Tutorial on Grand Canyon fish population dynamics and adaptive management

Carl Walters

A fundamental balance relationship in population dynamics

$$\begin{pmatrix} \text{Population} \\ \text{next} \cdot \text{year} \end{pmatrix} = \begin{pmatrix} \text{survival} \\ \text{rate} \end{pmatrix} \begin{pmatrix} \text{Population} \\ \text{this} \cdot \text{year} \end{pmatrix} + \text{New.recruits}$$

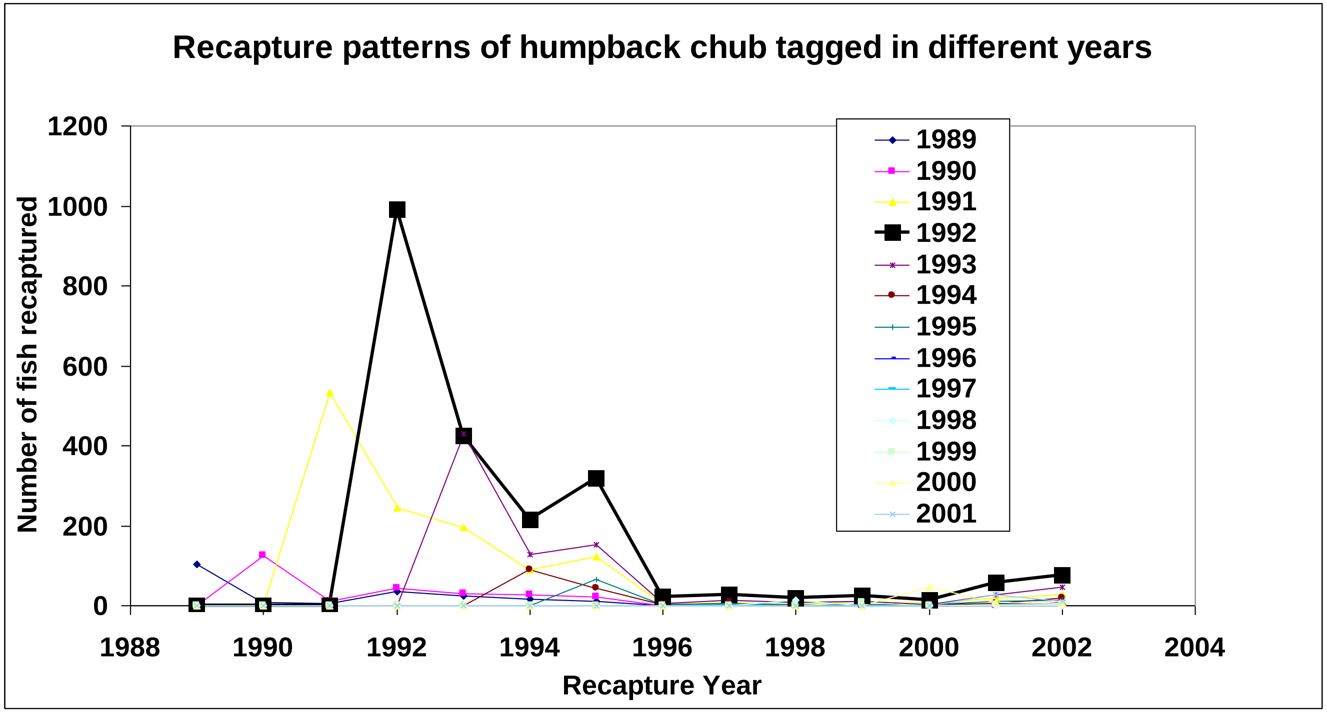
- This tautology tells us that prediction involves two key components:
  - Survival rate of fish present this year
  - Number of new recruits
- In most fish populations, survival rates are stable and predictable
- Recruitment rates are sensitive to environmental factors (habitat, predation, food), almost always involve density related changes in survival rates from egg to recruitment

How do we know survival rates are high and stable for humpback chub?

- Very large numbers of fish have been PIT-tagged since 1989, and we have recaptured those fish over the years
- Various methods have been applied to the data, all involving comparison of observed recaptures to predicted recaptures under different survival assumptions

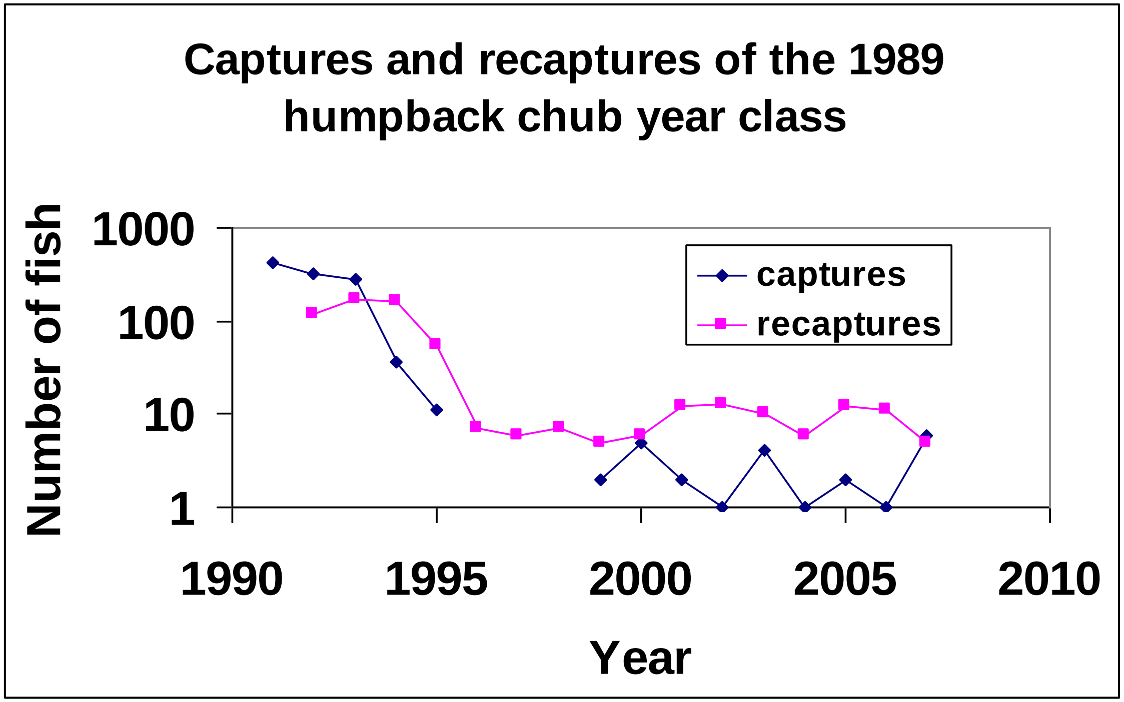
How do we know survival rates are high and stable for humpback chub?

- As of the late 1990s, we thought survival rates were relatively low, but then old fish “appeared” again when sampling was increased in 2000. This warned us of need to account for age and year effects in the data



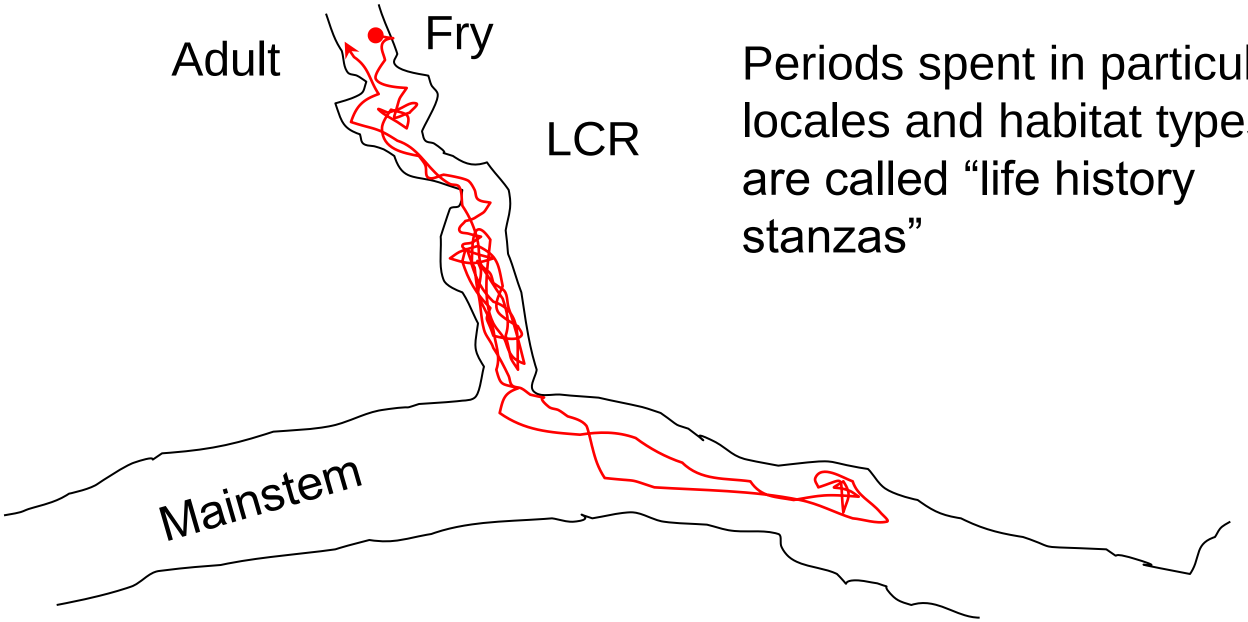
How do we know survival rates are high and stable for humpback chub?

- The ASMR model was developed to track tagging and recapture histories by birth-year cohorts, and to account for changes in capture probabilities with age, year. The main problem with it is assigning age at tagging



Life history trajectories

- Almost all fish exhibit complex spatial movement patterns as they grow
  - “Ontogenetic habitat shifts”
  - Seasonal and diurnal migrations, dispersal
  - Homing to natal areas results in “closed” trajectories
- This greatly complicates the problem of obtaining representative estimates of abundance



Periods spent in particular locales and habitat types are called “life history stanzas”

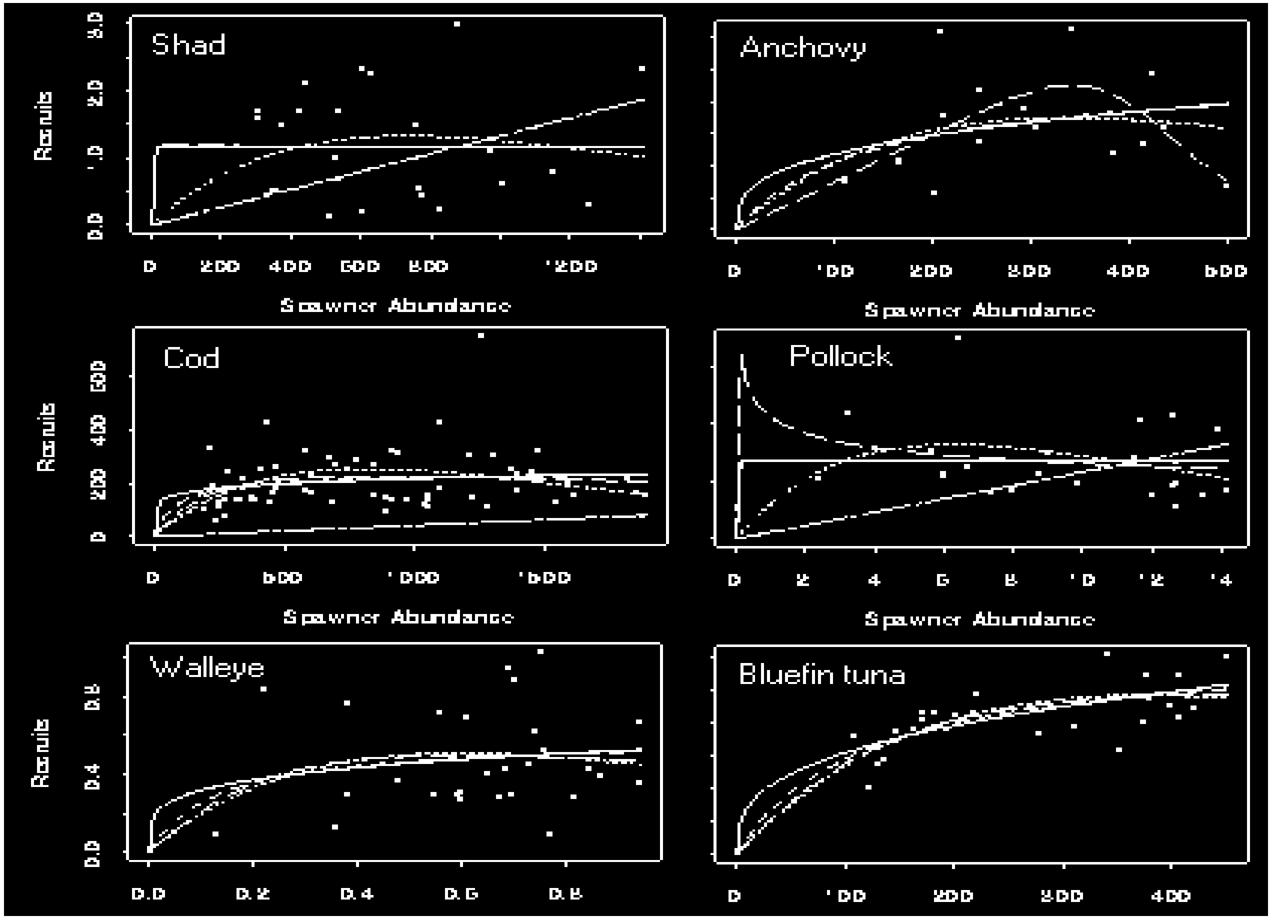
Why are we uncertain about chub recruitment predictions?

- Every year, humpback chub lay at least 5,000,000 eggs, enough to grossly overstock the ecosystem if survival rates were high
- But only about 2000-4000 of these eggs survive to age 2
- We know that recruitment=Eggs x survival rate
- There are two key prediction problems:
  - Variation in survival due to density-dependent effects
  - Variation in survival due to physical habitat, food, and predation

Density-dependent effects are really important in prediction of egg-to-recruit survival

- Again, Recruits=Eggs x survival rate
- This relationship implies that recruits should be proportional to eggs, if survival rate is constant or varies independently of eggs.
- But over many, many fish studies, we have almost never seen such proportionality; instead, we see apparent limits on recruitment

Compensatory juvenile survival: Beverton-Holt shape and recruitment "limits" (over 300 examples now):

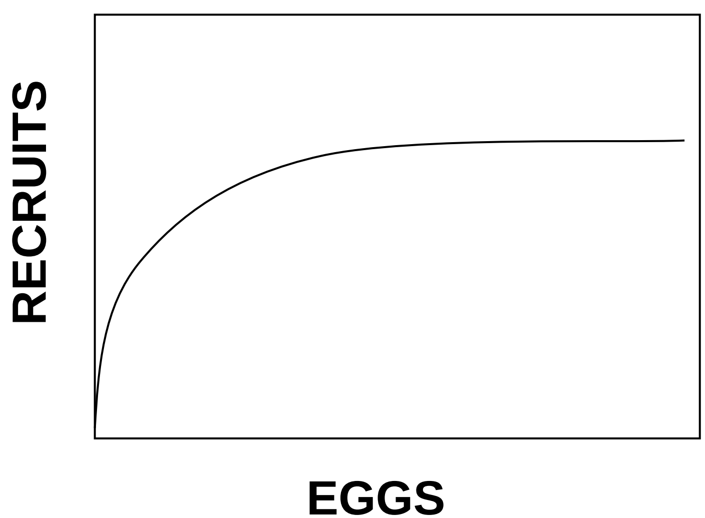


Why is density-dependent (compensatory) juvenile mortality so universal?

- Wee fish have to satisfy two objectives:
  - Grow enough to be able to reproduce
  - Not get eaten along the way
- These are fundamentally conflicting objectives: they can’t eat without exposing themselves to predation risk
- Required exposure time depends strongly on local density of competitors
- Part of their solution to meeting these objectives generally involves following complex life history “trajectories” over space and time (ontogenetic habitat shifts, homing to natal spawning areas)

Foraging arena theory

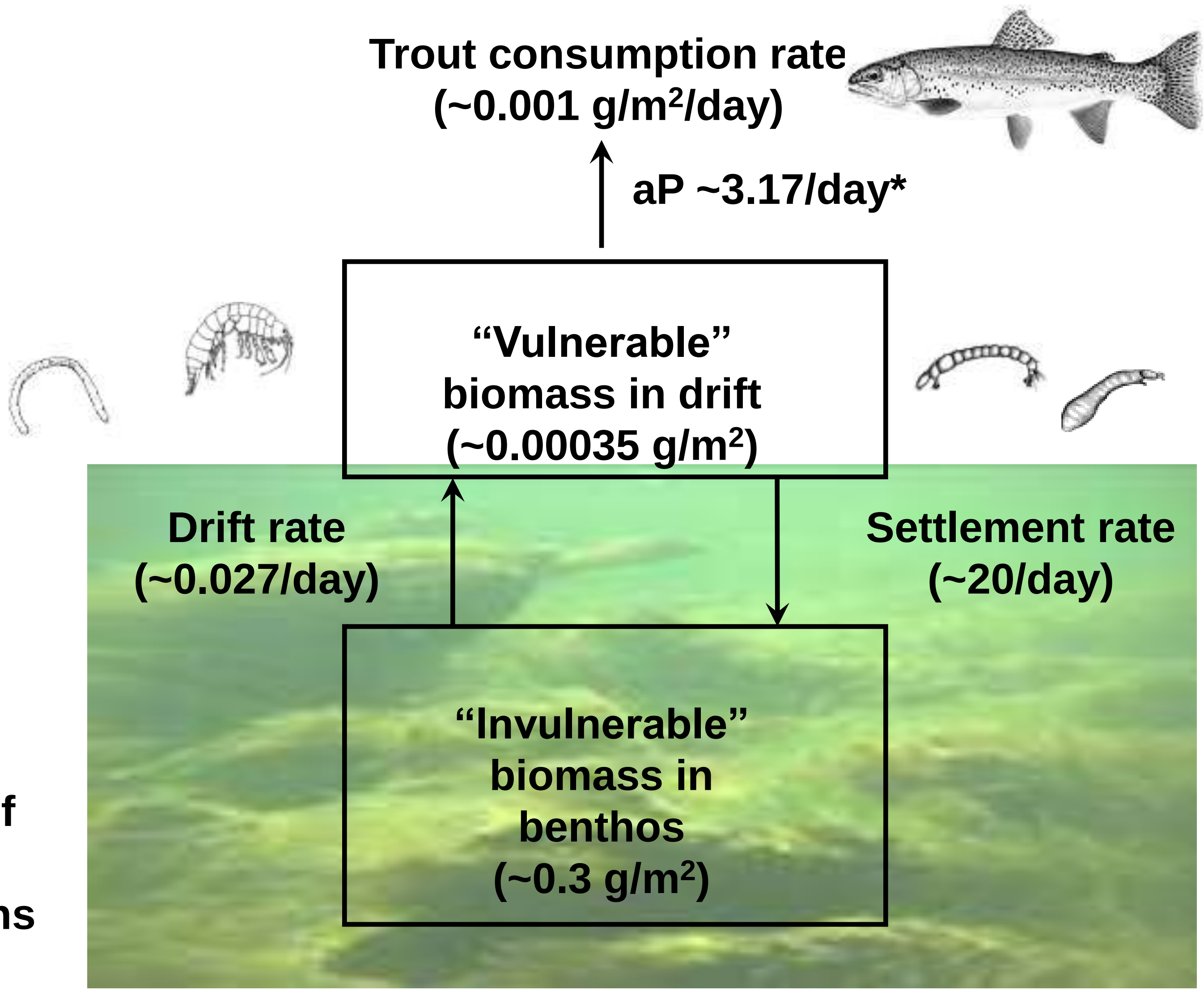
- This theory predicts that recruitment “capacity” (maximum recruitment rate) arises from feeding-predation risk tradeoff, along with usable habitat area



$$Max = k_1(habitat.area)e^{-k_2\frac{predation.risk}{food.supply}}$$

i.e. “capacity” increases with increases in habitat area and food supply, decreases with increasing predation risk

Vulnerability exchange rates of invertebrates into/from the drift are critical for understanding ecosystem stability and limitation of consumption and recruitment rates of fish



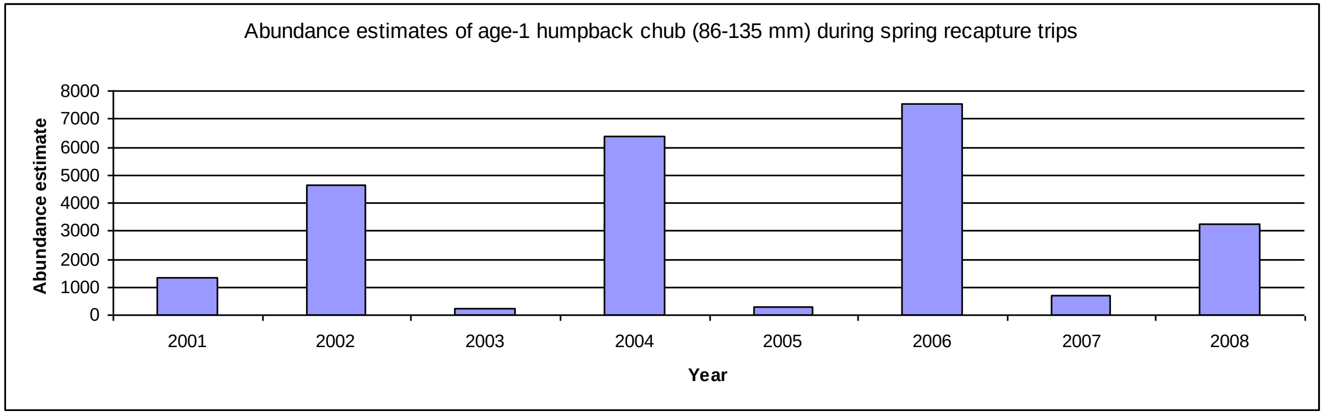
* Implied max reaction distance to prey implied by this rate is 0.49m

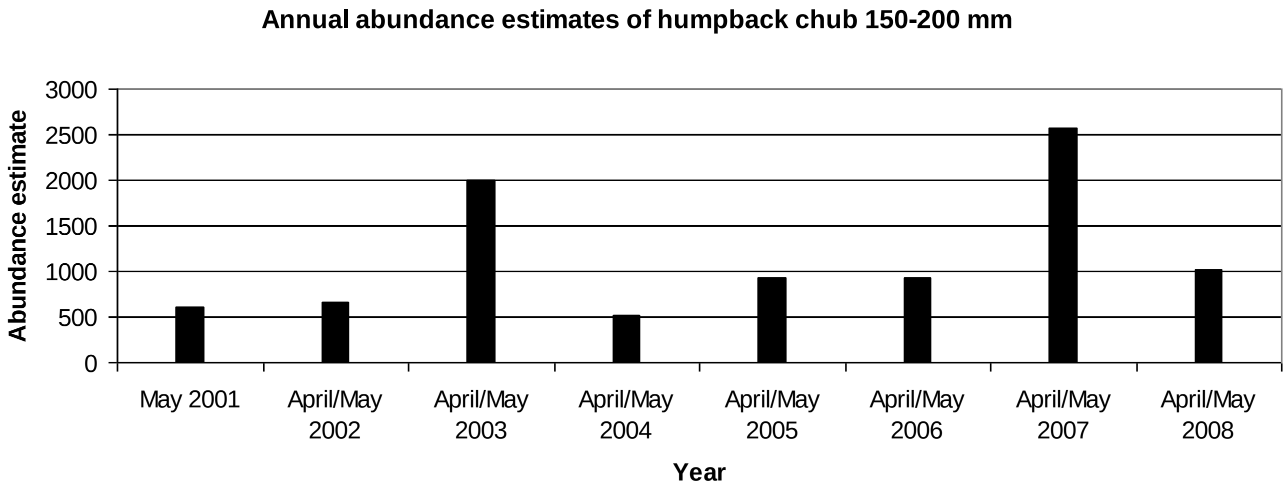
(Details of these calculations are in "vulnerability

Two critical implications of density dependence in juvenile survival rates

1. Early life abundances are not good predictors of eventual recruitment to the adult population (must track fish for several years to see final impact)
2. Manipulations of early life abundances do not imply changes in abundance of larger/older fish (enhancement or culling of small fish is less effective)

Humpback chub show density effects in recruitment, and evidence of strong competition among year classes rearing in the restricted LCR environment

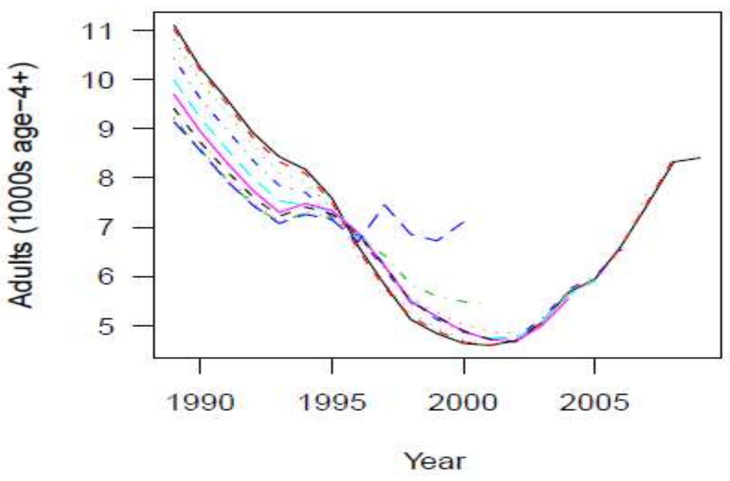


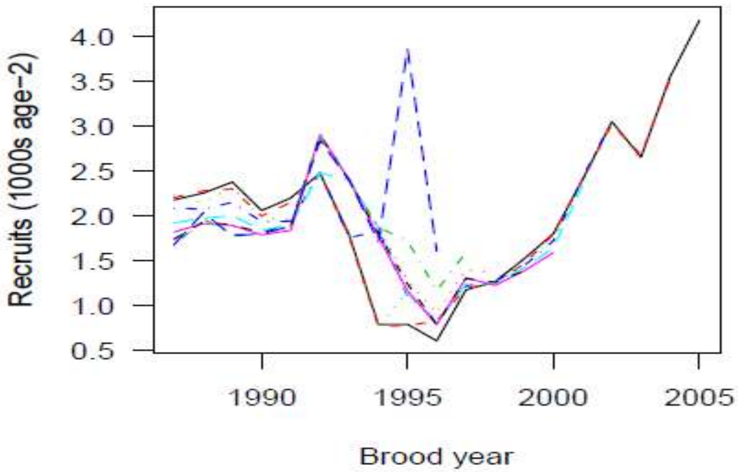


From VanHaverbeke

The latest ASMR chub estimates

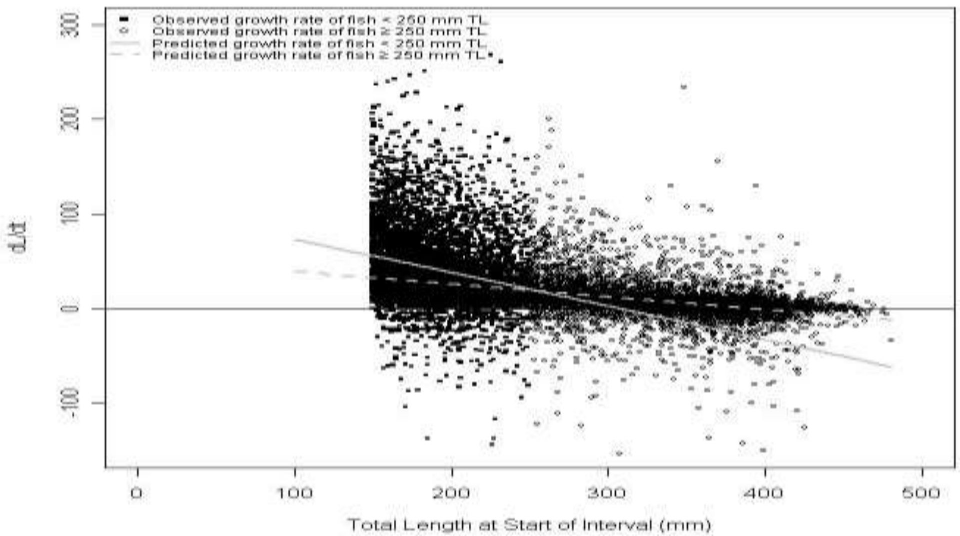
- Notice that we cannot "see" most recent year-classes (not enough tagged yet)
- Notice how estimates keep changing as we get more data to pin down cumulative survival, capture rates
- A new approach now being developed by Martell will use length sampling data, including for small fish, to reduce errors in year-class estimates due to age assignment, and provide estimates for each year class sooner



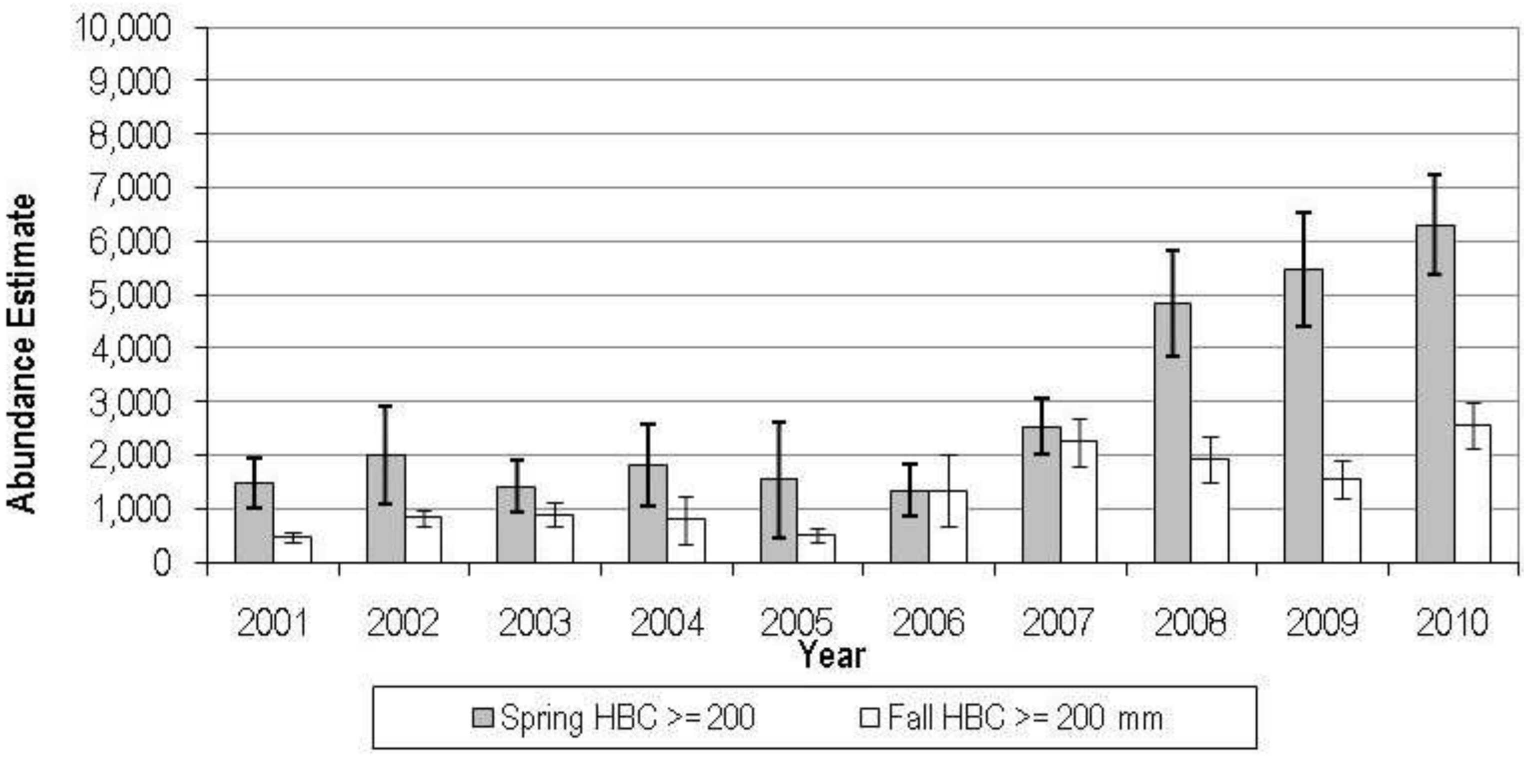


The main problem with ASMR is assignment of age to each fish when it is first tagged

- Variation in growth causes “smearing” of fish across birth year cohorts
- There is more variation than we expected, probably due to partial mainstem rearing

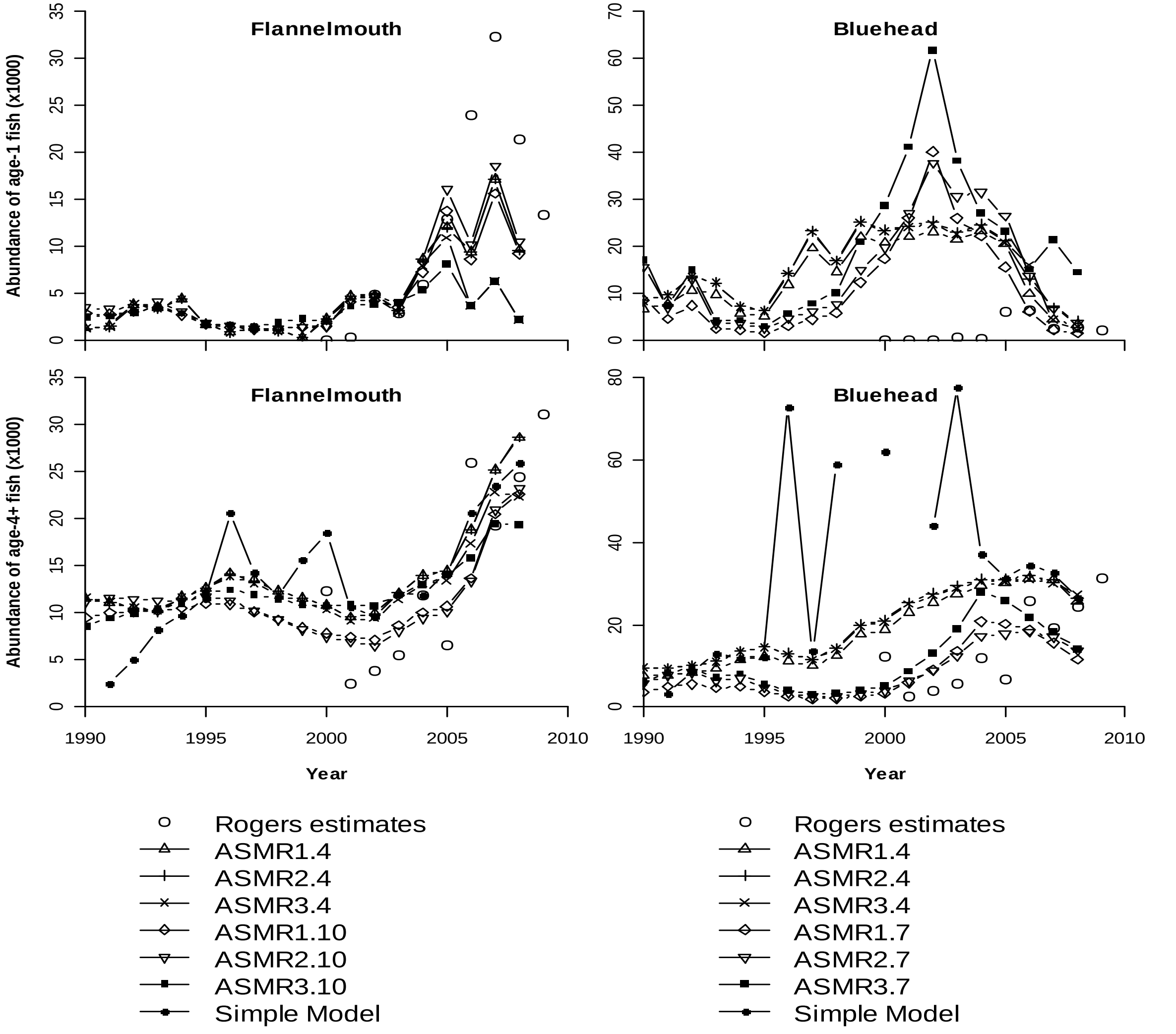


ASMR trend estimates agree well with USFWS closed population mark-recapture estimates



(Such crossvalidation with alternative models, and with independent trend index data, is critical)

ASMR is also being used for sucker assessments (Trans. Am. Fish. Society in press)



Why do our estimates keep changing?

- New data, new structural models (methods)
- We are not alone: this happens in all sciences, e.g. even in measurement of the speed of light: many confident estimates whose "confidence limits" don't even overlap:

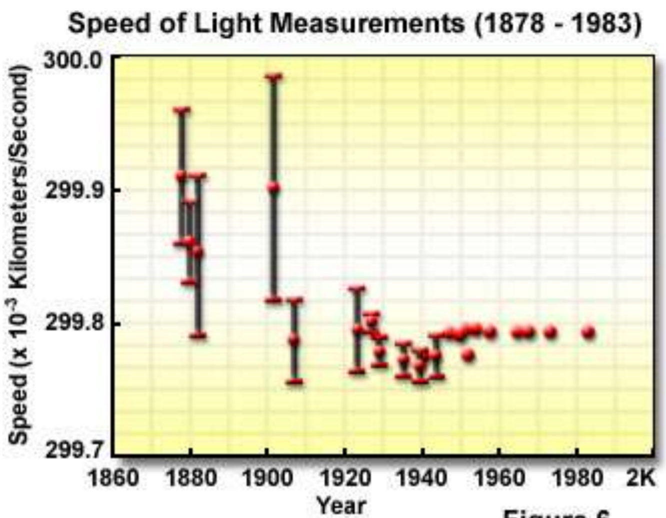
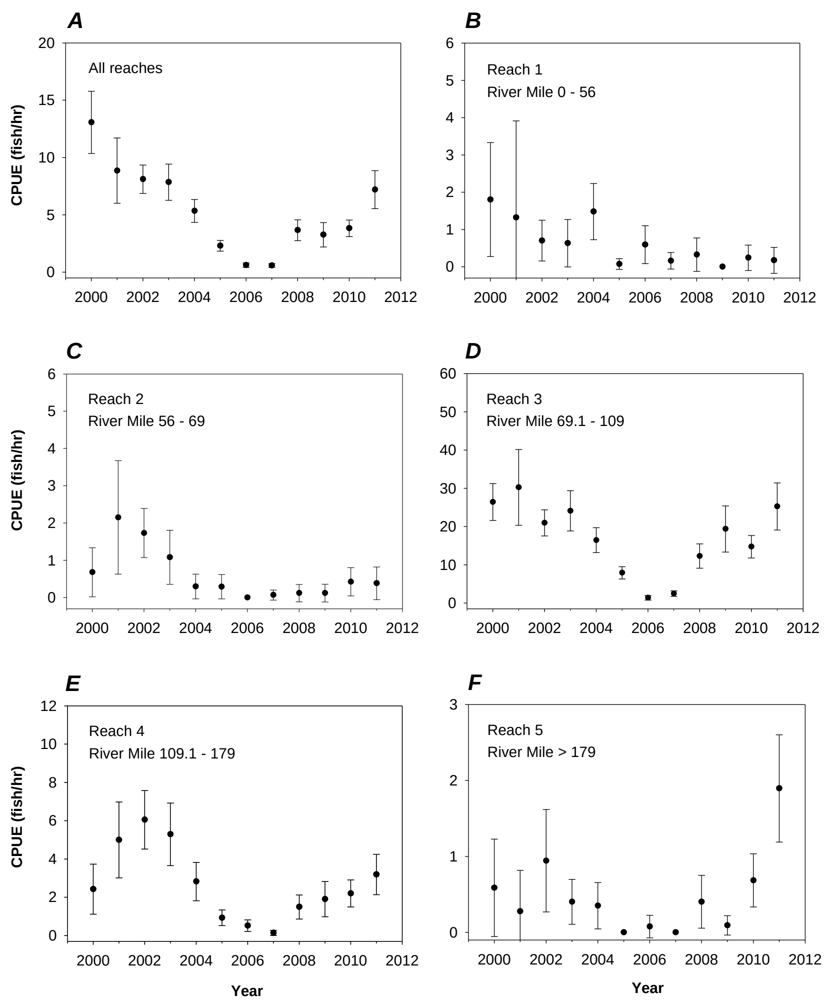
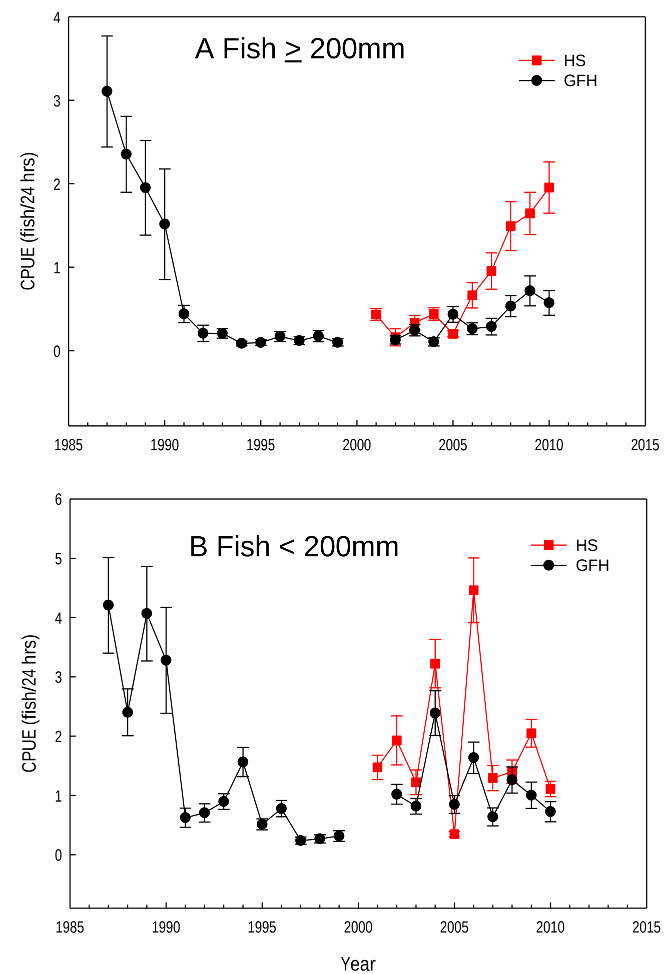


Figure 6

A smorgasbord of trend indices based on catch per effort (Persons)



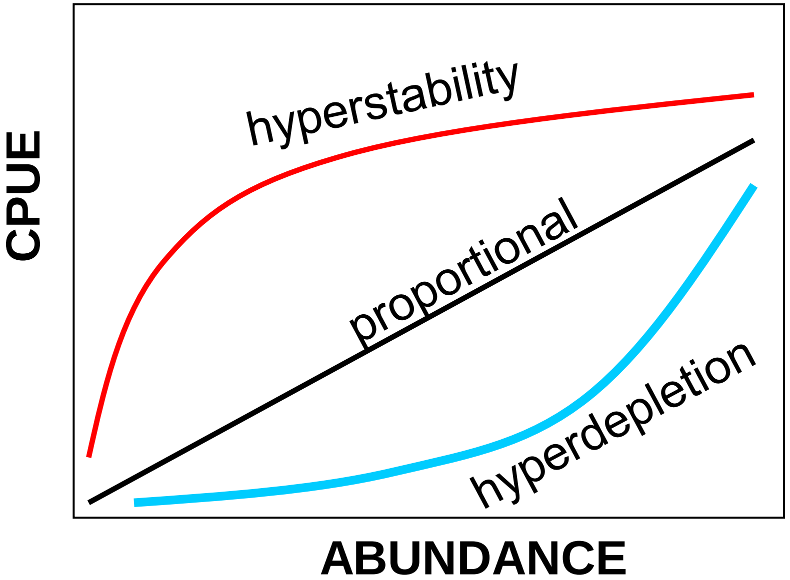


Using catch per effort data

- To cheaply assess spatial and temporal patterns in abundance of major species
- As statistical “explanatory” variables for trends in abundance of other species
- To challenge ability of ecosystem models to explain patterns of change
- To provide cross-validation of abundance trend patterns based on other methods, e.g. ASMR
- Conversion to absolute abundances using catchability estimates from depletion and marking experiments

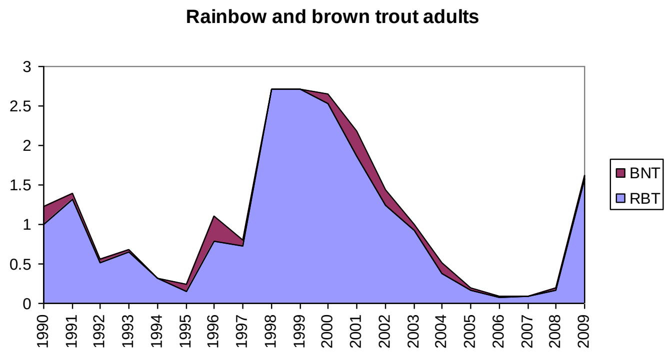
Problems with cpue indices

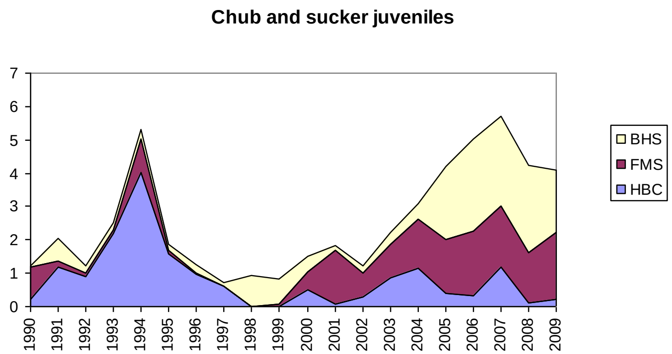
- High variability due to fish patchiness, flow and turbidity effects on vulnerability
- Nonlinear relationships between cpue and abundance

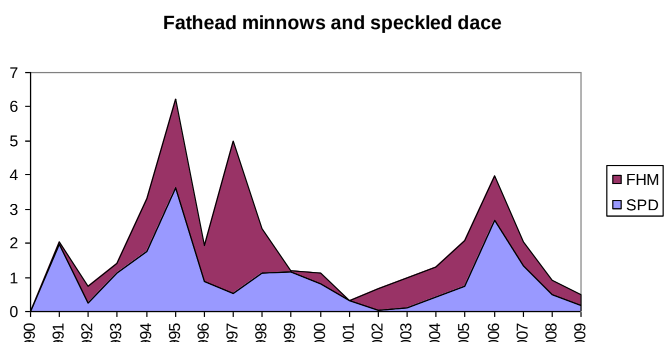


- Hyperstability when gear saturates or sampling targets fish concentrations
- Hyperdepletion when high proportion of fish are not vulnerable to gear

Predation impacts of trout on other fishes near the LCR?



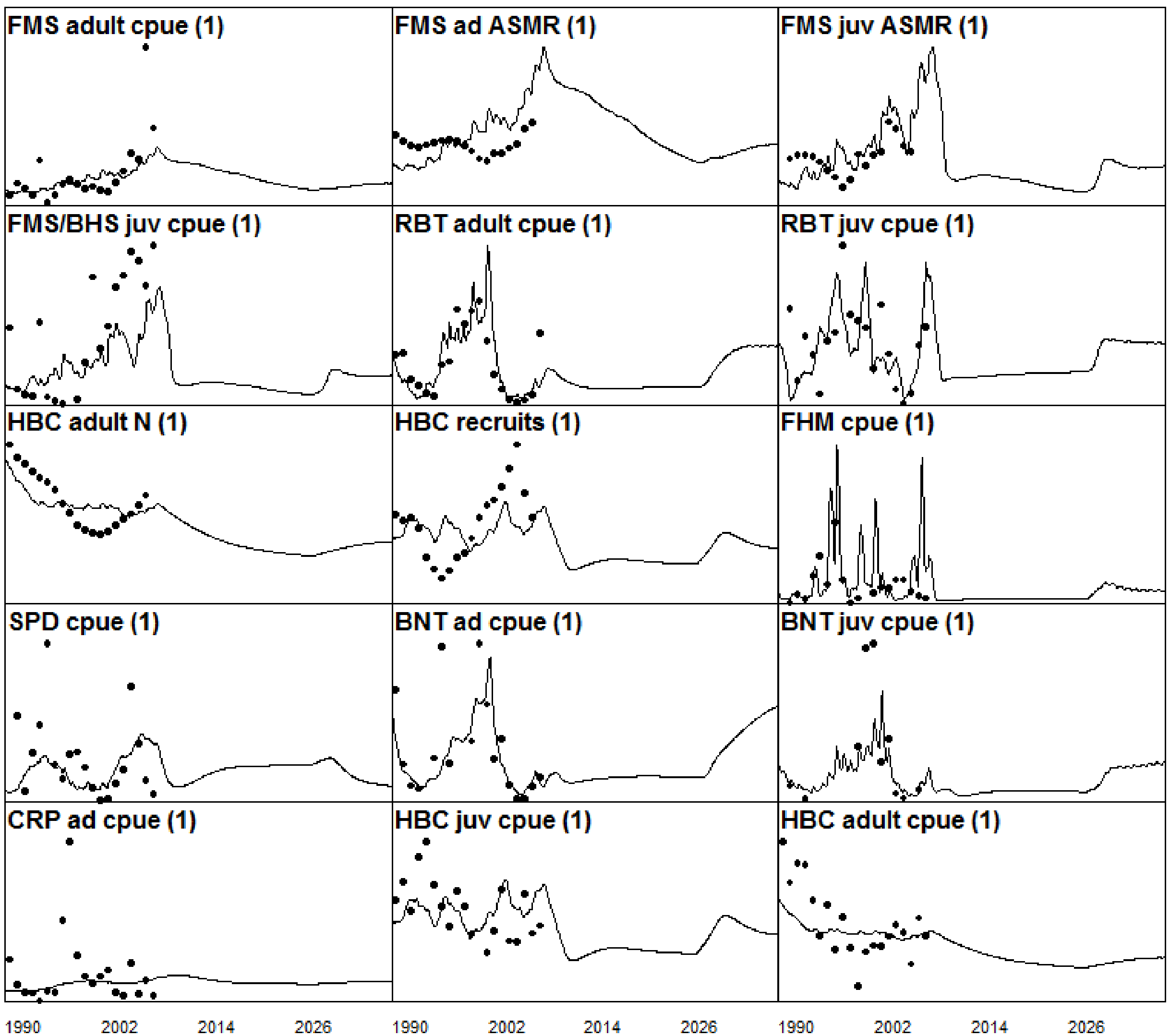




- **Trout declines are correlated with increased catch per effort of small fishes, native and non-native**
- **Increases after 2000 began before 2003-2005 warm water period and 2003-2006 mechanical removal, but after trout decline began**
- **Catch per effort remained high after the river cooled, are now dropping as trout recover from mechanical removal**
- **No evidence that peak of native fish juveniles in mid-1990s led to any increases in adult abundance; post-2000 juvenile increases are associated with increases in adult abundance, especially for suckers**

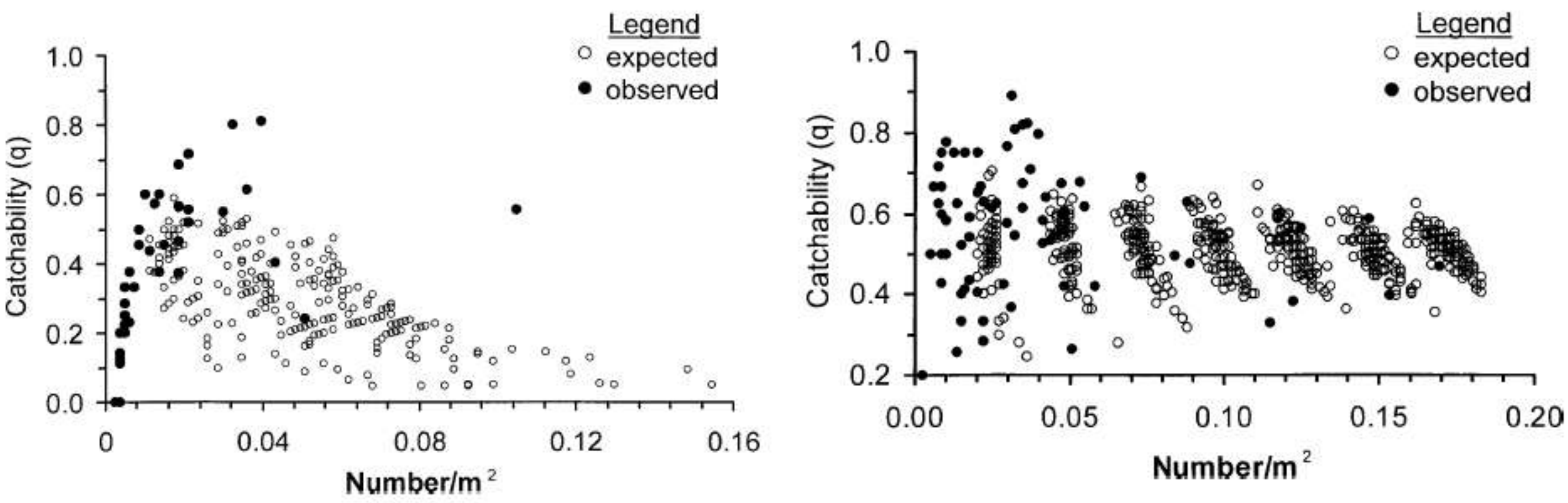
From LCR composite fish trends.xls

Using catch per effort data to challenge ecosystem models: can we explain trends?



Estimating absolute abundances from catch per effort

- Assume cpue=qN (q is “catchability”)
- Observe local cpue values, estimate local N values, check to insure q is constant



(From Speas et al 2004 North Am. J. Fish Management)

Management as experimentation

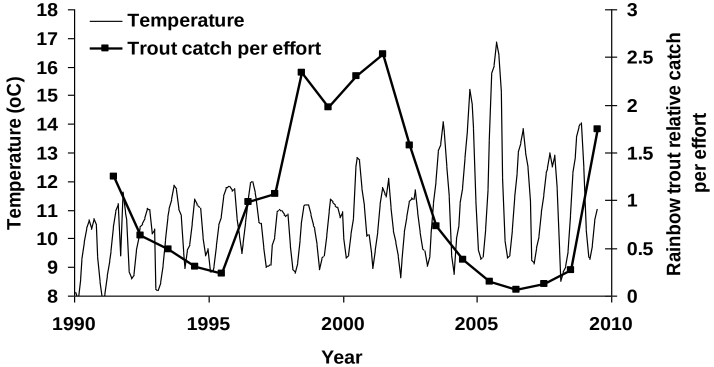
- There are important policy choices for which we cannot confidently predict even the direction of ecological response
- In this case, <u>every</u> choice is an “experimental” treatment, whether it is admitted to be or not
- The only issue is whether to design such experimental choices well, not whether they are experiments

What do we mean by “experiment” in science?

- An experiment has two critical components
  - Contrasting treatments (comparison of alternative choices)
  - Replication and interspersion of treatments
- It is not true to claim that a policy can just be implemented then evaluated over time for possible negative effects (to what can its results be compared, if no other policy is tried?)
- Replication is the only way we have to guard against misinterpretation due to other causal factors changing at the same time (confounding)

Confounding of effects in the observation of apparent effects of any one treatment application

Temperature vs predation?



- Temperature increase in 2003 coincided with start of mechanical removal program.
- There have been somewhat elevated temperatures over the whole period of low trout abundance since 2003.

You should not ask a scientist to tell you which factor caused the change, e.g. native fish increase; all you will get is a guess. The real answer is to replicate the treatment.

Can we reduce HBC sampling effort without causing bias?

Scenario 1 represents the base line scenario where all available records between 1989 and 2009 are used to construct the ASMR input file.

Scenario 2 all September and October USFWS records have been removed (i.e., no fall sampling).

Scenario 3 all September USFWS records have been removed.

Scenario 4 all October USFWS records have been removed.

Scenario 5 all lower 1200 records have been removed.

Scenario 6 all April or first sampling trips of the spring have been removed, second trip or May trips have not been excluded.

Scenario 7 all USFWS lower 5 km samples have been removed from the spring sampling periods (lower 1200 spring trips have not been excluded).