Robert L. Vadas, Jr.
(Robert.Vadas@dfw.wa.gov)
Washington Department of Fish & Wildlife (WDFW): Habitat > Wildlife & Fish programs

Long-term population response of Coastal Cutthroat Trout (CCT) to environmental fluctuations in a temperate-rainforest stream: hydrology, temperature, and invasive weeds & other biotic factors

Washington departments of Ecology (WDOE) & Natural Resources (WDNR)

National Park Service (NPS) & U.S. Forest Service (USFS), Olympic Region

Trout Unlimited (Olympia Chapter) & Coast Salmon Partnership

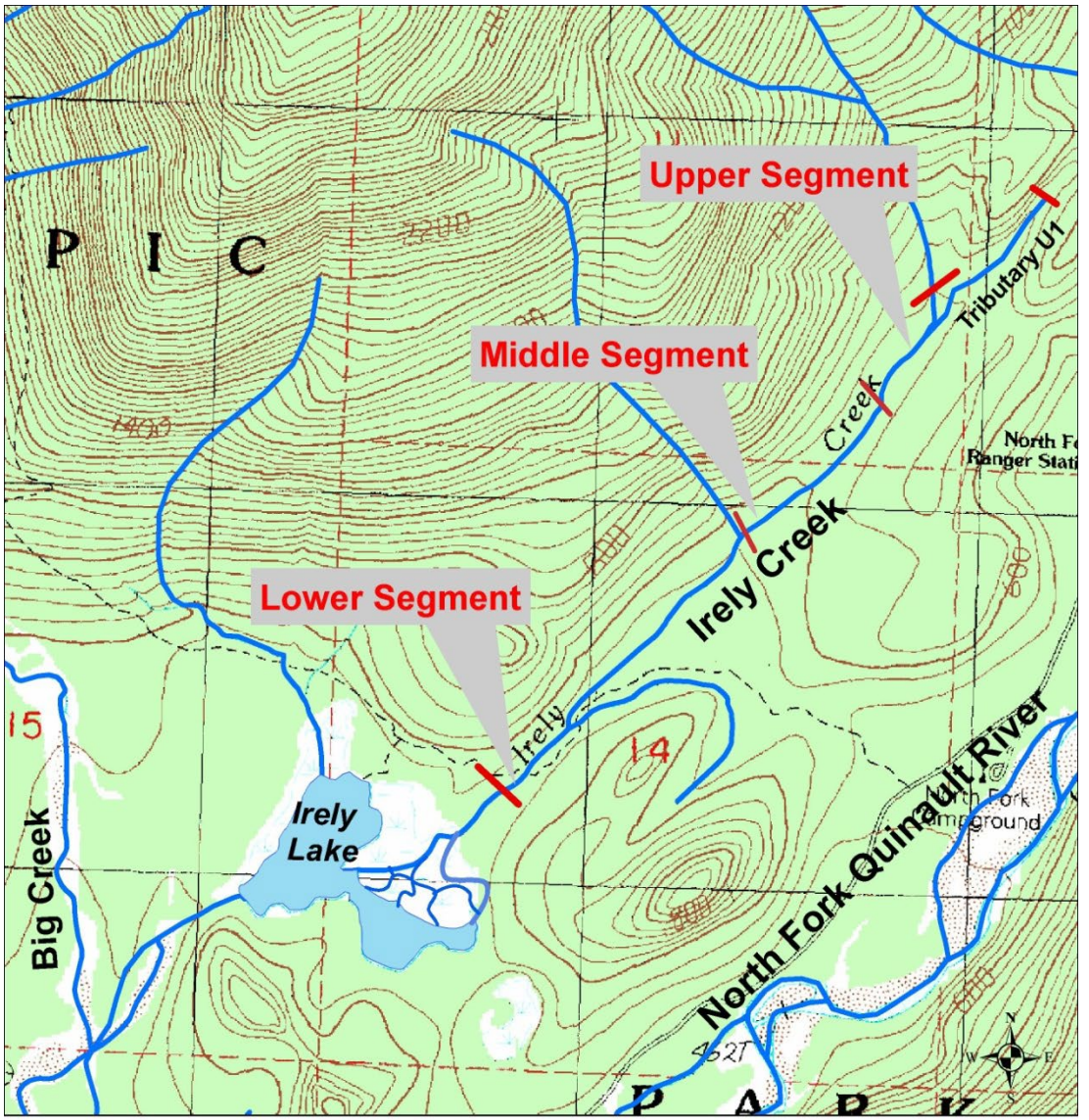
10,000 Years Institute (10KYI, Forks, WA)

Other volunteers ('trout groupies') & NMFS funds (initially)

Presentation assistance:
Timothy Quinn (WDFW-Habitat), Hal A. Beecher & Joanne P. Schuett-Hames (WDFW-retired), Jill Silver et al. (10KYI), Pat Crain (NPS), Alex D. Foster (USFS), Hal Michael (EWB), Dylan Glaser (U. Calgary), APR 30 2002 **& G. Marlantes (Centralia College)**

Study Area

2 main tribs. enter <u>Irely Lk.</u> on the east (Irely Cr.) vs. NW (unnamed crk.) shores, & there's a **lake outlet** to Big Cr.



Irely Creek
Olympic National Park
Washington

October, 2005

0 600 1,200 2,400 Feet

Can We Predict Future Trout-Run Size?

* **We began intense microhabitat-HSI work on an abundant CCT run** (in only 1 of 2 lake tribs.)
  # Unnamed trib. (dubbed 'Campout Cr.') w/ stream order (SO) = 2 *(see right photo)*
    - Salmonid rearing only (D/S)
  # SU/FA trout angling in Irely Lake (C&R) for *adfluvial run*
  # Main trib. Irely Creek (mouth SO = 3, headwaters = 2)
    - *Trout-run decline* after lake dry-out in 2002 (SU/FA)
    - Along w/ (since '02) *reed canarygrass (RCG)* influx D/S & in lake (bare mud then)

Can We Predict Future Trout-Run Size?

- Also expanding *beaver dams* (which provide pool refuges for fishes but may spread RCG)

Developed multiple-regression models for CCT escapement based on 2001-'12 data

- Using physical & biotic variables of potential importance for future-run size (*cumul. impacts?*)

Follow-up surveys of trout redds during 2015-'23 (for model testing)

Cont'd redd surveys (future)

- CCT recovery from *RCG removal* via lake-level &/ or water-quality benefits?
- *Out-of-kind mitigation* (for hydrology) = field expt.

Can We Predict Future Trout-Run Size?

*** 2001-'18 "natural expt." of CCT ecohydrology**

Hydrologic variables assessed

- Lake level, streamflow, & Forks (WA) precip'n
- Snowpack in the Olympic Mountains

Forage-fish sampling via stream > lake netting & snorkeling (especially during SU/FA)

- Few fish spp. in these headwaters (but *other trout spp.* in lake)

Can We Predict Future Trout-Run Size?

* **Stream walks** to estimate salmonid escapements
  - Coho carcass/adult (CAC) counts (esp. *late WI*)
    # Mainstem & 5 larger tribs.
    # Some yrs. w/ earlier &/or later counts (for full-escapement estimation)
  - Trout-redd counts (adults rarely on nests) in SP (*Vadas et al. 2016*)
    # L, M, & U mainstems (the former w/ long-term *beaver dams & RCG*) & trib. U1

Cutthroat Trout Rearing

- Dominant adult fish in Irely Lk.
- Subdominant in Irely Cr.
  - *YOY* prominent here
    - ~2 mo. incubation
  - *Juveniles* common to age 2+
  - *Adults* uncommon
    - Resident fish the only spawners after SU/FA drought years (natural selection)?
- *Run size uncorrelated* w/ that for sea-run coho there (in the same year) via different life histories

Cutthroat Trout Escapement

- **Spawning in mainstem & 1 headwater trib. (U1)**
  - Field methodology *(Vadas et al. 2016)*
    - 2001-'02 (full counts before lake dry-outs, but *spatial extrapolation* upstream above the 'big bend')
    - 2003-'12 & 2015-'23 (usu. only 2 peak-season counts in later years, requiring *temporal extrapolation*)
      * But 2007 fully counted & 2009 needed spatial extrapolation (given flood-turbidity problems D/S & incomplete walks U/S)
    - Estimated *adult coho:cutthroat ratio* during 2001-'12 was 1.3-60.5 (median 8.9)
      * Above *expected, healthy ratio* of 4:1 for PNW streams)

Cutthroat Trout Spawning

– Main-channel > side-channel habitats
  - Late peak; early > late April (mid-late March to mid-early May spawning)
    * Vs. WDFW's SASI report for periodicity b/c stream-specific T_w matters *(Vadas et al. 2008; cf. Vadas 2006)*
    * 0.5-1.5 mo. when T_w = 4-10^{O}C (peak ~6^{O}C) for 2010-'18 (coldwater-oriented)

– Less commonly seen above larger (0.9-1.5 m), temporary hydraulic drops that form in upper segment *(unlike coho)*
  - Hence, such partial barriers still required spatial extra-polation *(Vadas et al. 2016)*

Summer/Fall Ecohydrologic Dynamics

(esp. 1-y time lag suggests adult kills; *Vadas et al. 2016*)

- **<u>Full lake dry-out</u> (creek intermittent far D/S in both mainstem & tributary U1)**
  - # 2002-'03 (two years in a row) & 2009
    - * Impacted 2003-'04 & 2010 CCT runs
    - * Then trout-run recoveries (2005 & 2011-'12)
      - *Coho recovered* during 2010-'11 (also + for CCT)

Summer/Fall Ecohydrologic Dynamics

- **<u>Semi-dry</u> (lake reduced, creek low)**
  - # 2005-6 (two years in a row, w/ *full dry-out* in 2006)
    - * Impacted 2006-'07 trout runs, then 2008 recovery
  - # 2010 (two years in a row, w/ *full dry-out* in 2009)
    - * Impacted 2009-'10 trout runs, then some recovery (2011-'12 & likely thru 2014 based on modeling)
  - # 2000 (three years in a row, w/ *full dry-out* in 1998)
    - * Likely impacted 2001 trout run
    - * But ~K-level run of 2002
      - Nearest to *carrying capacity (K)*

Summer/Fall Ecohydrologic Dynamics

- Cutthroat-run escapement (adult-run size)

Estimated as 2*redd count (assumes 1:1 sex ratio & that all adults spawned)

Decreased by 3.5-8 times after lake dry-outs (midpt. 5.75)

Increased by only 2-3 times after wetness returned (midpt. 2.5)

Hence, a general run drop during 2001-'19

* But better trout runs for 2011-'15 & 2020-'21 (*from better lake levels*)

Summer/Fall Ecohydrologic Dynamics

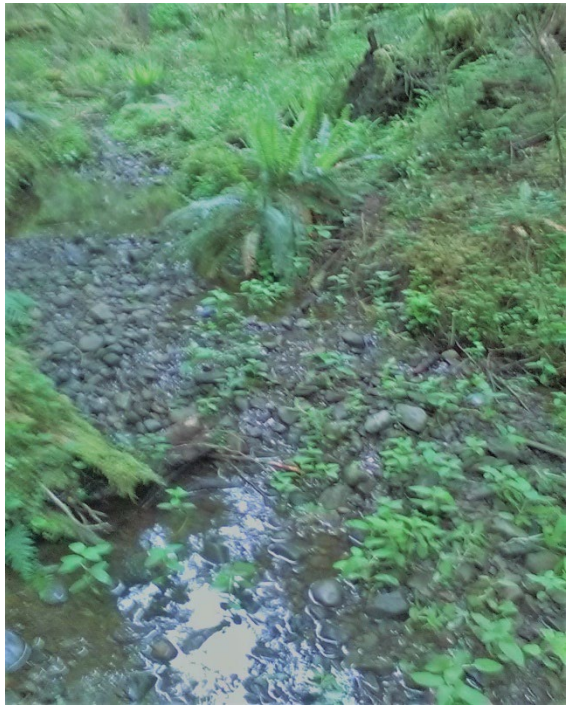
- Statistical analyses (on transformed data)

Spearman & Pearson *correlation (also factor) analyses*

* Clustering (redundancy) of environmental variables

Stepwise, linear, & curvilinear *regression analyses*

* Future prediction of trout-run size



Trout-Environmental Relationships

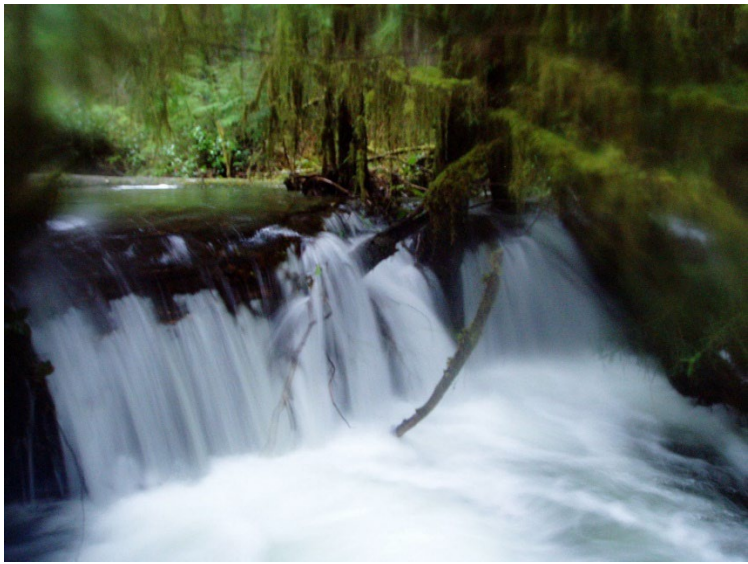
- Unimportant variables (NS, inconsistent effects)

Present-year physical (flow/thermal) & food (coho-abundance) conditions

* *Minor sea-run effect* for CCT (at best)

Some last-year physical conditions

* *Hydraulic-drop "barriers"* in the upper mainstem (sieve-like &/or w/ side-channel passage)
  - Spawning habitat rarely limiting
* *Flood-scour impacts* (during & after trout spawning)
  - Flood protection in forested headwaters



Trout-Environmental Relationships

- Important variables (final multiple-regression model)

 # Hydrology (short time lag = landlocking)

* Cumulative (drought-related) impacts (- effect)

- Across years (even though *preceding year* was a strong effect *[cf. Vadas et al. 2016])*

 # Cumulative thermal (peak CCT-spawning) variable

* Last > present year index (coldwater benefits) (- effect)

Trout-Environmental Relationships

- Important variables (cont.)

 # Last-year biotic (density-related) variables (mostly beneficial; *minor curvilinearity*)

* Cutthroat escapement (forecast'g)
  - Weaker (likely *Beverton-Holt*) density dependence (- effect)

* Food abundance (coho salmon)
  - *Late-winter* carcass/ adult abundance best (+ effect)
  - Via *flood scour* that moved food D/S to Irely Lk. or beyond?

Best Multiple-Regression Models

- Monotonic equation

 # Best lake model is CONSEC-E

* Threshold lake level for (-) impacts on trout
  - Drier (semi-dry/dry) = +1 & wet yrs. = -1 pts.
* TROUT = A – (B_1*CONSEC) – (B_2*TROUT1) + (B_3*CAC1) (adjusted R^2 = 88%, realistic)

- Quadratic equations

 # "Goldilocks effect"

* TROUT = ±A – (B_1*CONSEC) – (B_2*CUMUL-T_W) ± TROUT1 ± CAC1 terms

 # "Best" lake model seems to be CONSEC-C

* Dry yrs. w/ the strongest effects
  - Dry = +1, semi-dry = +0.5, & wet yrs. = -0.5 pts.

Best Multiple-Regression Models

- Quadratic equations (cont.)

* As w/ monotonic model, explains net-downward decline of trout run during 2001-'21
  - In contrast to CONSEC-B (see below)

* Adjusted R^2 = 96% (but underestimated in 2013)

 # Best model for CONSEC-B

* More-symmetric dry- vs. wet-yr. effects
  - Dry = +1, semi-dry = +0.5, & wet yrs. = -1 pts.

* Adjusted R^2 = 88%, but run overestimated in 2013)

Best Multiple-Regression Models

- Quadratic equations (cont.)

 # Best model for CONSEC-E

* Threshold lake level (again)

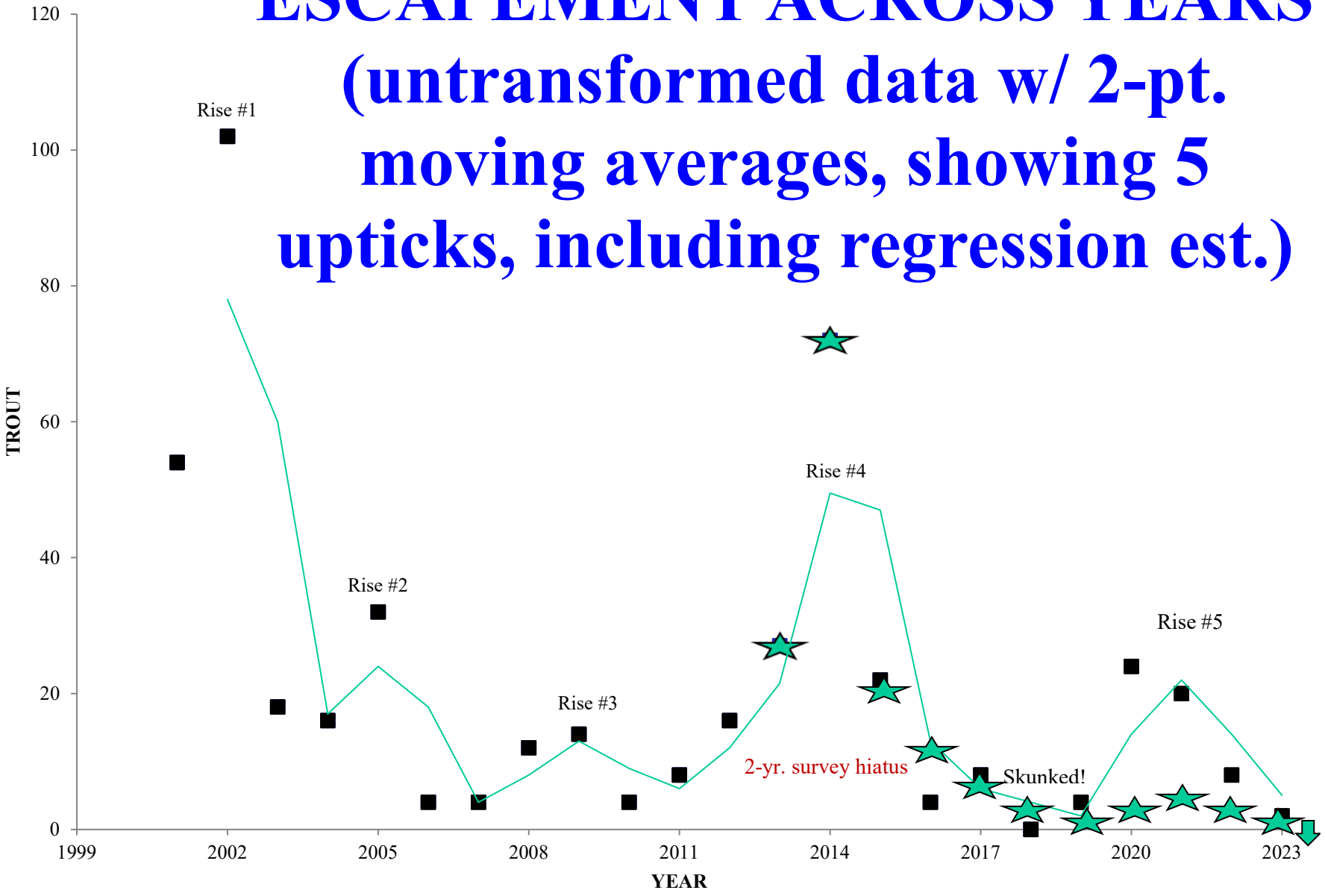
- Drier = +1 & wet yrs. = -1 pts.

* Adjusted R^2 = 90% (realistic, "warm porridge")

- 'Hybrid' approach (use of both CONSEC-E equations, most accurate)

Because monotonic & quadratic eqns. slightly under- vs. overpredicted trout escapement, resp., during *drier yrs*.

ESCAPEMENT ACROSS YEARS (untransformed data w/ 2-pt. moving averages, showing 5 upticks, including regression est.)



Best Pair of Multiple-Regression Models Predict Trout Extirpation by 2024

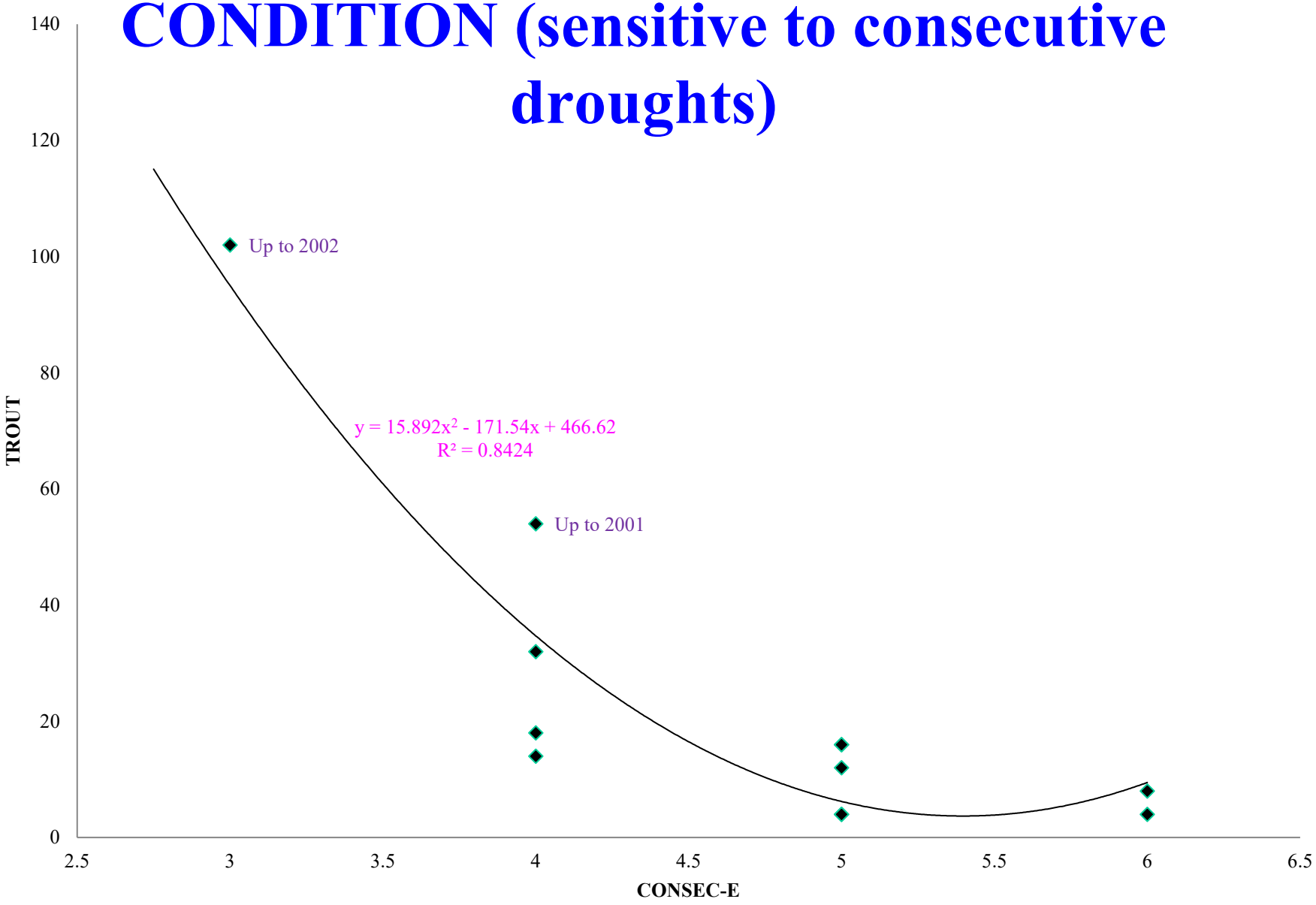
- Modeling was simplified

* Beyond 2012, assumed no trout data & consistent thermal & coho-carcass conditions

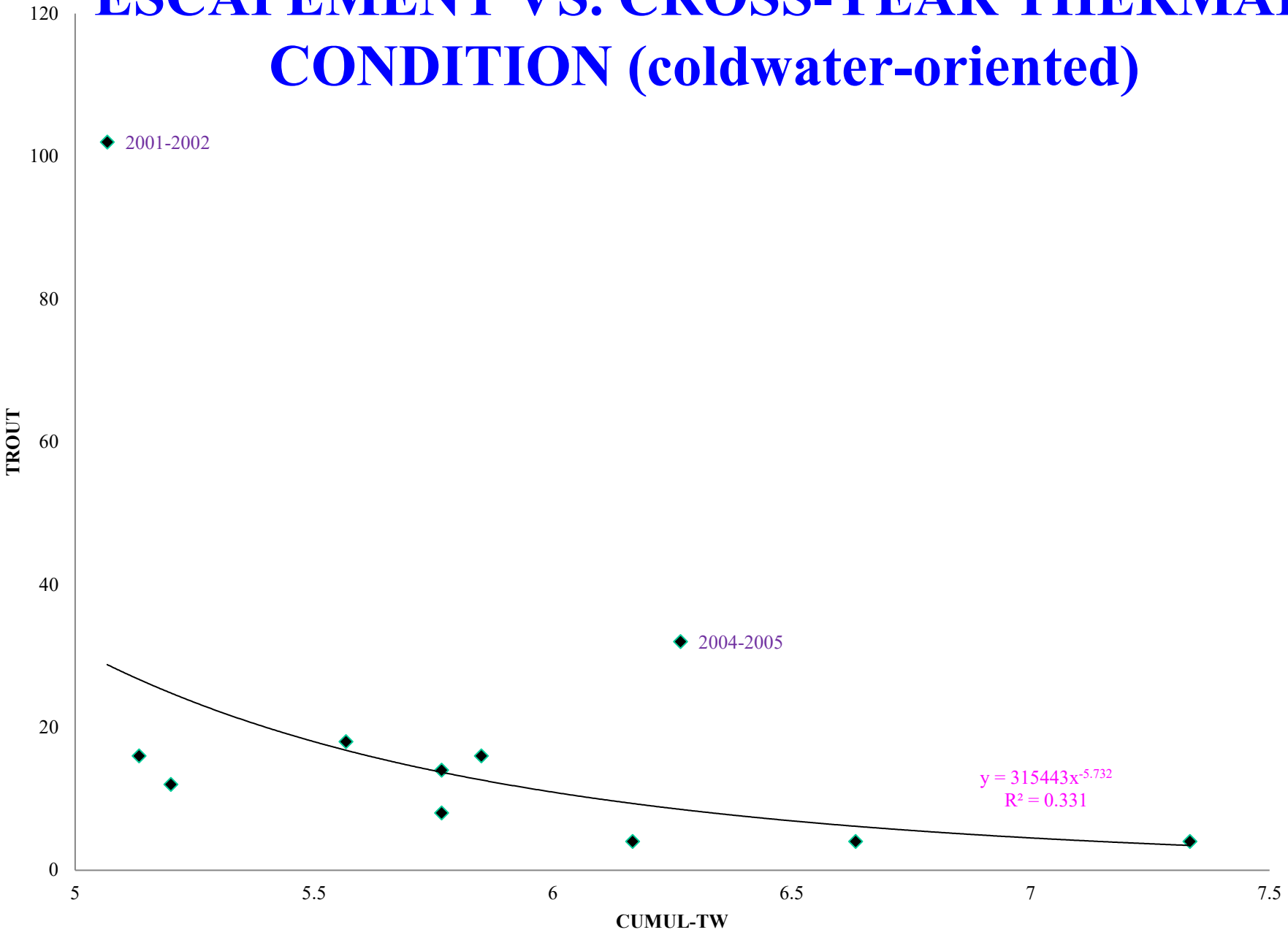
* But still predicted trout escapement well thru 2019 & OK qualitative trend thereafter

* Weirdly high runs of 2020-'21 (when *redd/fry data* were collected) could be sea-run influx &/or good non-hydrol. conditions)

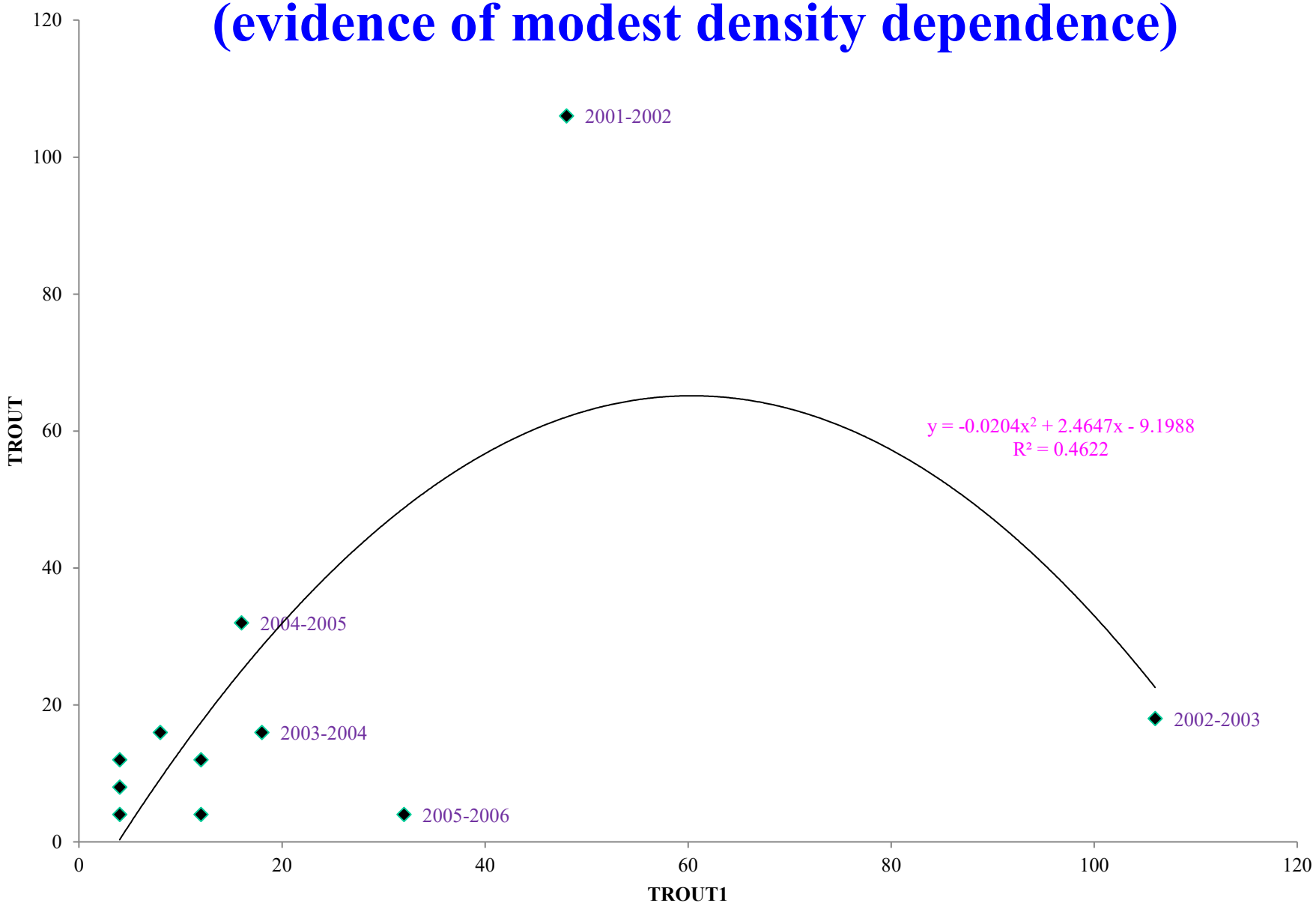
ESCAPEMENT VS. CROSS-YEAR LAKE CONDITION (sensitive to consecutive droughts)



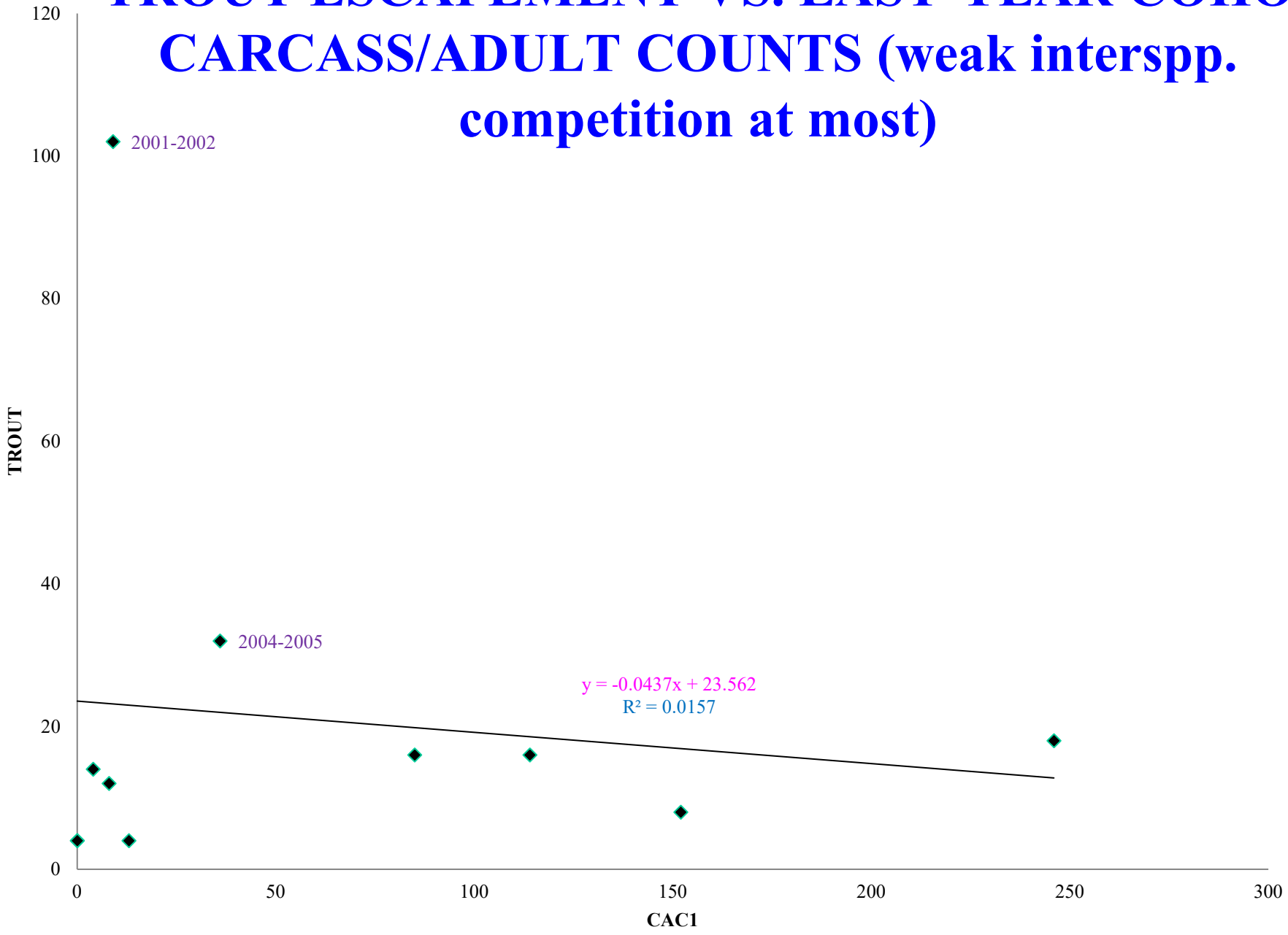
ESCAPEMENT VS. CROSS-YEAR THERMAL CONDITION (coldwater-oriented)



PRESENT- VS. LAST-YEAR TROUT ESCAPEMENT
(evidence of modest density dependence)



TROUT ESCAPEMENT VS. LAST-YEAR COHO CARCASS/ADULT COUNTS (weak interspp. competition at most)



Effects of Warm-Weather Dry-Outs: 1998-2000, 2002-'3, 2005-'6, & 2009-'10

- Irely Lk. often dries out down to middle Big Cr.

Full dry-out has recurred over the last few decades

* Based on remote-sensing info during 1984-2012 *(Vadas et al. 2016)*
* Worse dry-outs since interdecadal-climate shift of 1999 *(oddly; global-warming effect?)*

Dying sculpins, crayfish, & dragonfly nymphs there

Hence, cutthroat a climate-sensitive sp. *(cold-adapted)*

* Despite its *groundwater preferences* (i.e., relatively low spawning flows)

Effects of Warm-Weather Dry-Outs: 1998-2000, 2002-'3, 2005-'6, & 2009-'10

- **<u>Possible large-fish refuge</u> in flatter, deeper section near Irely Lk. (pool/beaver dominated)**

Immature coho & cutthroat of various sizes in lower mainstem of Irely Cr.

<u>Perennially flowing</u> in most mainstem reaches (but w/ some *residual pools* D/S)

Loss of <u>trout-fishing action</u> of 1990s

Effects of Warm-Weather Dry-Outs: 1998-2000, 2002-'3, 2005-'6, & 2009-'10

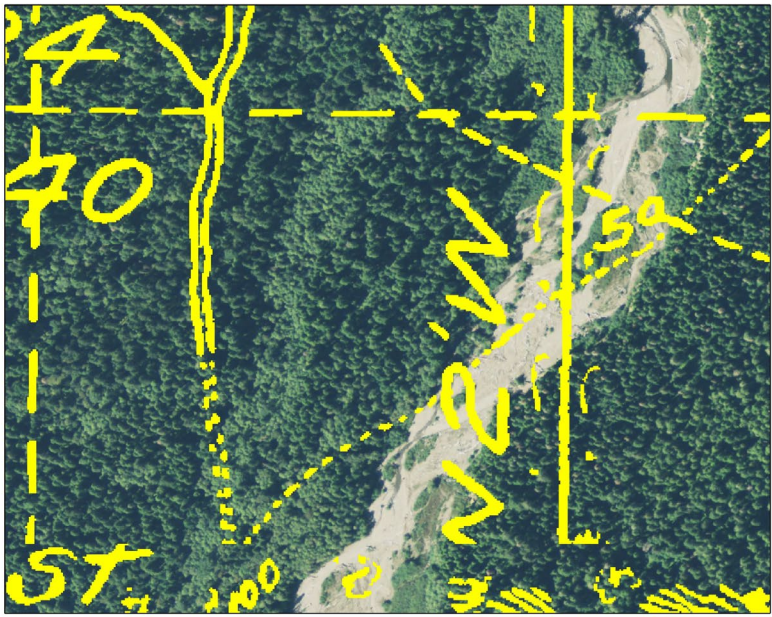
- Middle Big Cr. (long-term, intermittent fish passage via large-rock "sieve" effect)

Hyporheic flow during non-winter months (*flood scour*)

* Unlikely refuge *(until now via Irely Lk. outlet sedimentation?)*

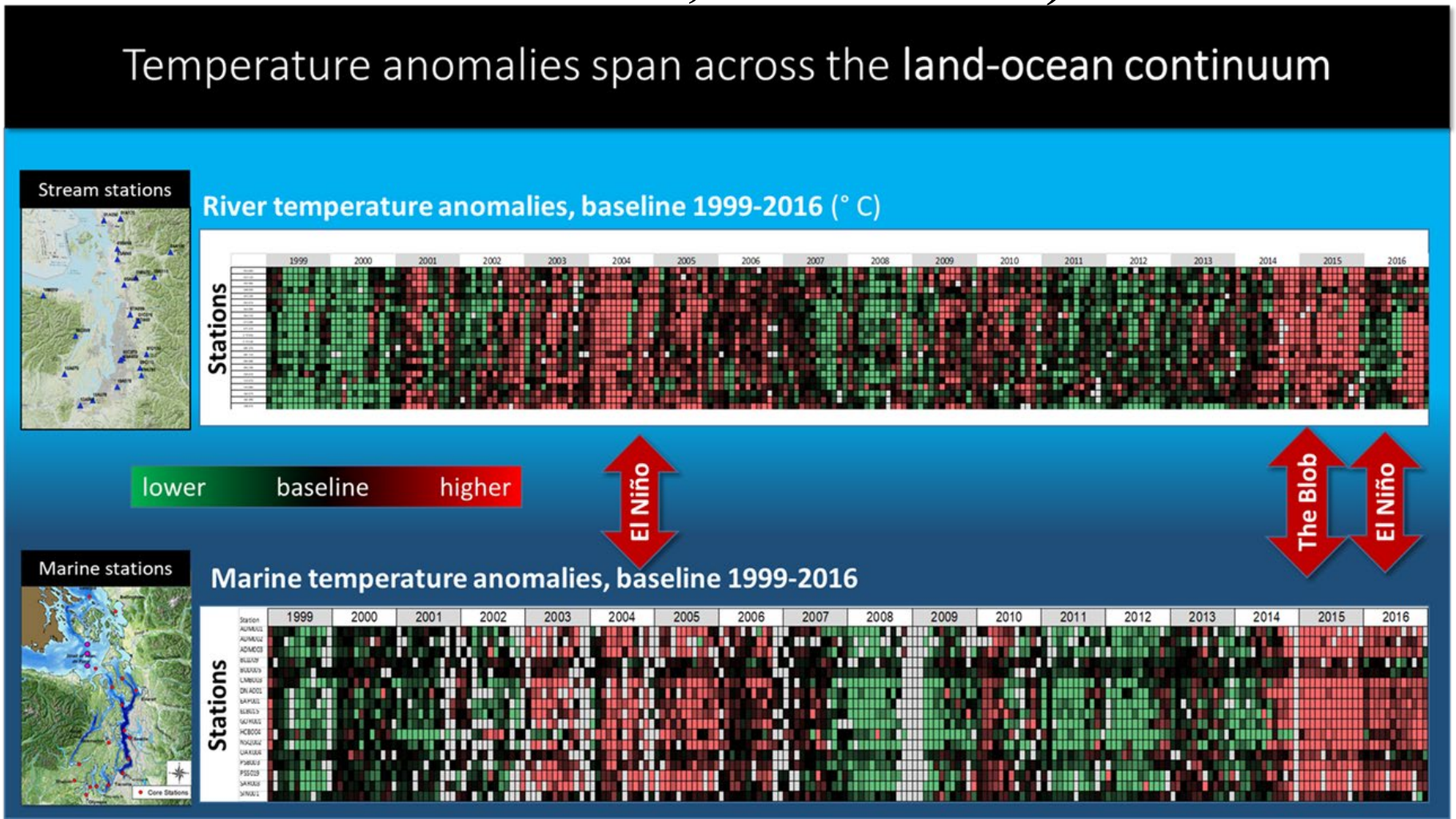
But 4 *salmon spp.* spawn in MBC (at least D/S there)

Well-forested watershed likely compensates (allowing *salmonid persistence*)



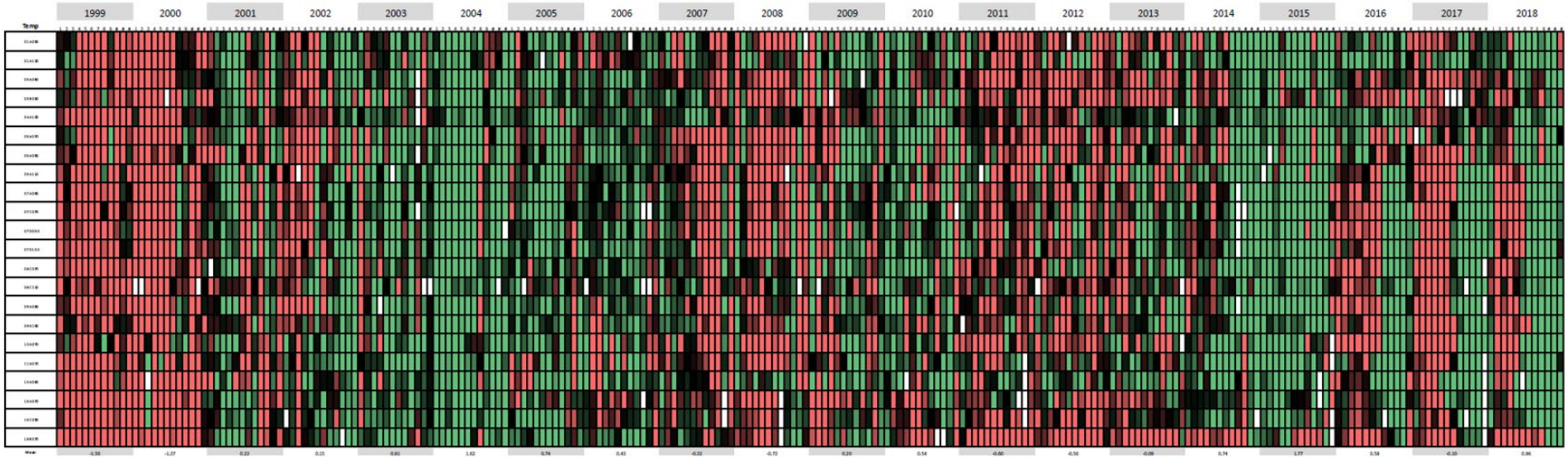
Biophysical Conditions Since 2015

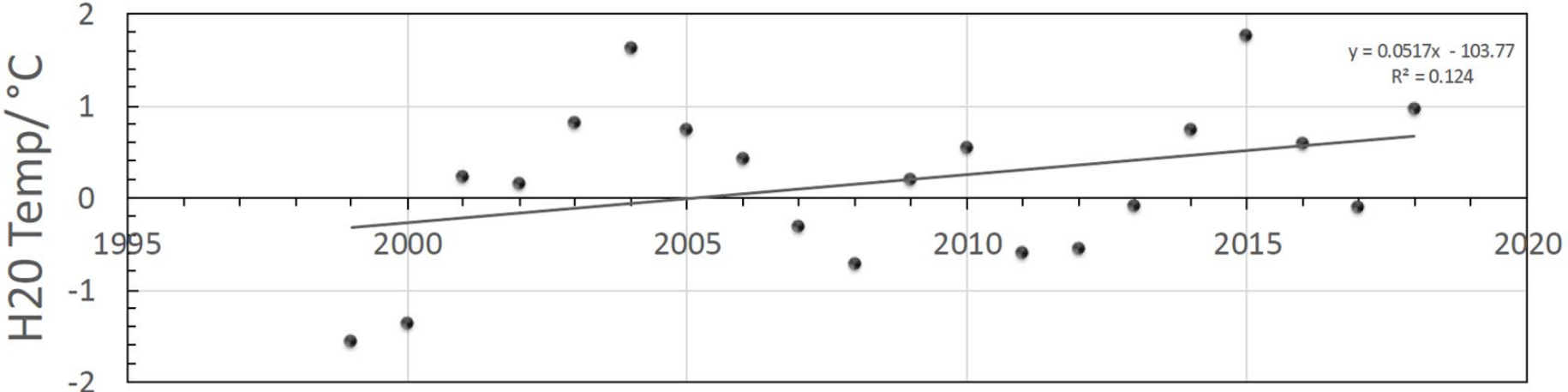
(major drought via El Niño/blob impacts, as portrayed by WDOE thermal data for Puget Sound, c/o WDOE; red is warm)



Biophysical Conditions Since 2015

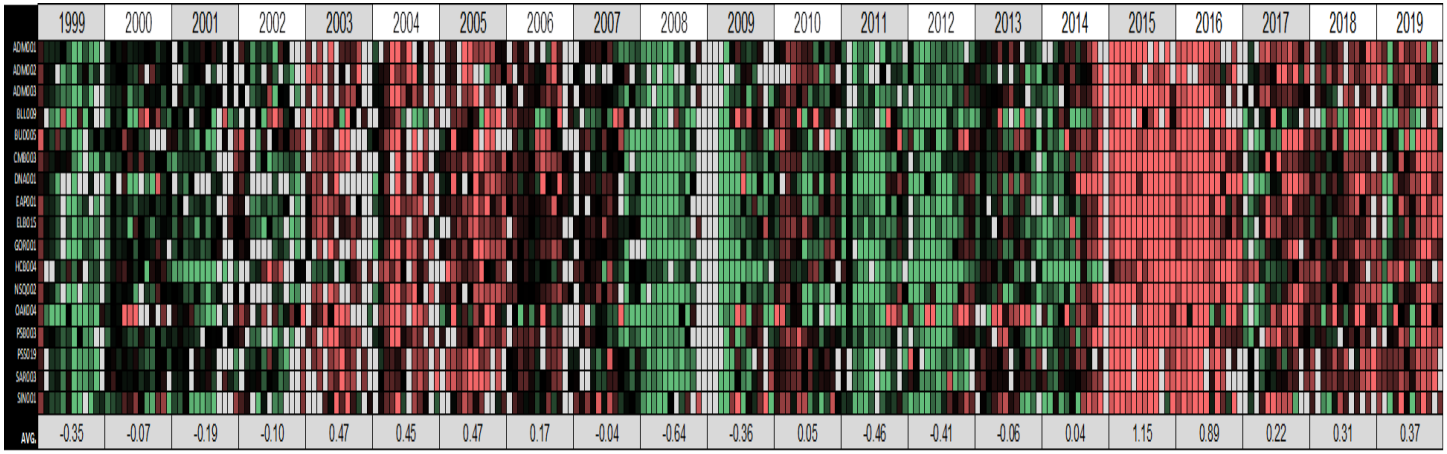
WDOE, Puget Sound T_w - riverine anomalies & trend, 1999-2019 (°C); green is warm

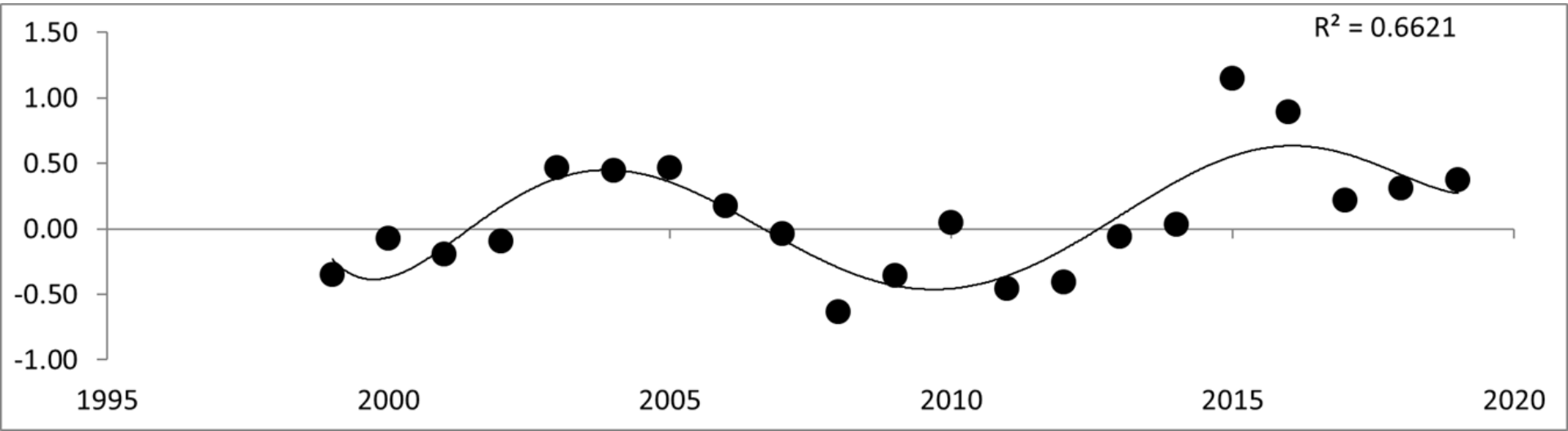




Biophysical Conditions Since 2015

WDOE, Puget Sound T_w – estuarine anomalies & cycles, 1999-2019 (°C); red is warm





Irely Lake - 2015 Drought

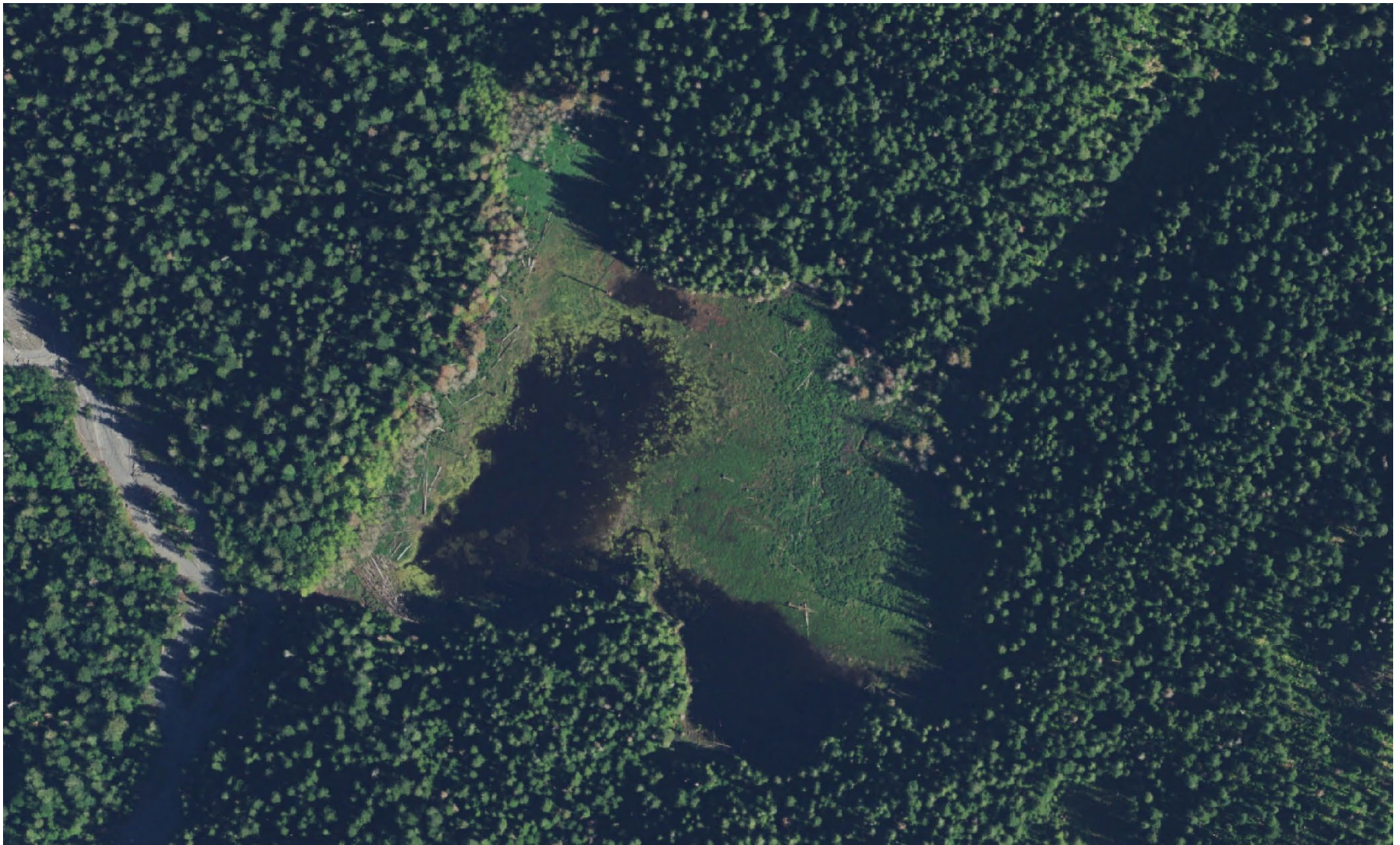
(<u>Aug. dry-out</u>, showing bare & weedy [esp. RCG] areas that reflect depth trends)

Irely Lake - 2015 After Rain

(Sep. full, showing exposed native plants > RCG)

Irely Lake - 2017 Post-Blob

(Aug. < full, showing exposed RCG along shores)



Biophysical Conditions Since Major Drought of 2014-16

- **Moderate trout escapement in 2015**
  - # Somewhat better than for last survey of 2012
    - * Likely better lake levels for the 2-yr. sampling hiatus (but not 2014 *[Marlantes et al. 2014, 2015]*)
- **Irely Lk. w/ full dry-outs during 2014-'16**
  - # So escapement dropped after 2014, but w/ some trout recovery recently (in 2017 & 2019-'21, the latter after lake >> crk. RCG control)
    - * Will estimate missing CARC data for *coho* (perhaps via late-winter flows for inmigration)

Biophysical Conditions Since Major Drought of 2014-16

- Escapement nil (for 1st time) in 2018

Was incentive to start lake & D/S-lotic RCG control (seed removal/herbicide) *(NPS/10YKI)* & *plant removal* from lower section of middle Irely Cr. (vs. U/S spreading)

Warm conditions in 2017-'18, when lake prob. semi-dry

- *Food* (late-WI coho carcasses) at medium-low levels
- *Delayed trout spawning* in 2017-'19

Biophysical Conditions Since Major Drought of 2014-16

- More RCG-control & trout-redd work since 2019

Tougher for several yrs. via storm-downed snags (much from >1 decade ago)

Including air/crk. loggers (*USFS & 10KYI*) for T_w &/or DO

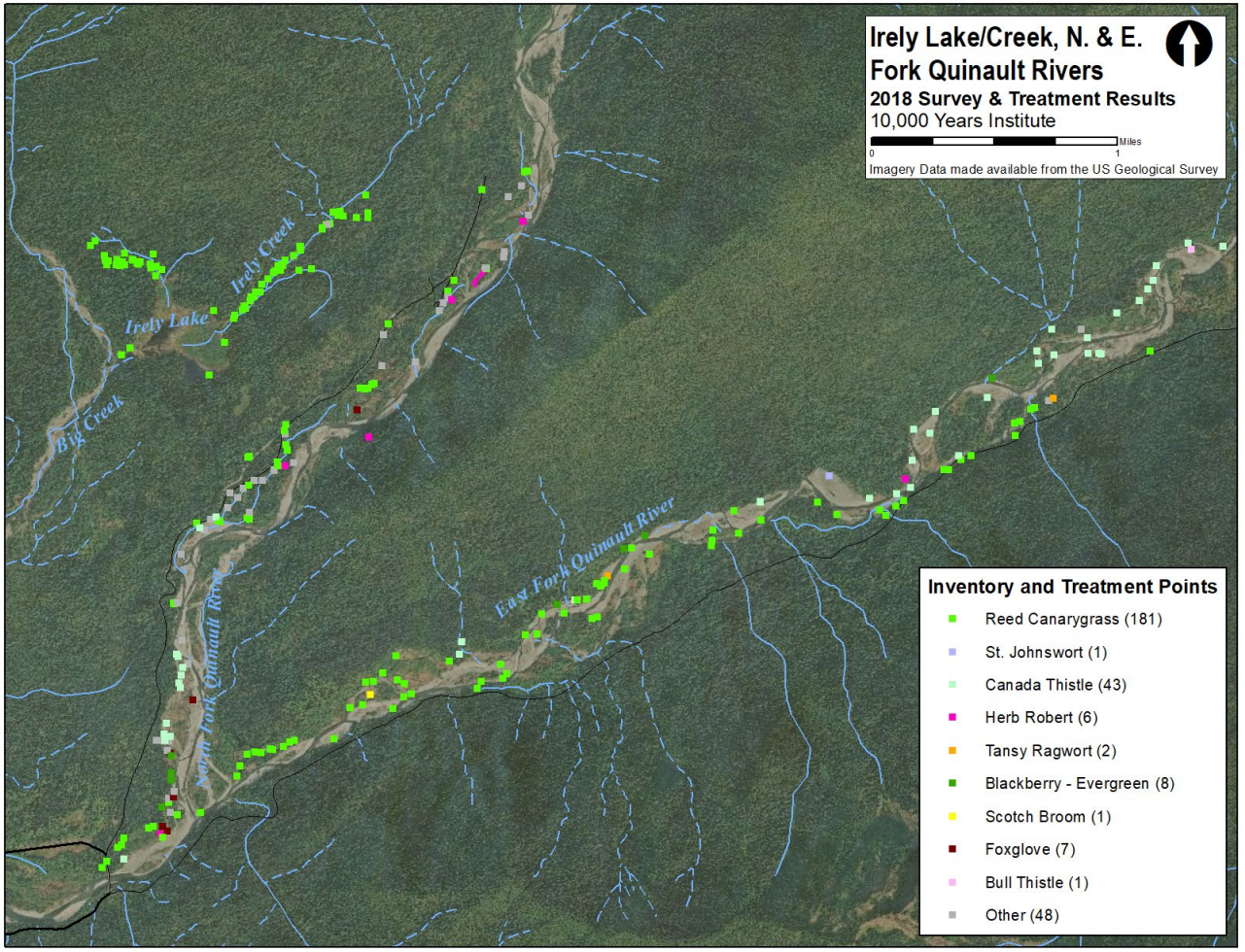
* To assess RCG-control benefits in lower Irely Cr.

Semi-dry Conditions during 2018

(w/ little trout recovery in 2019; but note the *native sedges & sweetgale* nr. the Irely Cr. outlet)

SU/FA 2018 - Start of Lotic Invasive-Plant (e.g., RCG) Inventory/Control Efforts

Spring 2019 - exotic velvet grass (but not invasive/allelo-pathic RCG) in the <u>upper half of Irely Cr.</u> (i.e., mainstem & 3 tributaries)

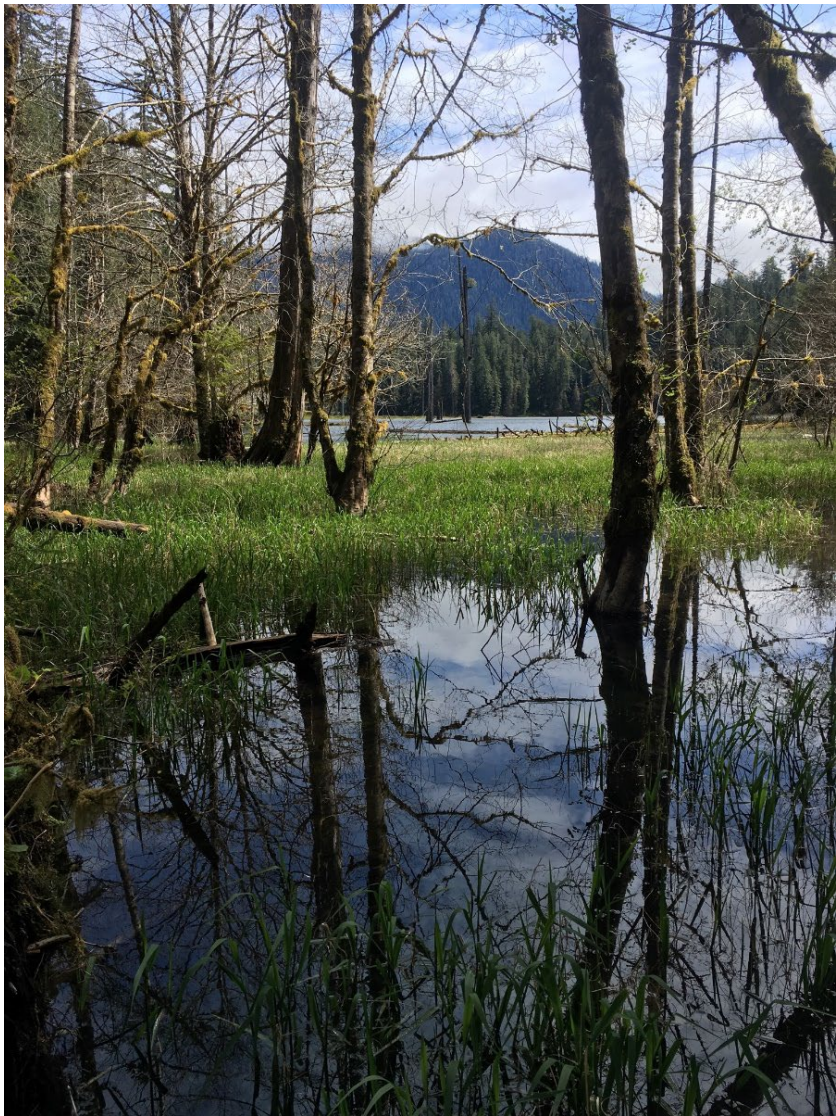


There & in N. & E. forks of the Quinault R.

Potential (lit.-based) RCG impacts *(10YKI 2019)*

(spring 2018 photos showed a very full lake, but would've needed summer/fall rains to stay full)

- **Channel (lake/creek) filling, hypoxia, & heating**
- **Creek flow/sediment transport**
- **Prey (zoobenthic) production**
- **Riparian succession (loss of native plants)**



2021 heat-dome drought *(10YKI)*

Only half of the counted trout redds had summer fry nearby, & the resultant 2022-'23 trout runs did drop

Conclusions

- Loss of iteroparous (repeat) spawning, so long-term decline of trout run *(lake/MDN down)*

  - Reproduction has recently failed, & >3 consecutive-drought yrs. (via "heat domes") could extirpate it (cf. Vadas 2003)

- Despite old-growth, temperate-rainforest conditions w/ high rainfall, existing water was limiting for CCT & COHO in the Irely Lake watershed (cobble/boulder sieve & RCG effects)

  - Additional water use from developed, headwater streams typically impacts salmonid-population viability

Conclusions

- Salmonid instream-flow needs quantified in lower Irely Creek via *PHABSIM studies* (unfinished modeling) in 2 reaches of this protected stream (i.e., constricted vs. alluvial sites)

- Joint riparian (e.g., RCG) & instream-flow management important for Pacific-salmonid protection in more-developed watersheds (e.g., Central/South Puget Sound)