An Index of Early Life History Diversity for Pacific Salmon

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Outline

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Problem Statement

- One premise for the Columbia Estuary Ecosystem Restoration Program (CEERP) is that increased habitat diversity will increase life history diversity which in turn will improve salmon resilience and recovery (Bottom et al. 2005).
- However, there is no existing, standard method to track progress to improve life history diversity and report to managers.
- A life history diversity index for juvenile salmon in the LCRE was mandated in RPA 58.2 of the 2008 FCRPS BiOp.

Goal and Objectives

- Goal: Establish an index of early life history diversity as a high-level metric that managers can use to track biological performance of salmon populations using the LCRE.

- Objectives:
  - Characterize and prioritize early life history traits for use in the index
  - Review diversity index literature
  - Identify an indexing approach
  - Test candidate indices using data from another study
  - Recommend an ELHD index

Desirable Index Characteristics

- Applies to multiple life history strategies using readily measurable life history traits.
- Incorporates fish abundance, density, or catch per unit effort data, not simply presence/absence data.
- Incorporates both species richness (number of species) and evenness (equitability of proportional frequencies).
- Is understandable and interpretable by non-mathematicians.
- Supports comparisons across like locales and examinations of trends through time at a given locale, where locale is a prescribed area of a river or estuary.

Life History Traits and Factors Affecting Them

Traits

- timing of entry into tidal freshwater, estuarine water, and the ocean
- age and size of fish
- residence times

Factors

- stock of origin
- distance upriver of origin
- habitat availability
- ecological conditions

For the purpose of this study, we focused on ***traits*** that are readily measured from typical data collection efforts for juvenile salmon: ***size*** and ***timing.***

<61 mm, 61-90 mm, 91-120 mm, >120 mm.

"Rare traits" are those that are observed infrequently.

Literature Review

- We did not find an established method to index salmon ELHD.
- ELHD application is analogous to species diversity.
  - Not concerned with functional, phylogenetic, biological or ecological diversity measures.
- Most important to ELHD is the commonality across these diversity concepts expressed by Patil and Taillie (1979) as the:
  - "*…apportionment of some quantity into a number of well defined categories, determined by the problem at hand*."
- Our quantity is juvenile salmon density (abundance) and our categories are the combinations of ELH traits.

‘True’ Diversity and Its Generalized Form

- Originally proposed by MacArthur (1965) and called the “Hill number” after Hill (1973).
- True diversity is the effective number of species

  = number of equally common species.
- **For ELHD, true diversity is the effective number of combinations of early life history traits.**
- The generalized form for a ‘true’ diversity is

$$ {}^{q}D = {}^{q}ELHD = \left(\sum_{i=1}^{T} p_i^{q} \right)^{1/(1-q)} $$

where, q is the order, p_i is the proportion of total density for the i^{th} combination of traits, and T is the total number of possible combinations of traits (after Jost 2006, eq. 1)

Proposed ELHD Indices

q = 0, Species Richness

$$^{0}ELHD = \left(\sum_{i=1}^{S} p_i^{0} \right) = S$$

q = 0.5, Square root-based

$$^{0.5}ELHD = \left(\sum_{i=1}^{S} p_i^{0.5} \right)^{2}$$

q = 1, Shannon-based

$$^{1}ELHD = \exp\left(-\sum_{i=1}^{S} p_i \ln\left(p_i \right) \right)$$

q = 2, Simpson-based

$$^{2}ELHD = \left(\sum_{i=1}^{S} p_i^{2} \right)^{-1}$$

Evenness and Normalization

- Evenness is derived from richness and diversity (after Pielou 1966).

$$^{q}ELHD_{even} = \frac{^{0}ELHD}{^{q}ELHD}$$

- Normalization converts the ELHD index to a value between zero and one by dividing the index by the maximum ELHD value possible.

$$^{q}ELHD_{norm} = \frac{^{q}ELHD}{T}$$

where, the maximum ELHD is the total number of possible combinations of ELH traits (*T*).

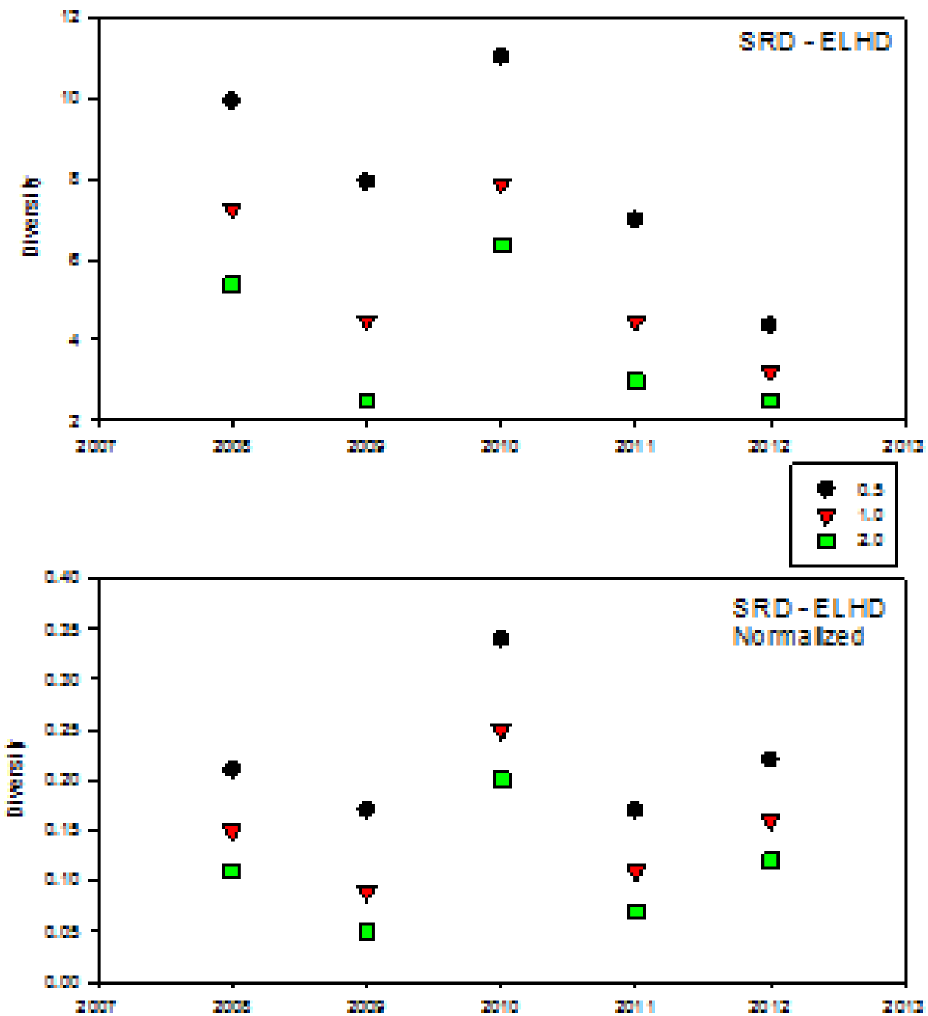
Case Studies

- Examine whether the ELHD indices capture and portray early life history of juvenile Pacific salmon in a meaningful, useful manner.
  - mock data set
  - monthly sampling, site-scale data
  - seasonal sampling, landscape-scale data
  - genetic stock composition data
- We chose Chinook salmon because it is the most common Pacific salmon species in our collections.
- Density (#fish/m^2) and genetics data are from beach seine samples collected to examine migration characteristics for juvenile salmon in shallow tidal freshwater of the lower Columbia River and estuary (Sather et al. 2011, 2012, unpublished data). This type of data is routinely collected in the LCRE.

Mock Data

Species Id.	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		Density (proportion)		
A	5 (0.1)	10 (0.2)	41 (0.82)	20 (0.4)
B	5 (0.1)	10 (0.2)	1 (0.02)	10 (0.2)
C	5 (0.1)	10 (0.2)	1 (0.02)	6 (0.12)
D	5 (0.1)	10 (0.2)	1 (0.02)	5 (0.1)
E	5 (0.1)	10 (0.2)	1 (0.02)	4 (0.08)
F	5 (0.1)	0	1 (0.02)	3 (0.06)
G	5 (0.1)	0	1 (0.02)	1 (0.02)
H	5 (0.1)	0	1 (0.02)	1 (0.02)
I	5 (0.1)	0	1 (0.02)	0
J	5 (0.1)	0	1 (0.02)	0
Total	50 (1.0)	50 (1.0)	50 (1.0)	50 (1.0)
q		${}^{q}ELHD$ (${}^{q}ELHD_{norm}$)		
0.5	10.0 (1.0)	5.0 (0.5)	4.75 (0.47)	6.52 (0.65)
1	10.0 (1.0)	5.0 (0.5)	2.38 (0.24)	5.48 (0.55)
2	10.0 (1.0)	5.0 (0.5)	1.48 (0.15)	4.25 (0.43)

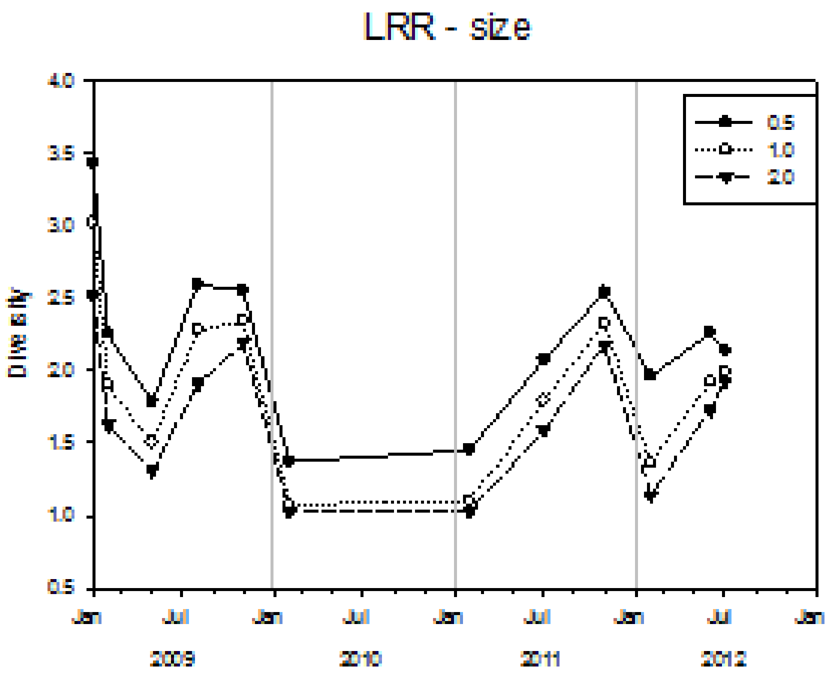
Monthly Sampling, Site-Scale Data

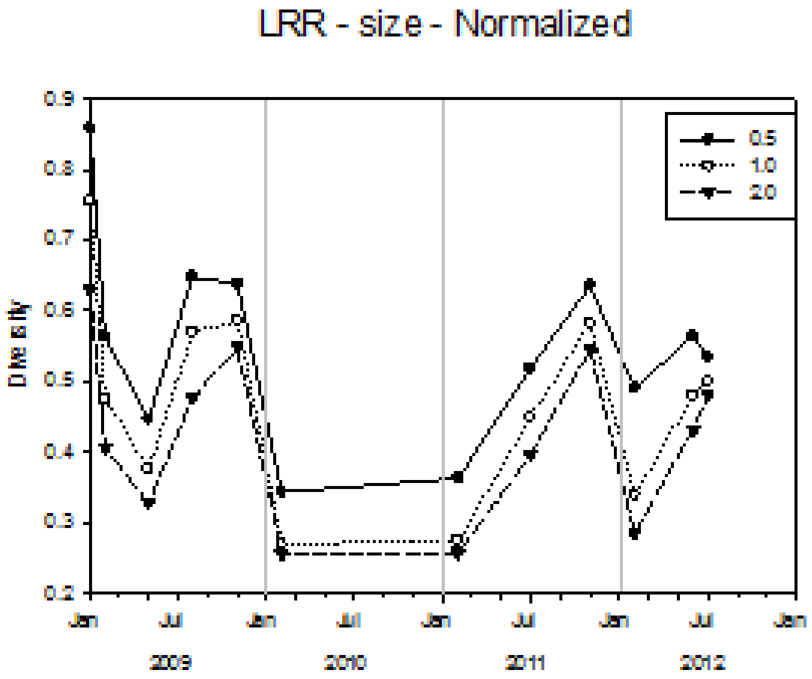


Timing (month) by Size Class Trait Combinations

- ✓ ^{q}*ELHD* was highest during 2010 and lowest during 2012.
- ✓ Note, however, monthly sampling effort among years was not equal, e.g. 2012 has lowest diversity values and was incompletely sampled (only 4 months).
- ✓ It appears rare traits are more predominant for SRD 2010 compared with other years.

Seasonal Sampling, Landscape-Scale Data



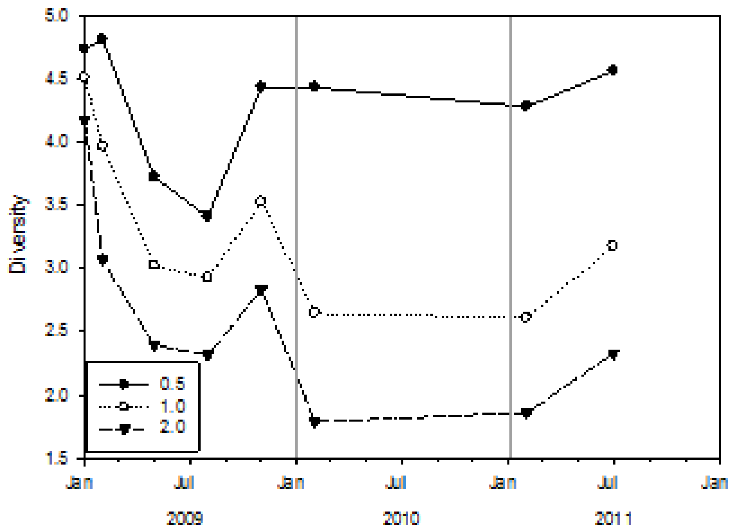


Size Class Trait

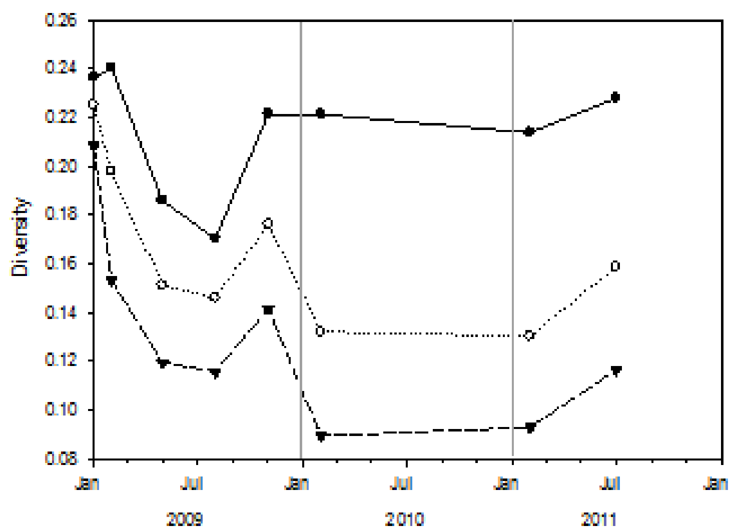
- ✓ During 2009 winter at LRR, ^{q}*ELHD* was higher than all other sampling events during all years.
- ✓ ^{q}*ELHD* increased from winter-spring to summer months. Large differences in diversity between $^{0.5}$*ELHD* and the two other *q*-levels were apparent in winter (February) 2010 and 2011.

Genetic Stock Composition Data

Genetics - LRR



Genetics - LRR Normalized



Genetic Stock by Size Class Trait Combinations

- ✓ Highest ELHD values in winter 2009 and lowest were observed in winters of 2010 and 2011 for ^{1}*ELHD* and ^{2}*ELHD*.
- ✓ $^{0.5}$*ELHD* in winters 2010 and 2011 was relatively high, revealing the effect of *q*-level.

Summary of Findings

To summarize, the case studies showed:

- As must be, $^{0.5}ELHD$ > $^{1}ELHD$ > $^{2}ELHD$ in all scenarios.
- All three q-levels produced tractable, understandable ELHD values.
- Patterns in the diversity results were similar among the q-levels.
- Sensitivity of $^{0.5}ELHD$ to rarer species was evident.
- As expected, patterns in the results were basically the same whether the diversities were normalized or not.
- Normalization was useful because it produced proportions of maximum diversity that were easy understand and interpret while accounting for zero observations in a dataset.
- Juvenile salmon timing and size class trait combinations worked well.
- An ELHD index based on effective number of species appears to have utility irrespective of *q*-level.

Recommended Index: True Diversity of Shannon Entropy

True diversity q-value	0.5	**1**	2
Basis	Square Root	**Shannon Entropy**	Simpson Concentration
Emphasis	Rare species	**None**	Dominant species
Unequal sample sizes	No	**Yes***	No

$$^{1}ELHD = \exp\left(-\sum_{i=1}^{S} p_i \ln\left(p_i\right)\right)$$

*Chao and Shen (2003) Nonparametric estimation of Shannon's index of diversity when there are unseen species in sample. Environ. Ecol. Stat. 10:429-433.

Caveats and Next Steps

- Caveats: indexing; hatchery fish; sampling methods, locations, times
- Next steps:
  - Incorporate Chao and Shen's approach for unequal sample sizes
  - Build a variance estimator and spreadsheet auto-calculator for the ELHD index
  - Further describe management implications and uses
  - Peer-review

Conclusions

- The selected ELHD index is the diversity expressed as effective number of species (true diversity) for the Shannon index. It meets the requirements of RPA 58.2
- It applies to multiple life history strategies; incorporates fish abundance, density, or catch per unit effort data, and both richness and evenness; and, produces understandable and interpretable values.
- The ELHD index supports comparisons across like locales and examinations of trends through time at a given locale.
- It has application as a high-level indicator to track trends in the status of the recovery of salmon and steelhead populations in the Columbia basin and elsewhere where salmon recovery efforts are underway.

Thank you

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