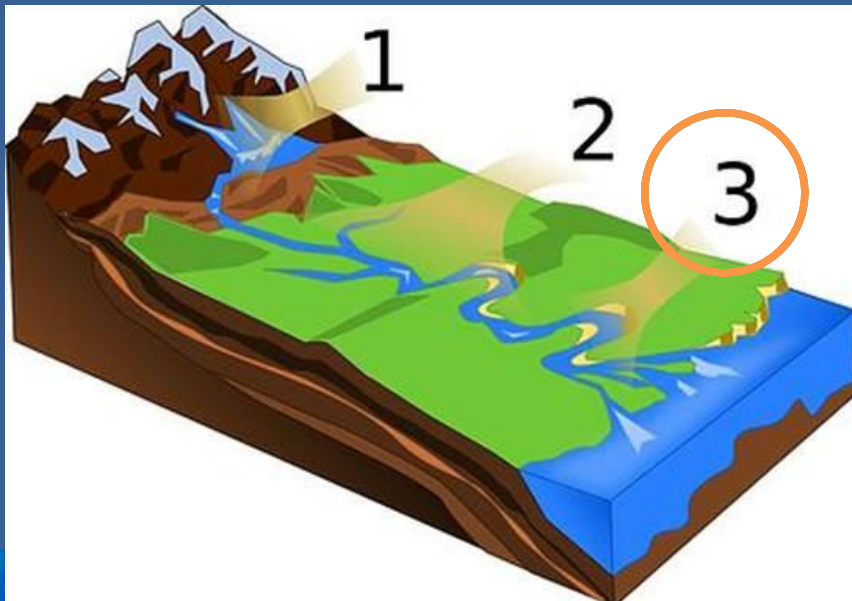
- Most of today's alluvial streams are the result of past management for flood control and land drainage
  - Focused on making sediment transfer zones and quick drainage– everywhere
- History of managing rivers for habitat is very short, and biased by 2 centuries of river management for drainage, minimization and stability.
- Restoration has focused on enhancement of low benefit Stages, not fundamentally changing their physical or ecological attributes.

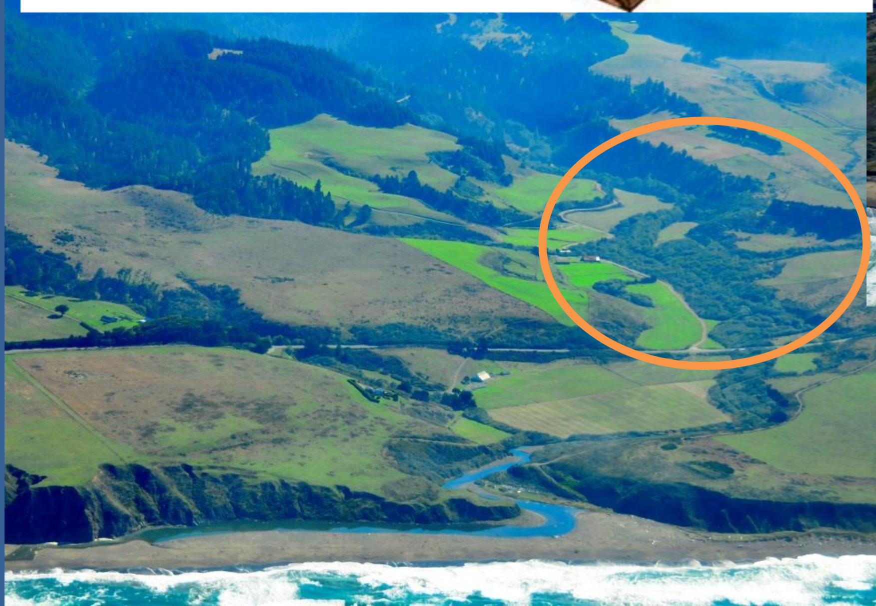
Suggestions:

- Manage **for** process <u>discontinuities</u>;
  - deposition and sorting,
  - sediment as a resource,
  - flow diffusion,
  - groundwater recharge, hyporhesis
- Reevaluate ‘stability’
  - A stable ecosystem is unrelated to a stable channel.



River-Estuary Ecotone



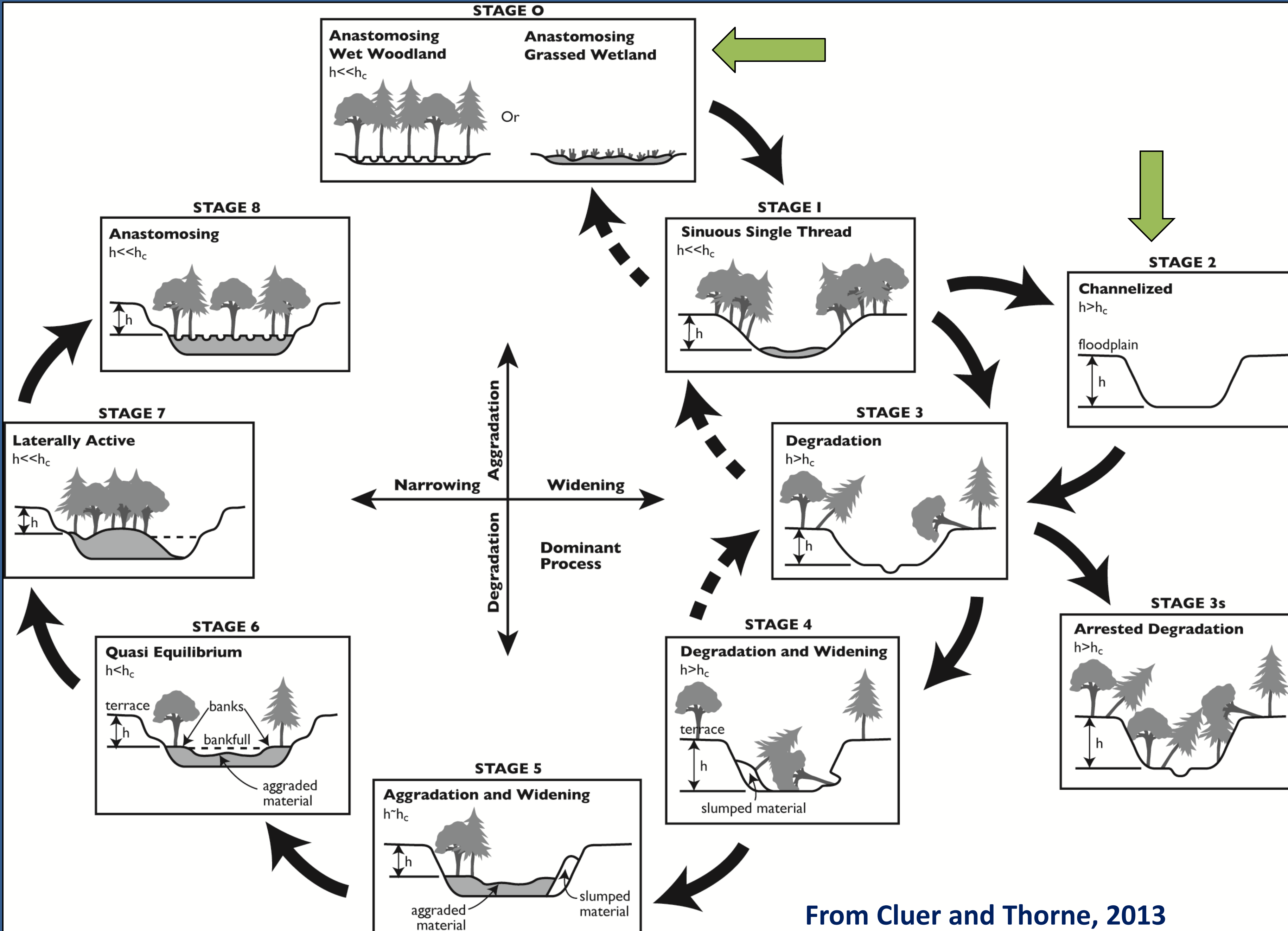


1st Example: Willow Creek, Sonoma County

Channel Conversion

From Single Thread - Channelized

To Multi-Thread Network



From Cluer and Thorne, 2013

History and Landuse - Upper Watershed

- 1848 – First recorded logging permit in California
- 1860 to early 1900s – Extensive logging using narrow gauge railroad and steam donkeys.
- 1953 to early 1970s – second growth and remaining old-growth clear cut.

History and Landuse - Lower Watershed

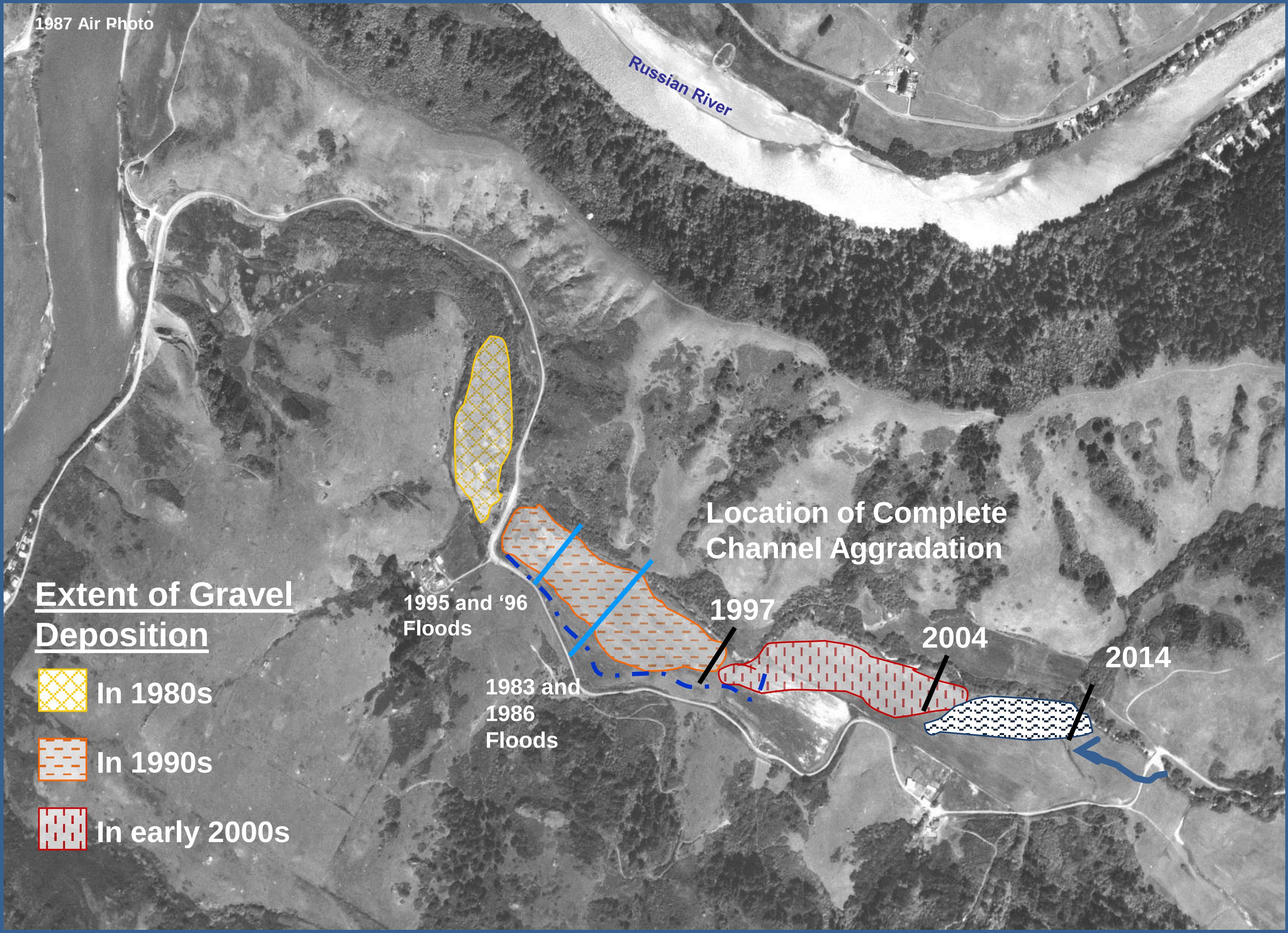
- **Late 1800s** valley cleared and channel routed to north side.
- **Thru mid 1900s** valley farmed, mill, community
- **1940s** channel straightened (2500’)
- **1960s to 1980s** channel regularly dredged.

Last Channel Dredging in 1983

1984

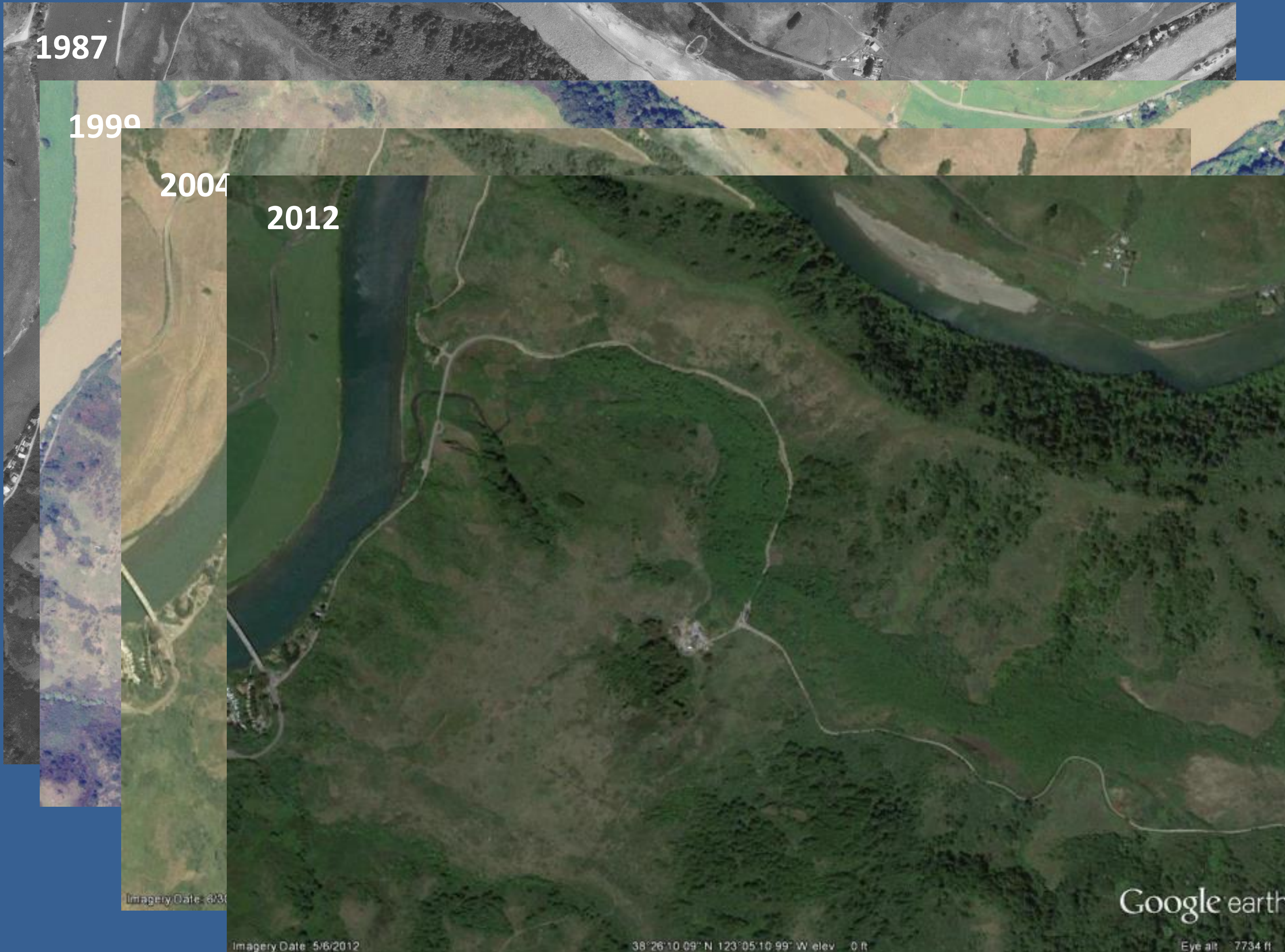
2008

Response to Change in Management

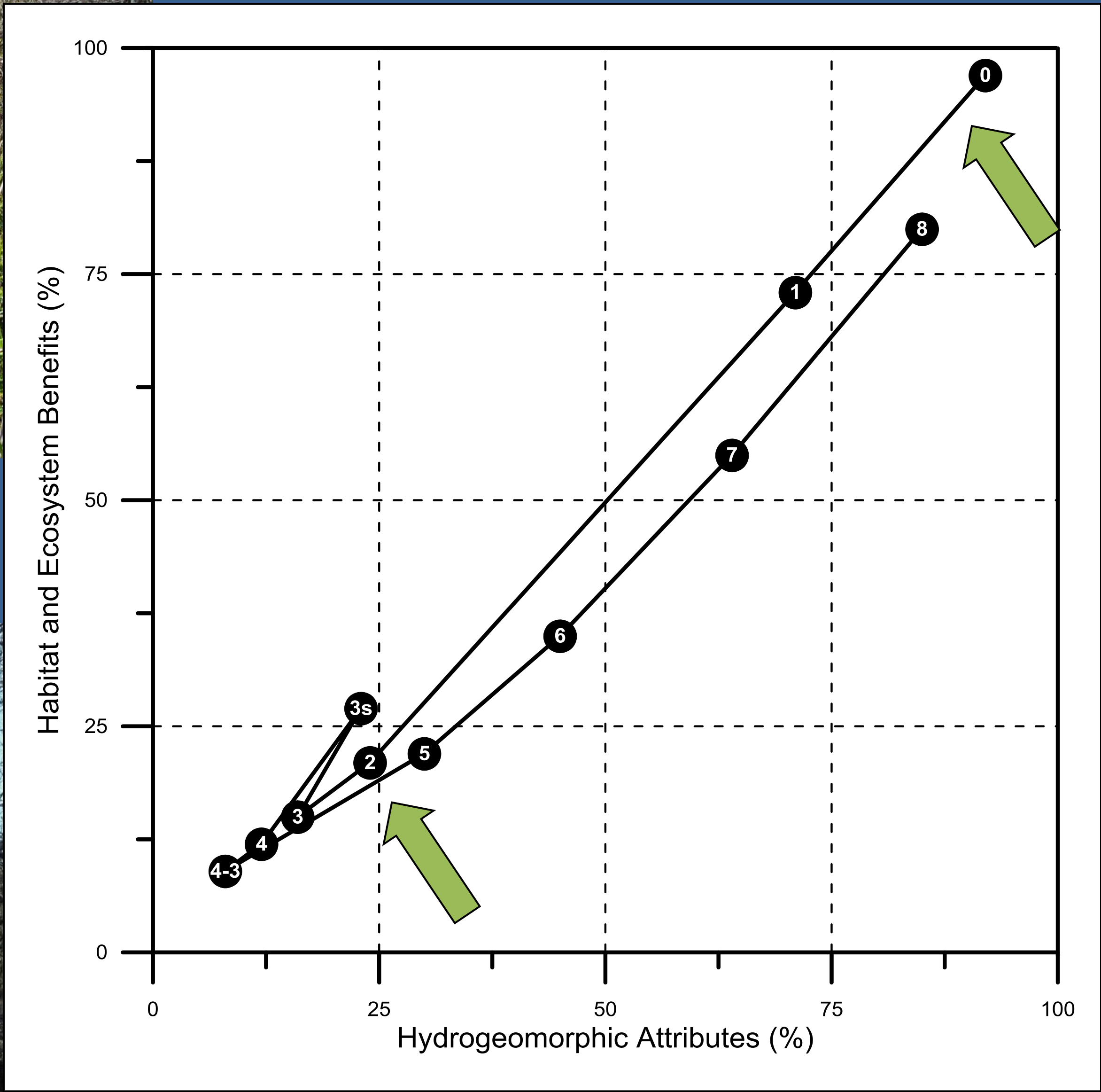


Filling of the Stage 2 channel progresses upstream.

Is followed by channel network development.

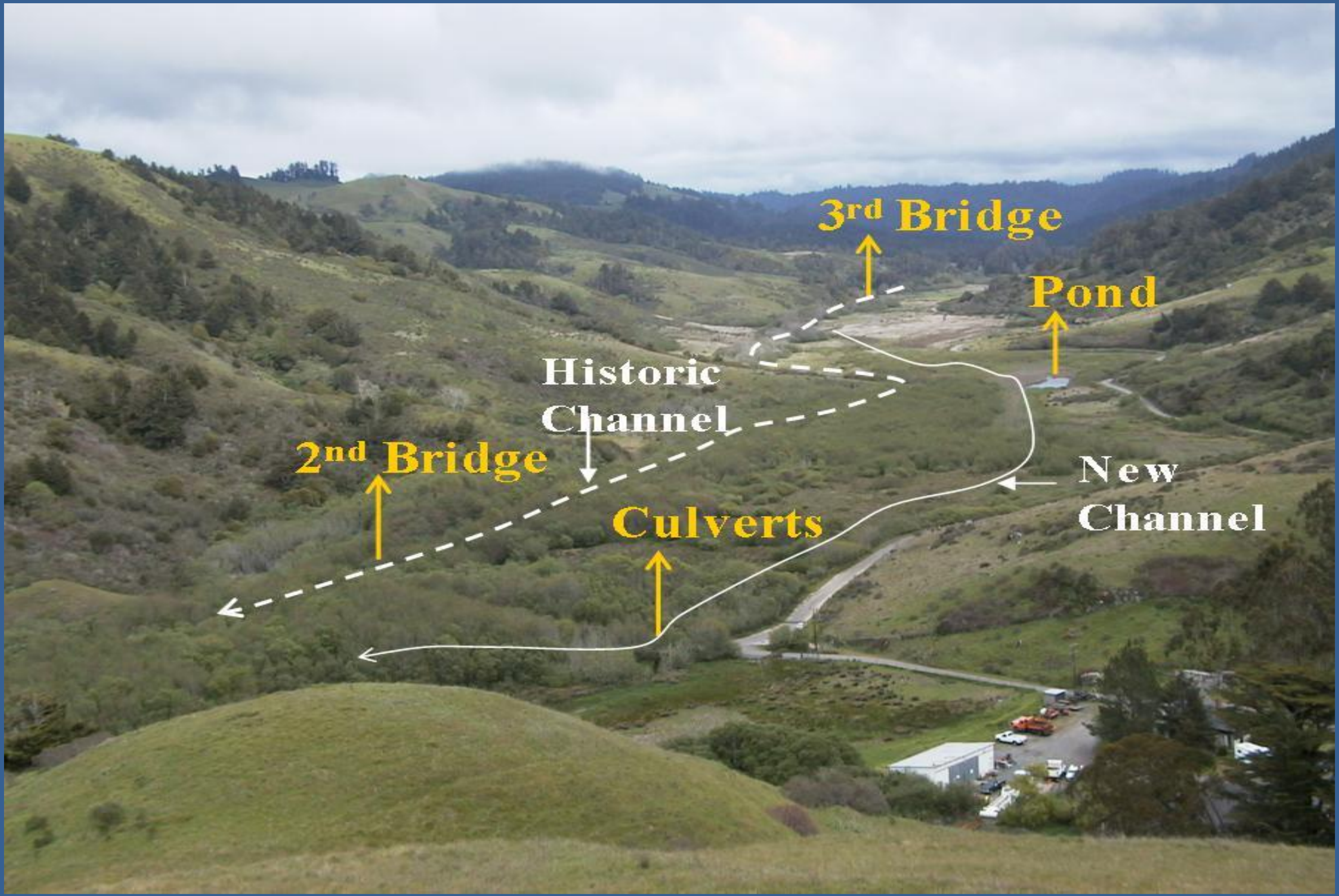


1987
1999
2004
2012
Google earth
Imagery Date 5/6/2012
38°26'10.09" N 123°05'10.99" W elev 0 ft
Eye alt 7734 ft



From Cluer and Thorne, 2013

Problem: Creek is no longer flowing under bridge. Salmon not getting into the watershed.

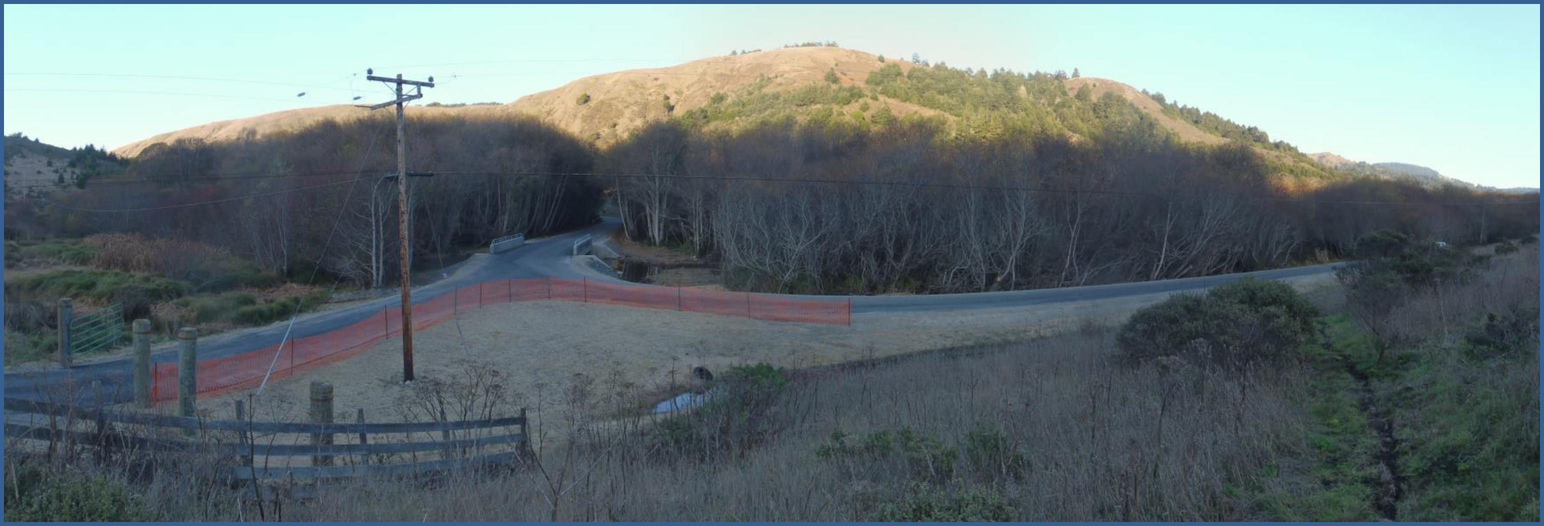


Bermed road across floodplain restricted adult and juvenile fish passage.

Flooded with every large storm.

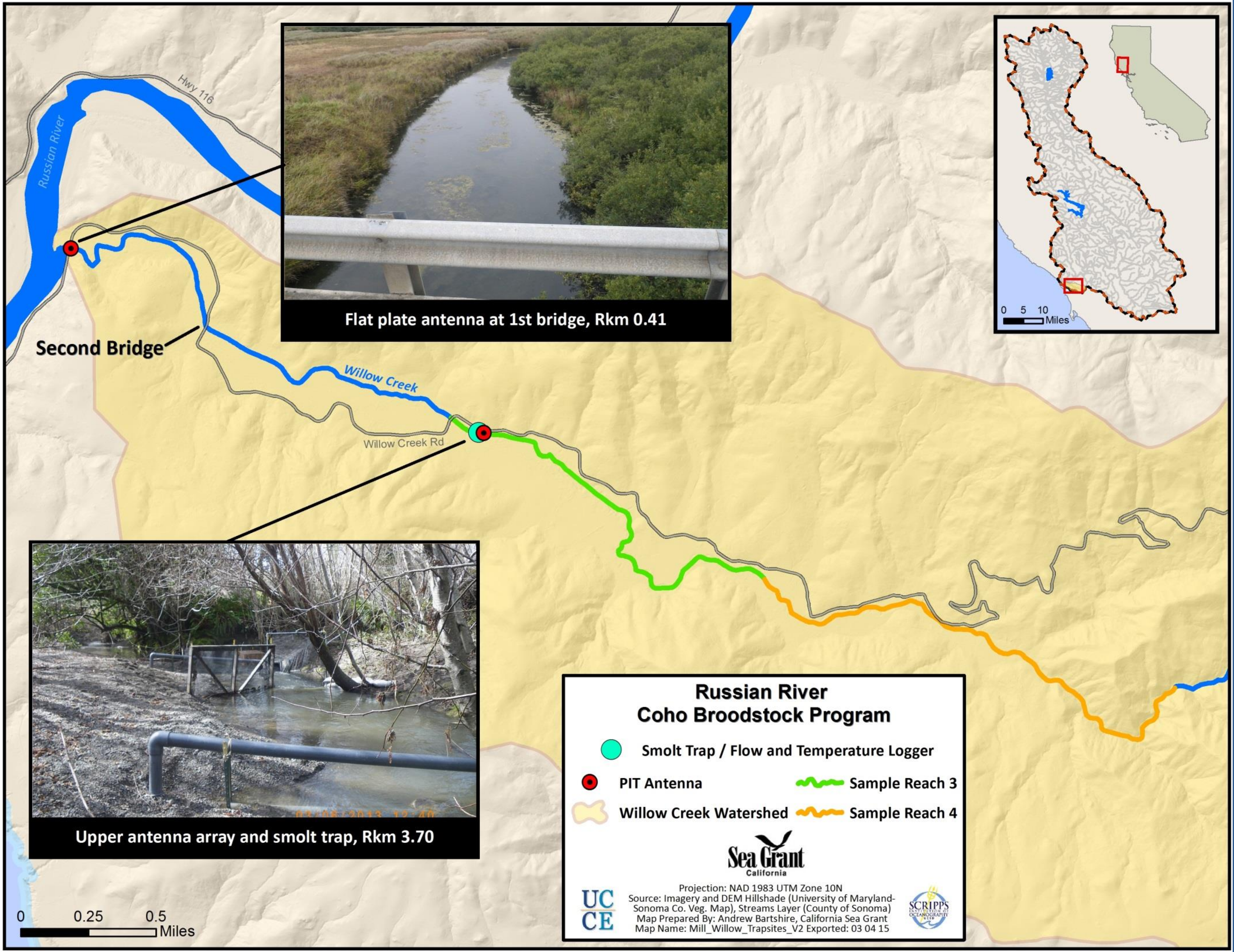
Photo courtesy of Derek Acomb

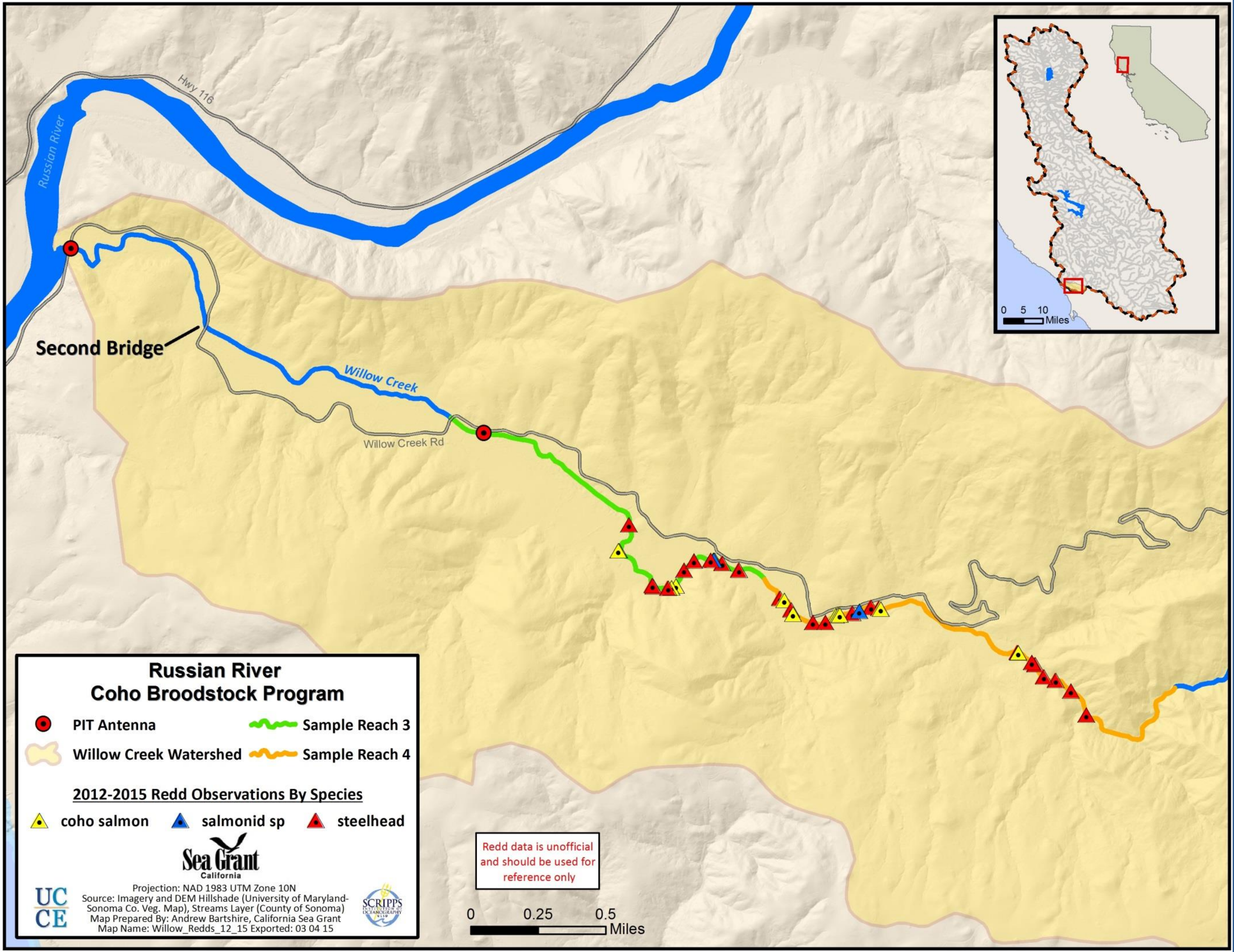
Replaced culverts with bridge in 2011

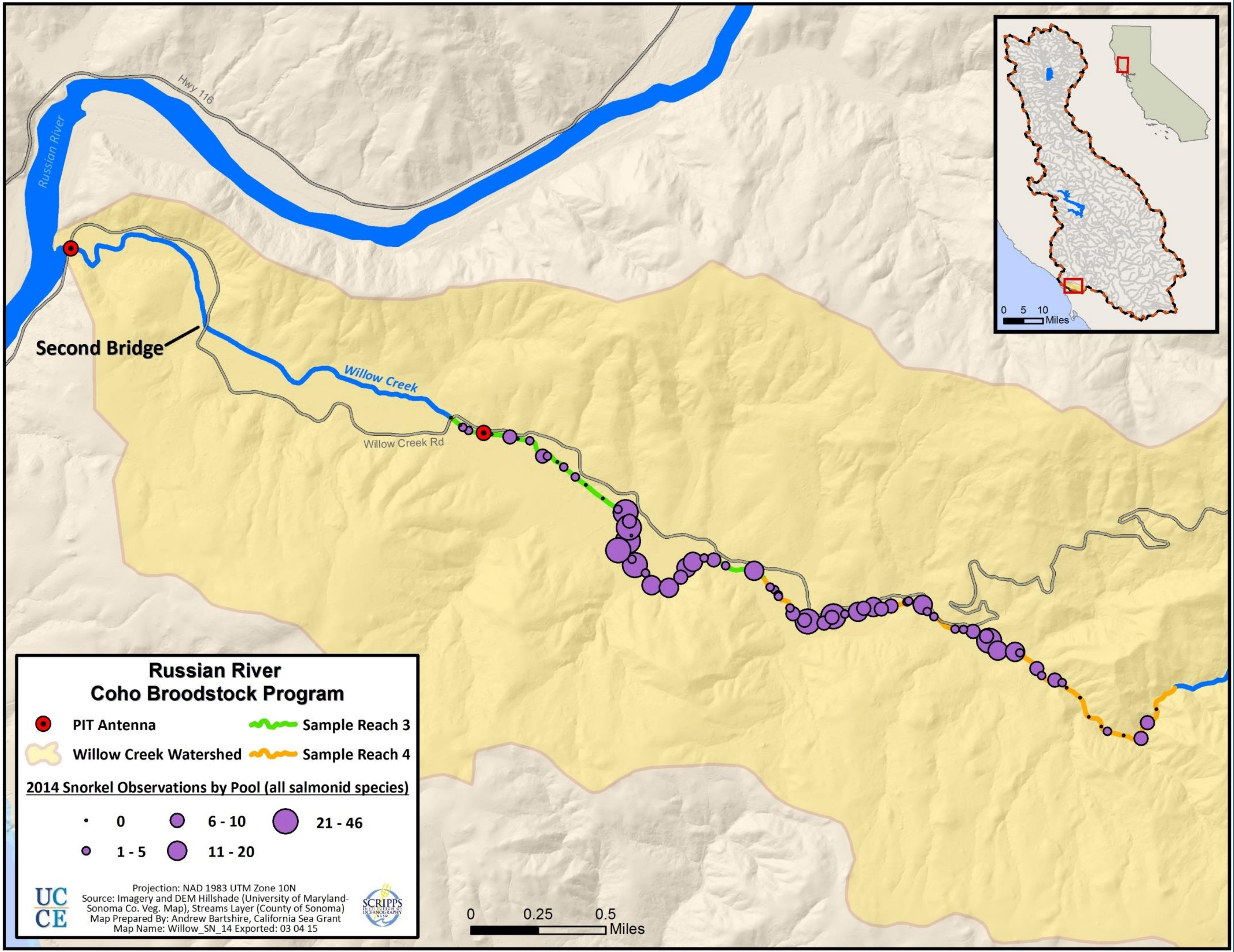


Lingering Questions and Concerns…

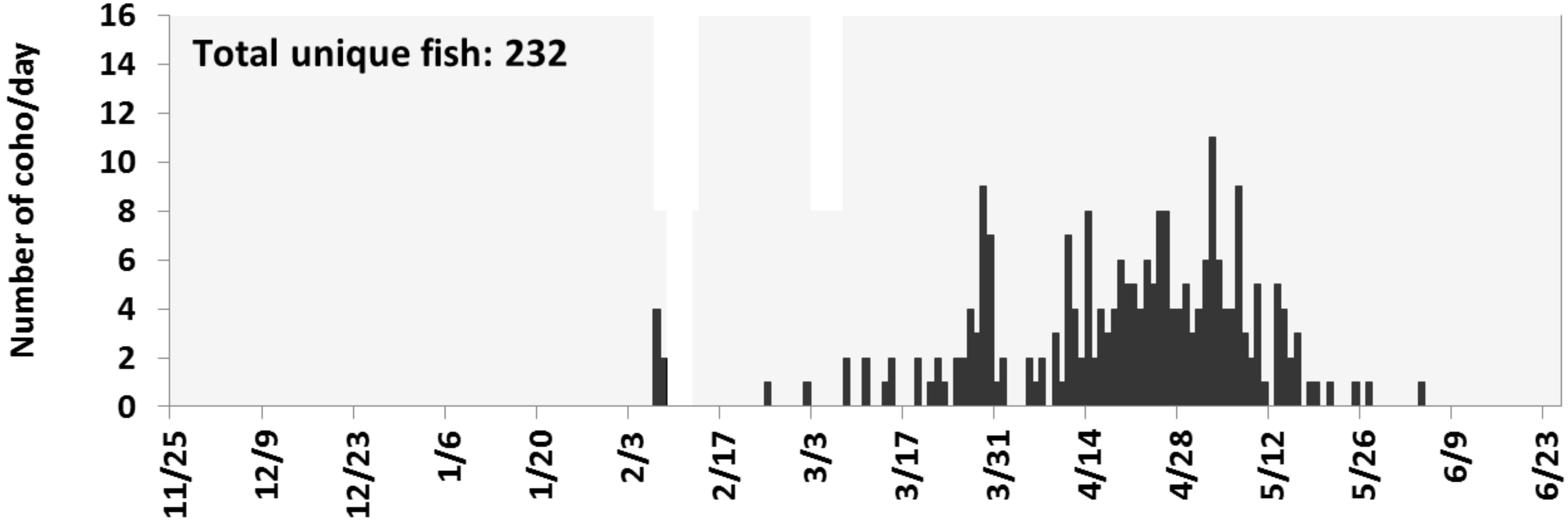
- Are there connected channels through the wetlands?
- Will adult fish be able to find their way up through?
- Will juveniles get lost on the way out?
- Will juveniles choose to rear in the wetlands?


Hwy 116
Russian River
Flat plate antenna at 1st bridge, Rkm 0.41
Second Bridge
Willow Creek
Willow Creek Rd
0 5 10
Miles
Upper antenna array and smolt trap, Rkm 3.70
Russian River
Coho Broodstock Program
Smolt Trap / Flow and Temperature Logger
PIT Antenna
Sample Reach 3
Willow Creek Watershed
Sample Reach 4
Sea Grant
California
Projection: NAD 1983 UTM Zone 10N
Source: Imagery and DEM Hillshade (University of Maryland-Sonoma Co. Veg. Map), Streams Layer (County of Sonoma)
Map Prepared By: Andrew Bartshire, California Sea Grant
Map Name: Mill_Willow_Trapsites_V2 Exported: 03 04 15
UC CE
SCRIPPS
0 0.25 0.5
Miles

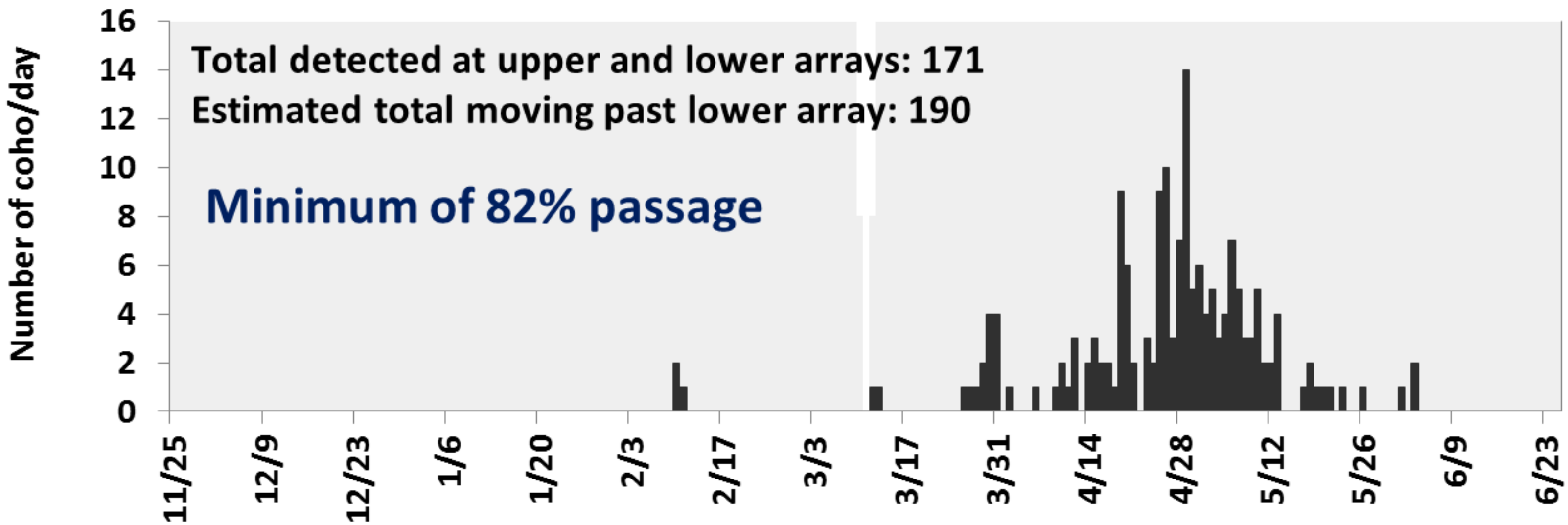

Hwy 116
Russian River
Second Bridge
Willow Creek
Willow Creek Rd
0 5 10 Miles
Russian River
Coho Broodstock Program
PIT Antenna
Sample Reach 3
Willow Creek Watershed
Sample Reach 4
2012-2015 Redd Observations By Species
coho salmon
salmonid sp
steelhead
Sea Grant
California
Projection: NAD 1983 UTM Zone 10N
Source: Imagery and DEM Hillshade (University of Maryland-Sonoma Co. Veg. Map), Streams Layer (County of Sonoma)
Map Prepared By: Andrew Bartshire, California Sea Grant
Map Name: Willow_Redds_12_15 Exported: 03 04 15
Redd data is unofficial and should be used for reference only
0 0.25 0.5
Miles


Russian River
Coho Broodstock Program
PIT Antenna
Willow Creek Watershed
Sample Reach 3
Sample Reach 4
2014 Snorkel Observations by Pool (all salmonid species)
0
1 - 5
6 - 10
11 - 20
21 - 46
Projection: NAD 1983 UTM Zone 10N
Source: Imagery and DEM Hillshade (University of Maryland-Sonoma Co. Veg. Map), Streams Layer (County of Sonoma)
Map Prepared By: Andrew Bartshire, California Sea Grant
Map Name: Willow_SN_14 Exported: 03 04 15
0
0.25
0.5
Miles
Hwy 116
Russian River
Second Bridge
Willow Creek
Willow Creek Rd
0 5 10
Miles

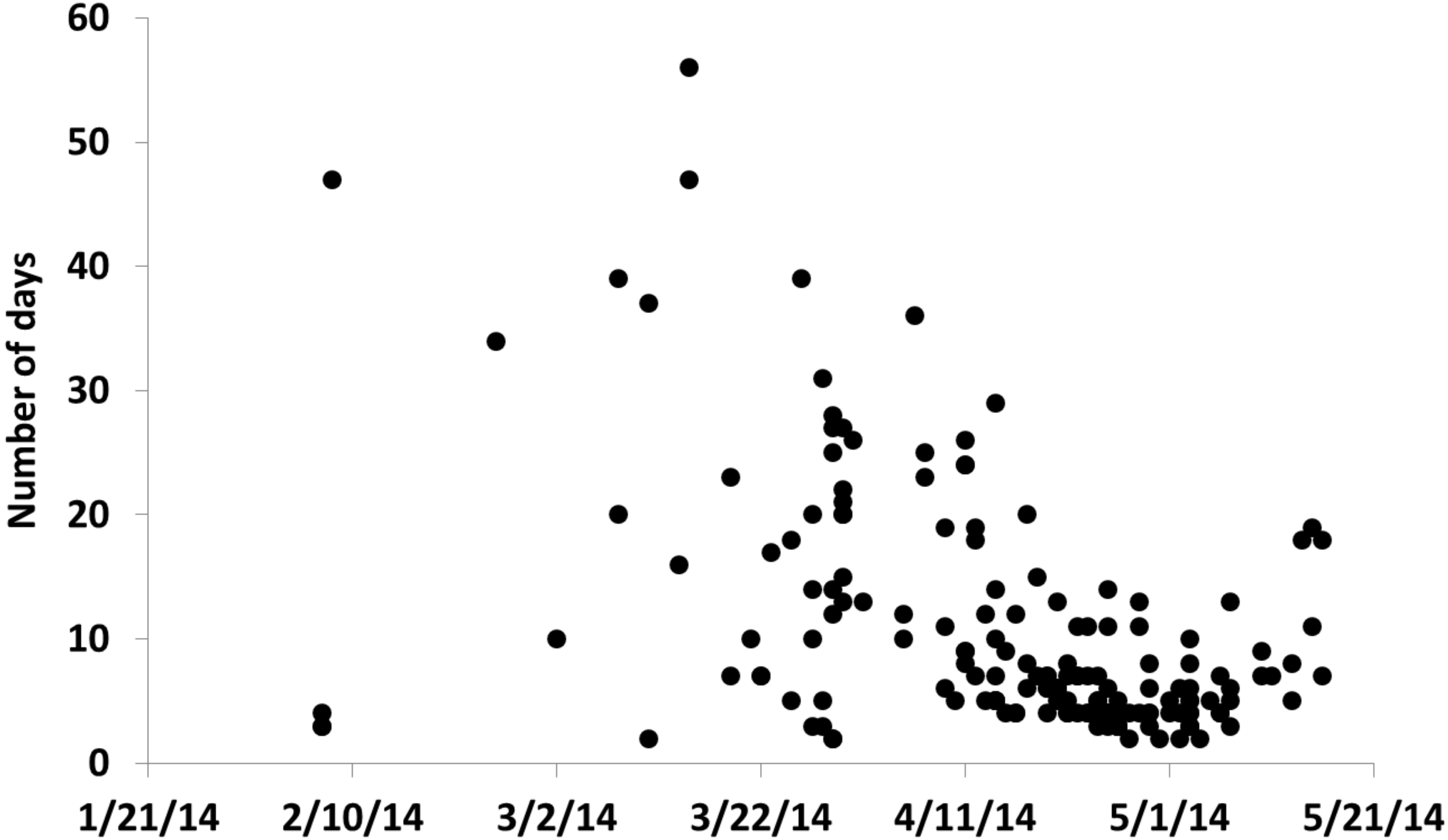
2013-2014 PIT Tag Detections at Upper Willow Array



2013-2014 PIT Tag Detections at Lower Willow Array



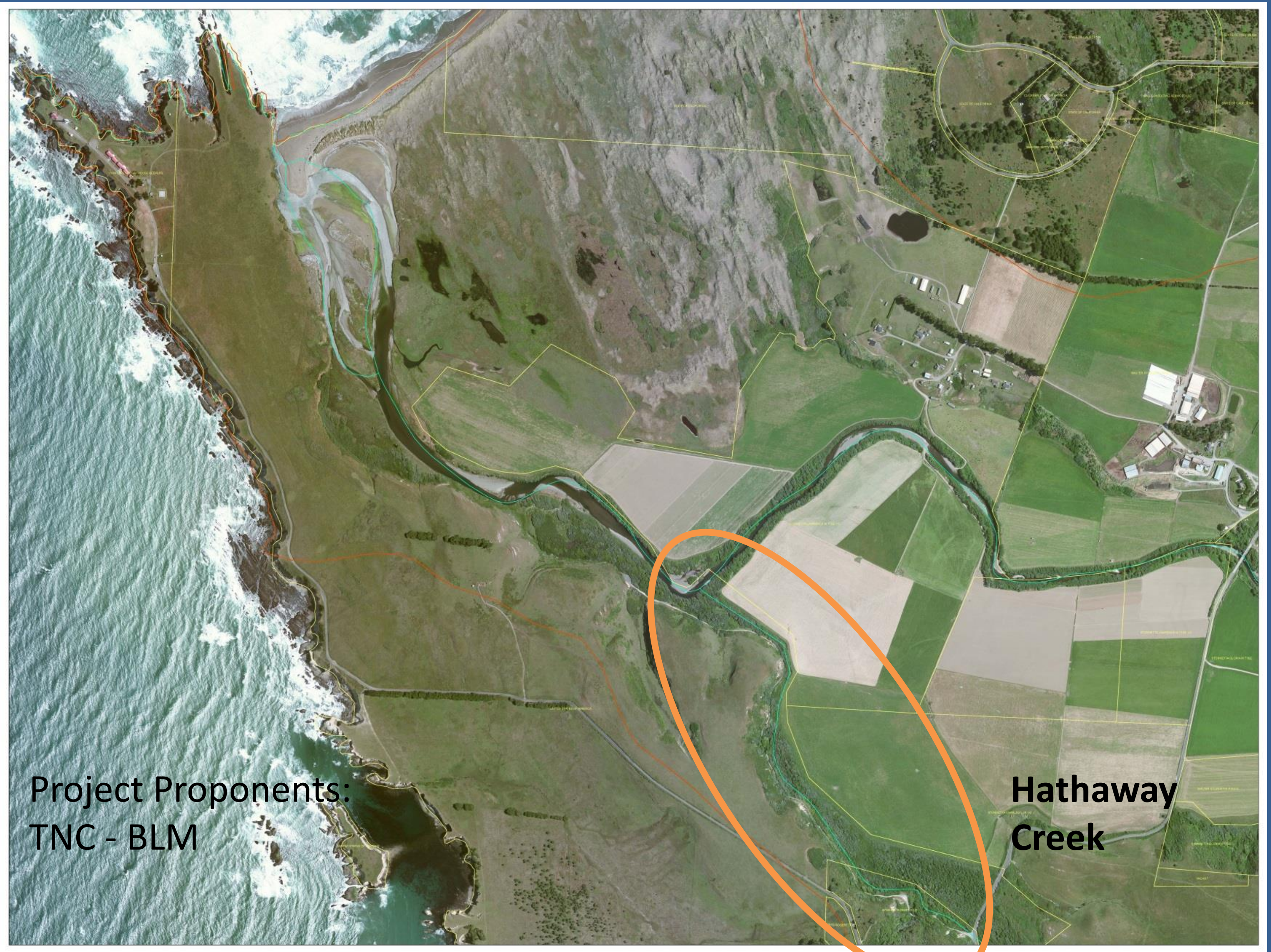
Number of days between detections on upper array and lower array



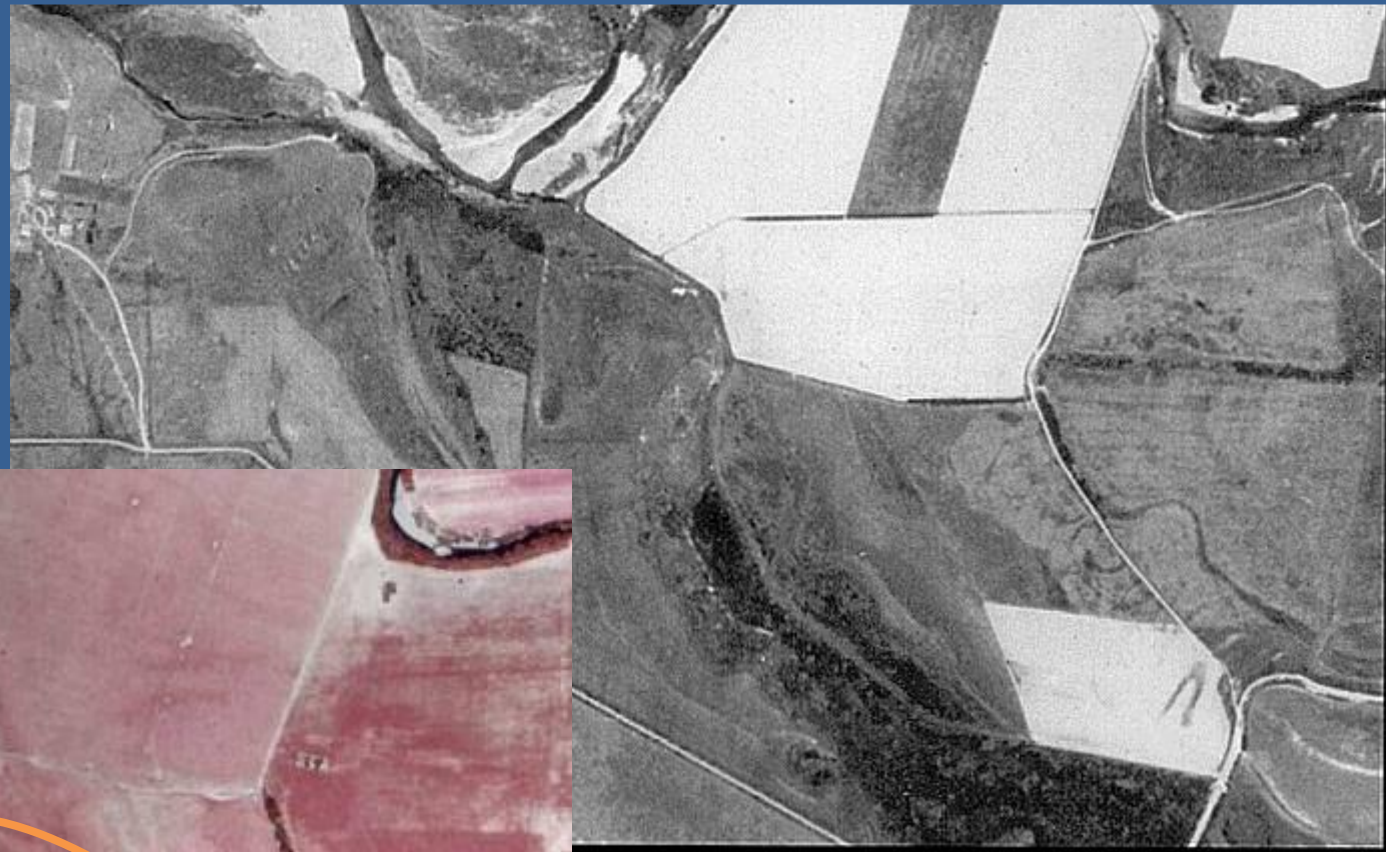
Answers after 3 years of Monitoring Willow Creek

- Are there connected channels through the wetlands? **Yes**
- Will adult fish be able to find their way up? **No problem**
- Will juveniles get lost on the way out? **A few**
- Will juveniles choose to rear in the wetlands? **Likely in wet years**

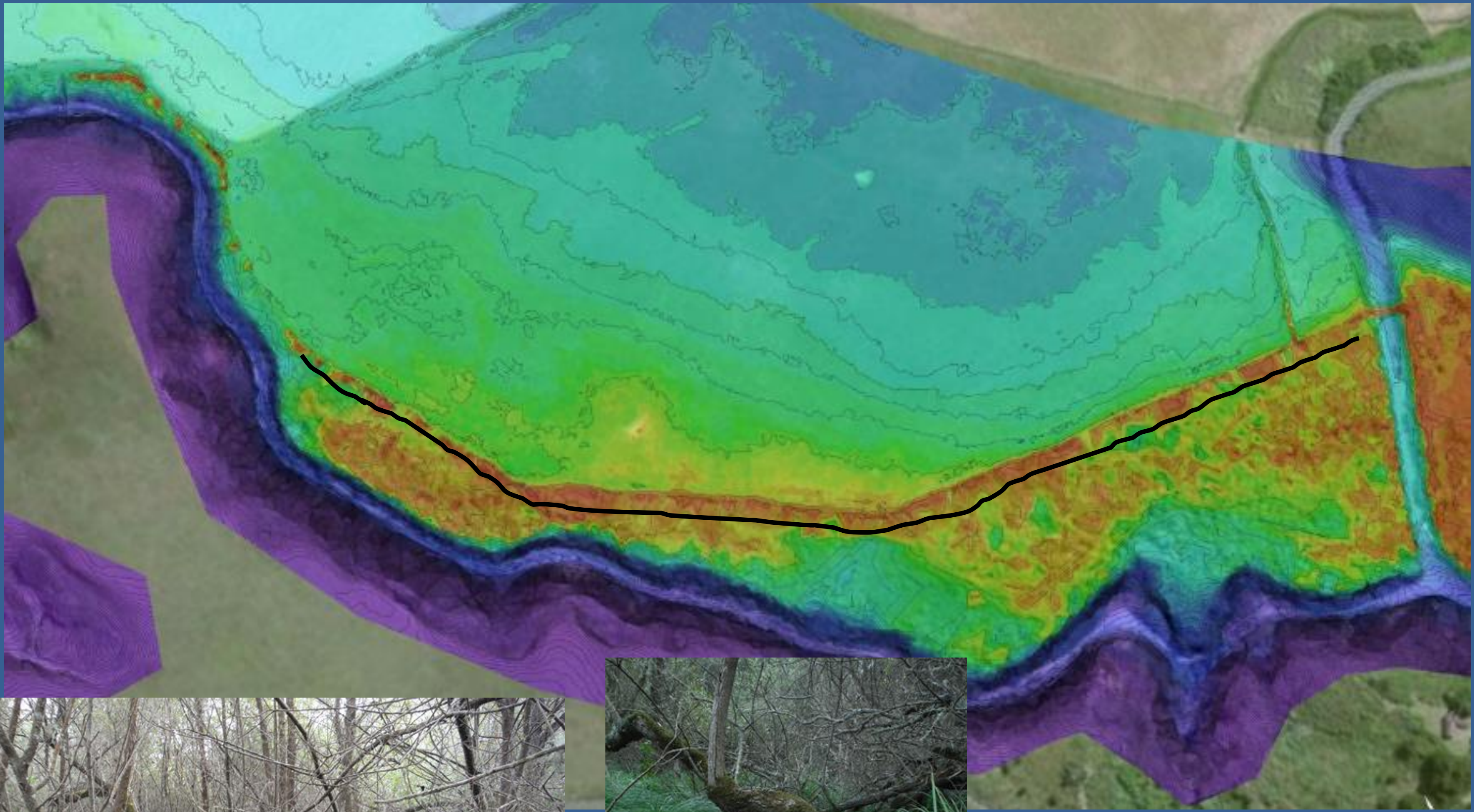
2nd Example: Lower Garcia River, Mendocino County



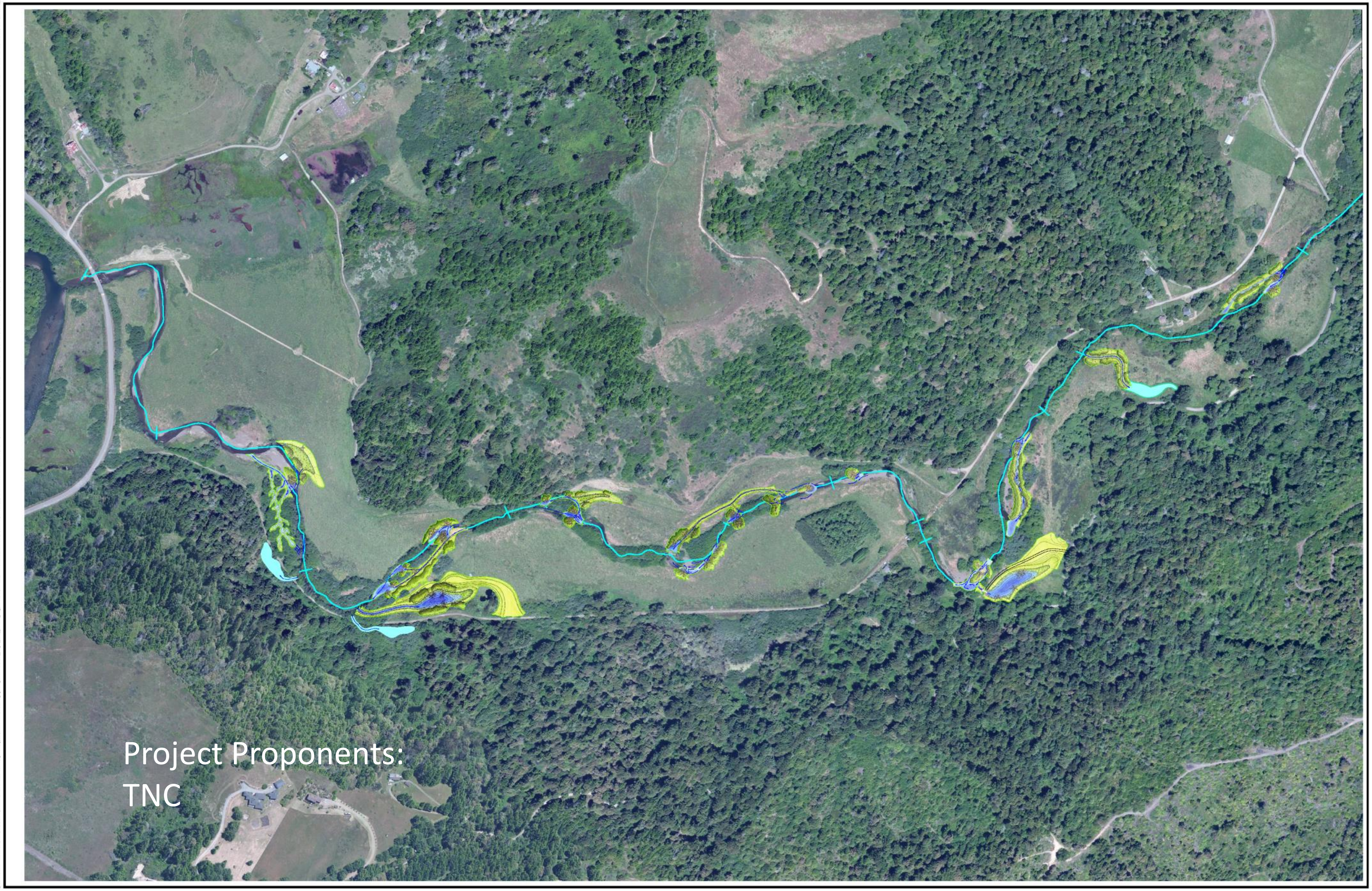
1942



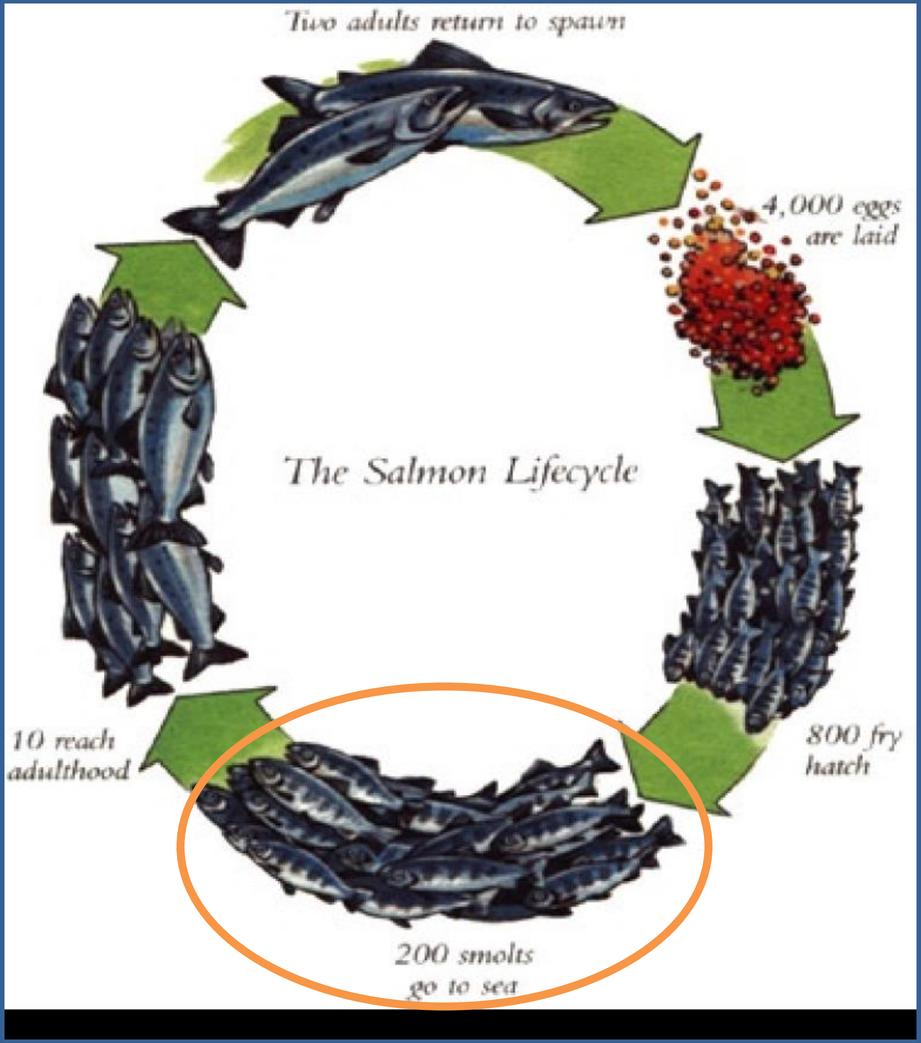
1992

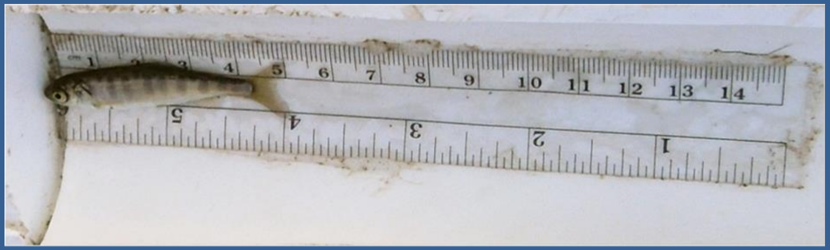


3rd Example- Ten Mile River, Mendocino County

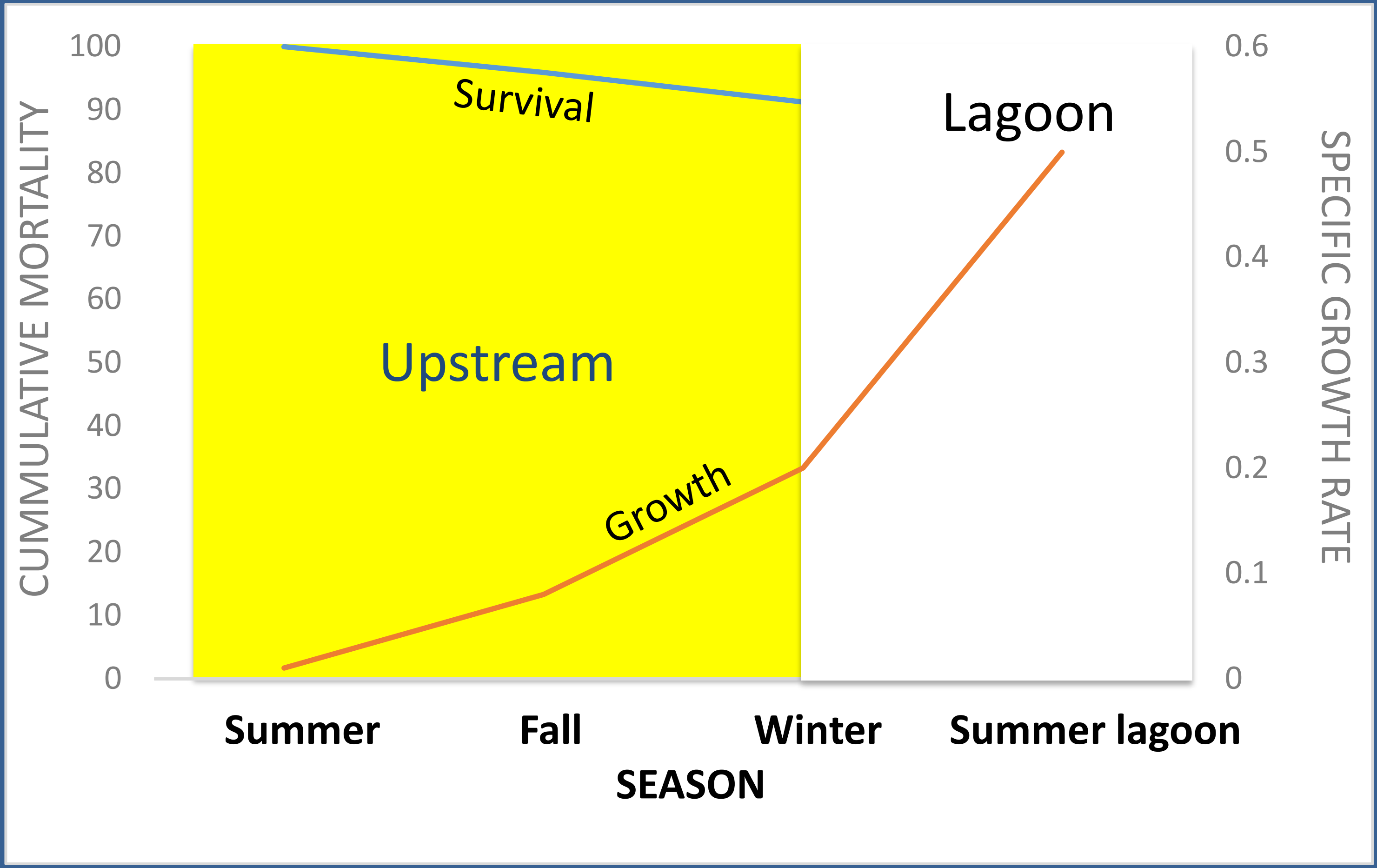

Project Proponents:
TNC

Salmonid Success is a growth and numbers game



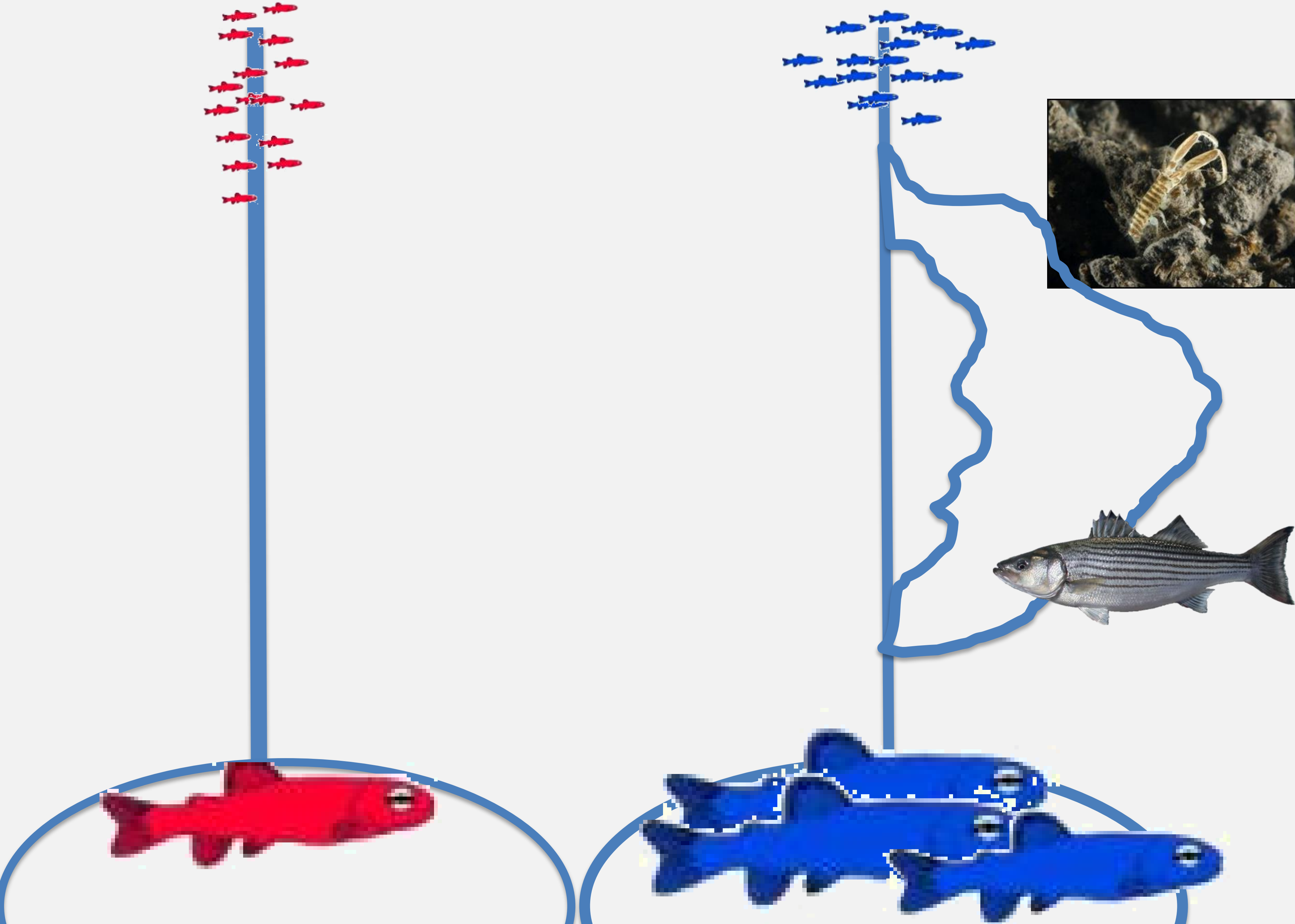


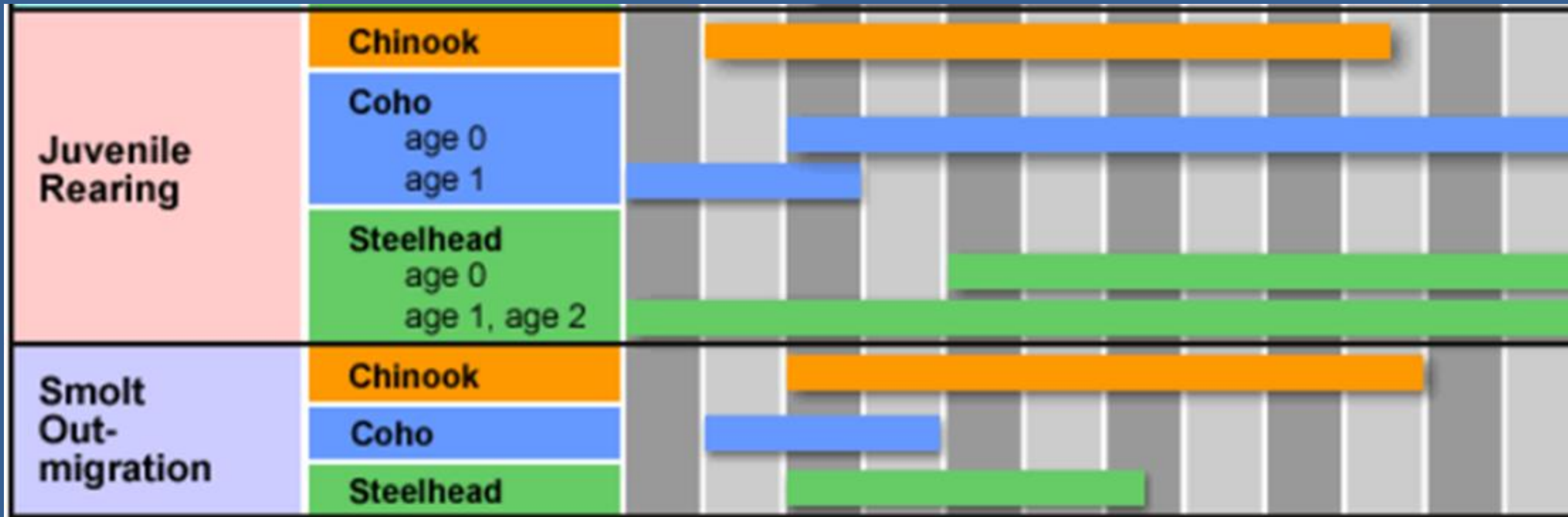
Survival and Growth by Habitat
Steelhead – Scott Creek



Courtesy of Sean Hayes, NMFS

Courtesy of Sean Hayes, NMFS




Juvenile Rearing
Chinook
Coho
age 0
age 1
Steelhead
age 0
age 1, age 2
Smolt Out-migration
Chinook
Coho
Steelhead