Above-dam life history diversity of juvenile spring Chinook Salmon

(*Oncorhynchus tshawytscha*)

Implications for life cycle modelling and population recovery

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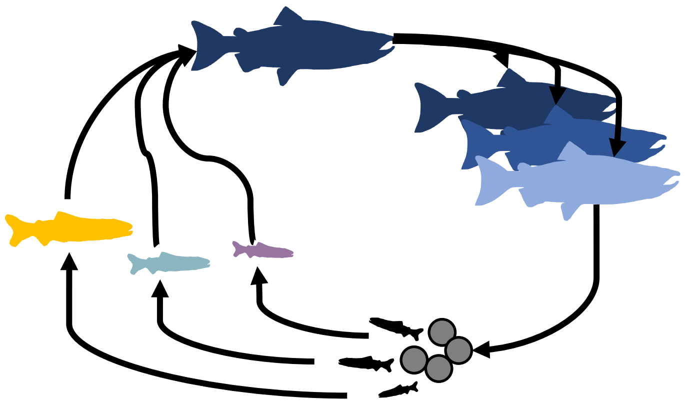
Integrated Passage Assessment

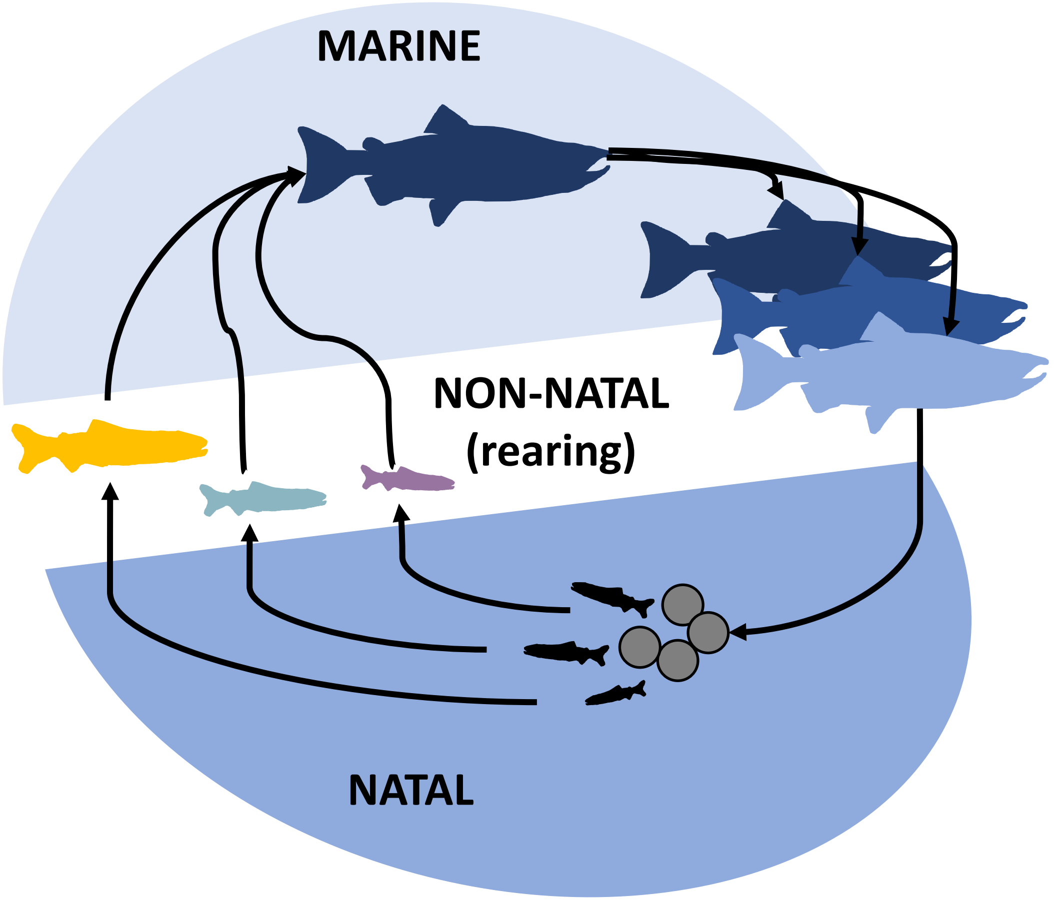
Objectives



1. Describe the importance of diverse juvenile migratory types above dams, including fish rearing in-reservoir
2. Modelling how dam operations might impact the diversity of juvenile migrant types
3. Summarize results modelling the diversity of juvenile migrant types in the Upper Willamette

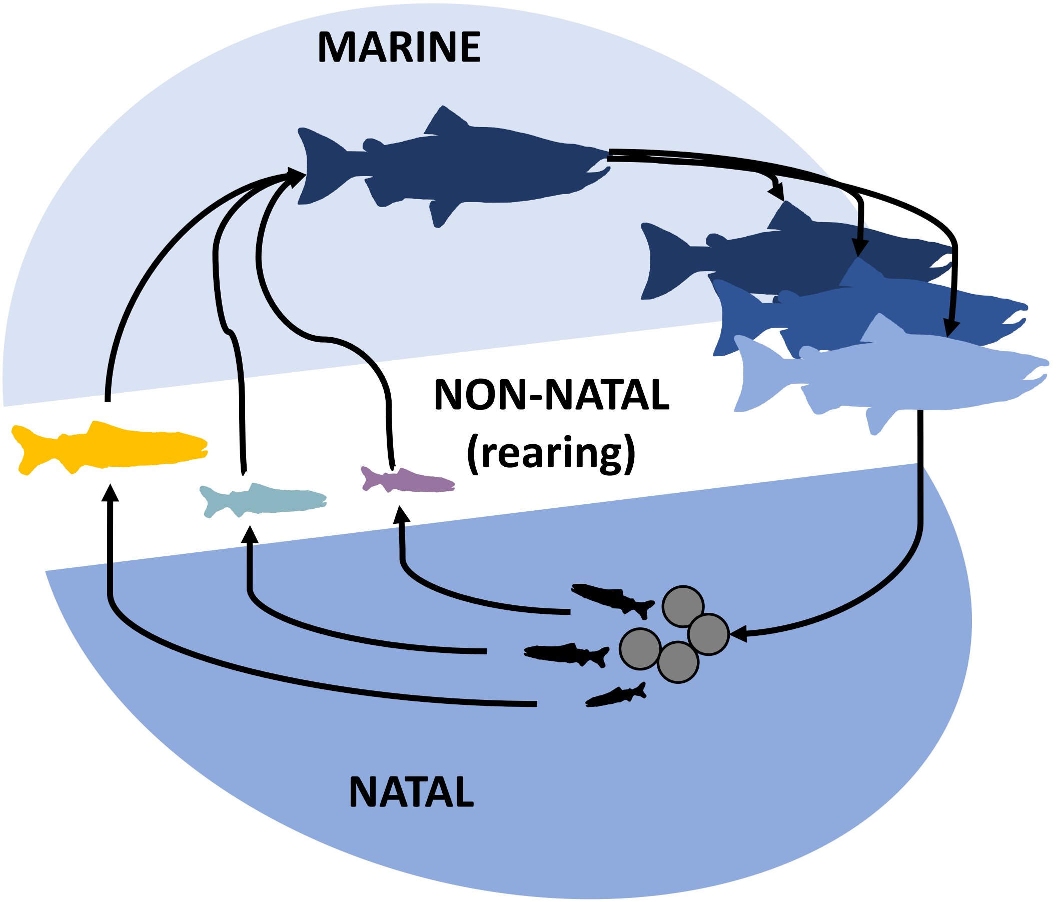
Juvenile migrant type diversity: Importance

- Spring Chinook salmon express phenotypic diversity in juvenile and adult migration types



Juvenile migrant type diversity: Importance

- Spring Chinook salmon express phenotypic diversity in juvenile and adult migration types
- Within-population diversity believed to increase population fitness
    - Diversify resource use, robust to dynamic environments, future adaptability



Moore et al. 2014, doi:10.1111/1365-2656.12212; Sturrock et al. 2015, doi:10.1371/journal.pone.0122380

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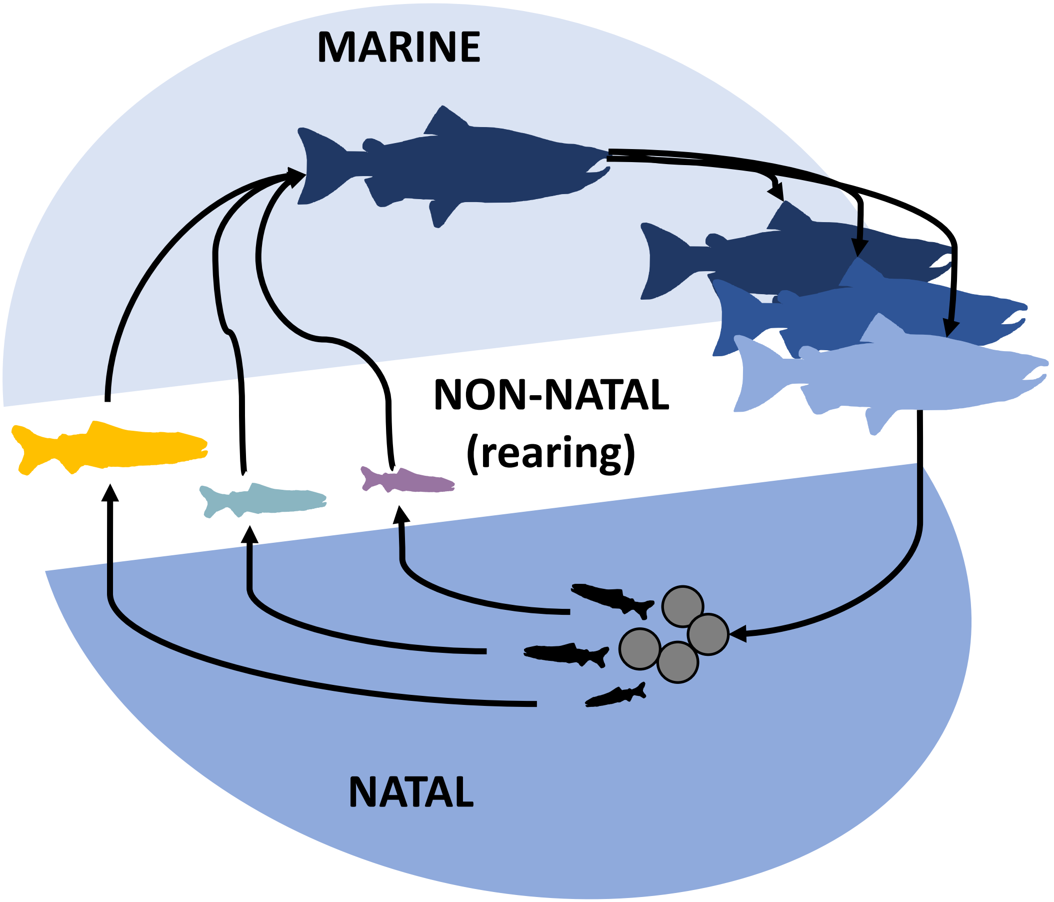


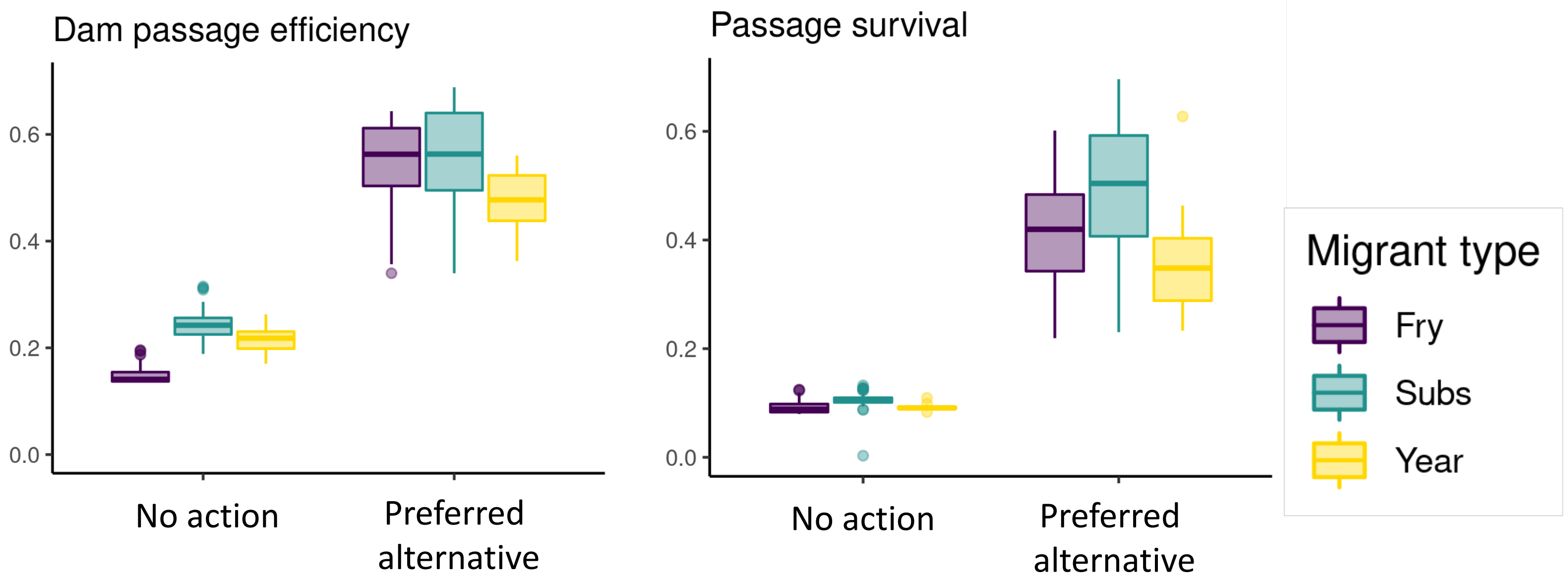
→ Valuable to consider how proposed dam passage improvements may impact **juvenile out-migrant diversity**

Moore et al. 2014, doi:10.1111/1365-2656.12212; Sturrock et al. 2015, doi:10.1371/journal.pone.0122380

Diversity in JMTs: Influence of dam passage alternatives

- USACE considering EIS alternatives = expected changes to **dam passage efficiency (% able to pass)** and **survival**

e.g. Cougar Dam in the McKenzie subbasin



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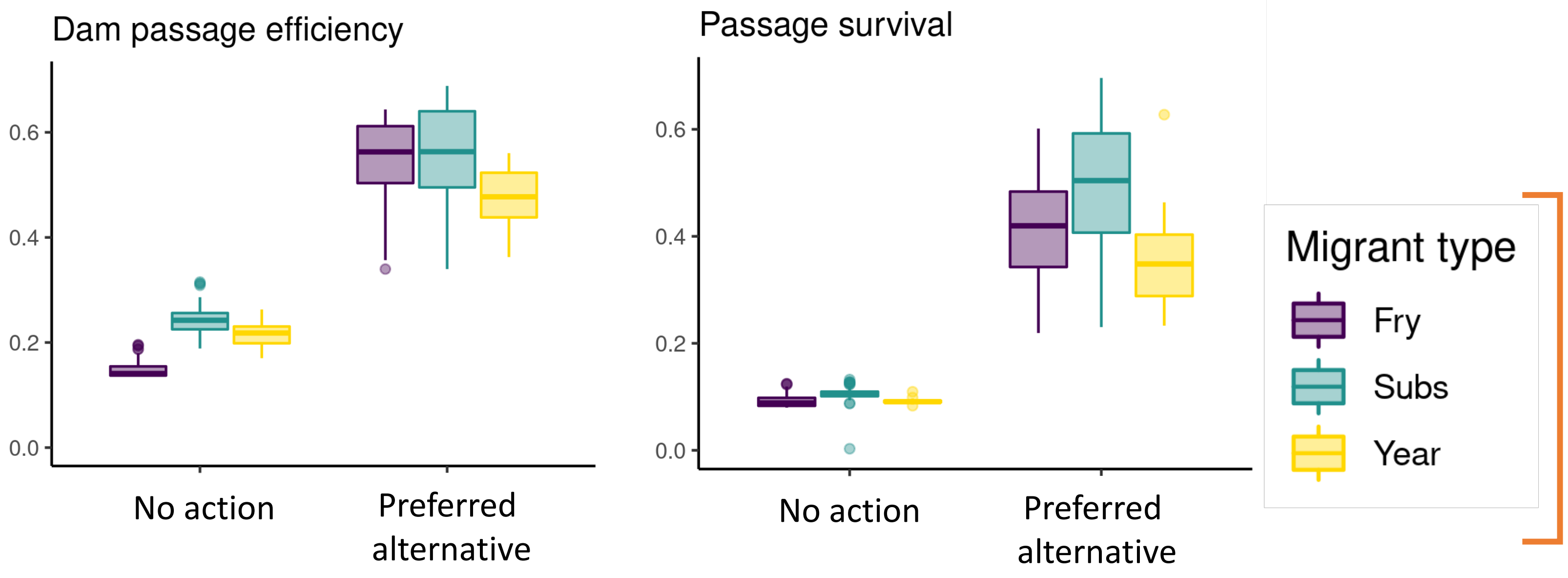

Based on age of attempted dam passage, fish that do not pass assumed to die

→ **Ignores in-reservoir rearing and how it may be impacted by dam passage**

Diversity in JMTs: Influence of dam passage alternatives

- USACE considering EIS alternatives = expected changes to **dam passage efficiency (% able to pass)** and **survival**

- If DPE is higher and in-reservoir rearing shortened, tradeoffs to growth:

  Benefits
  - Smaller size, higher passage survival (Keefer et al. 2012)
  - Lower risk of in-reservoir predation/parasitism*

Keefer et al. 2014, doi:10.1111/j.1600-0633.2011.00540.x

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Benefits

- Smaller size, higher passage survival (Keefer et al. 2012)
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Costs

- Smaller body size, lower smolt-to-adult survival
- Productivity difference between reservoirs and streams

Keefer et al. 2014, doi:10.1111/j.1600-0633.2011.00540.x

Diversity in JMTs: Influence of dam passage alternatives

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- If DPE is higher and in-reservoir rearing shortened:
  - Benefits
    - Lower risk of predation/parasitism in-reservoir*
  - Costs:

** Mitigated by dam operations like drawdown*

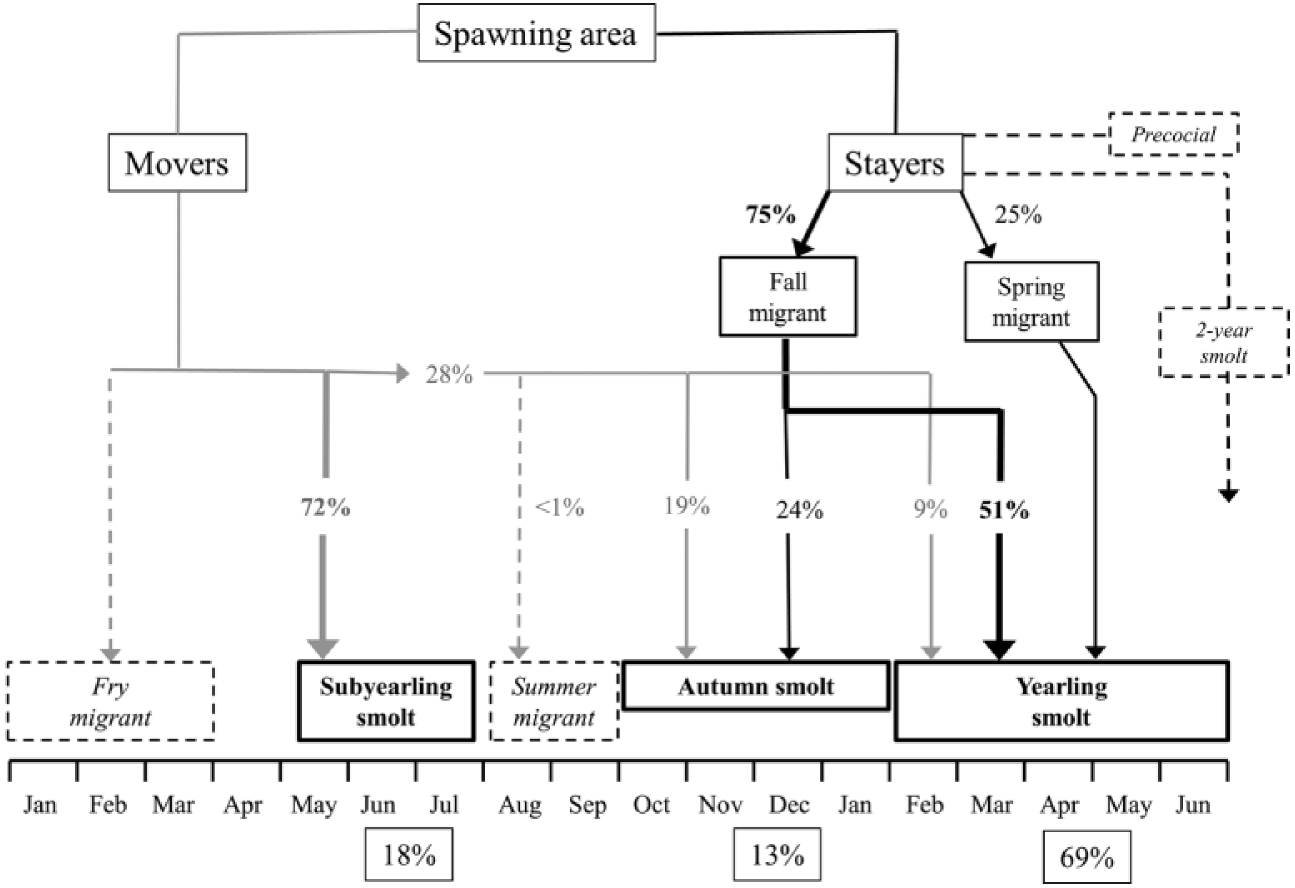
Lacking experiments, use life cycle models to project diversity of JMTs under dam passage alternatives

Representing juvenile migrant diversity

In the Upper Willamette Basin, up to six juvenile migrant types in freshwater

- **Stage 1:** age at which fish leave spawning areas

Schroeder et al. (2016)



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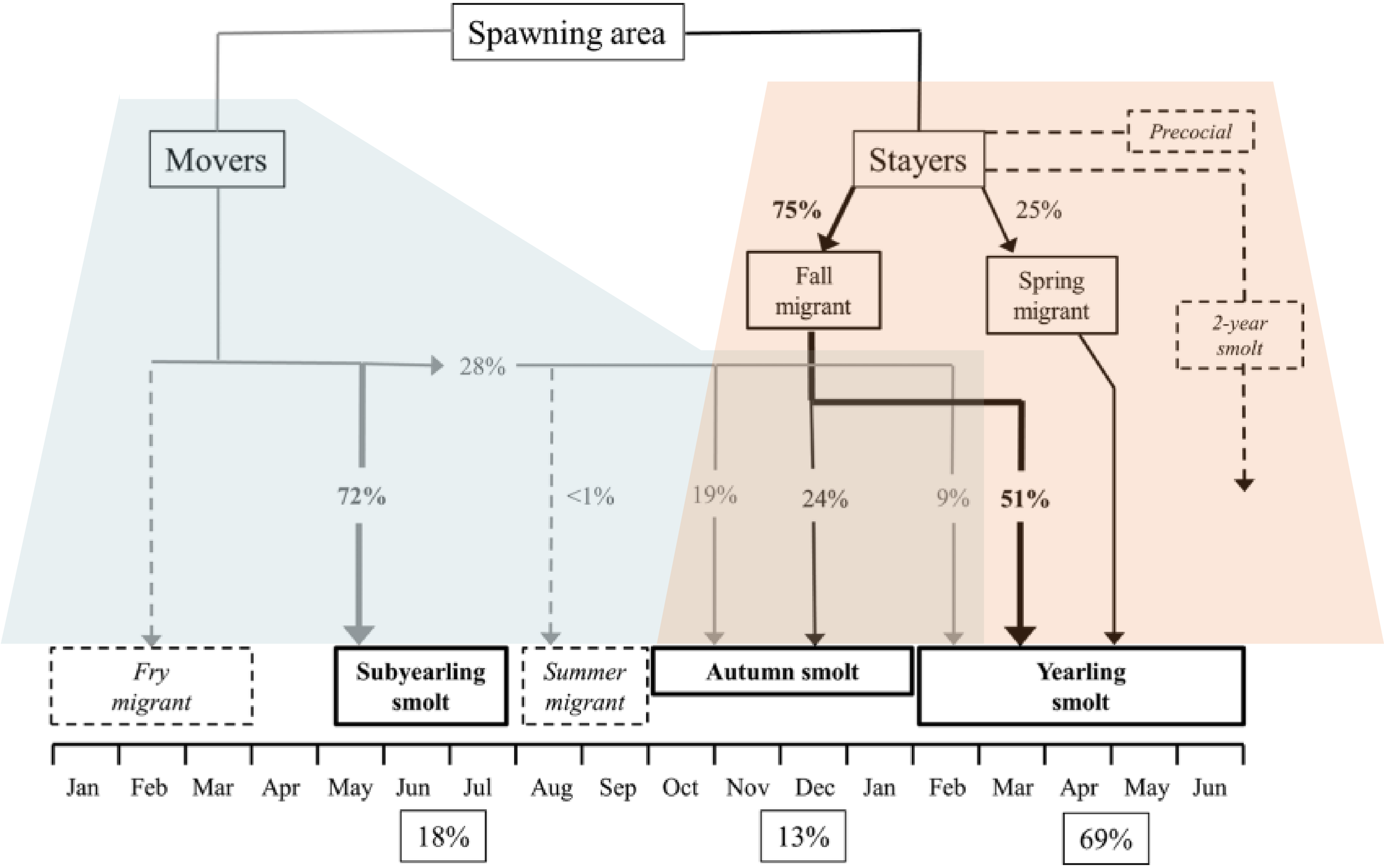
Representing juvenile migrant diversity

In the Upper Willamette Basin, up to six juvenile migrant types in freshwater

- **Stage 1:** age at which fish leave spawning areas

  Movers & stayers
  (aka. ocean & stream type)

Schroeder et al. (2016)



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Representing juvenile migrant diversity

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- **Stage 1:** age at which fish leave spawning areas
- **Stage 2:** age at which fish smolt and migrate to sea

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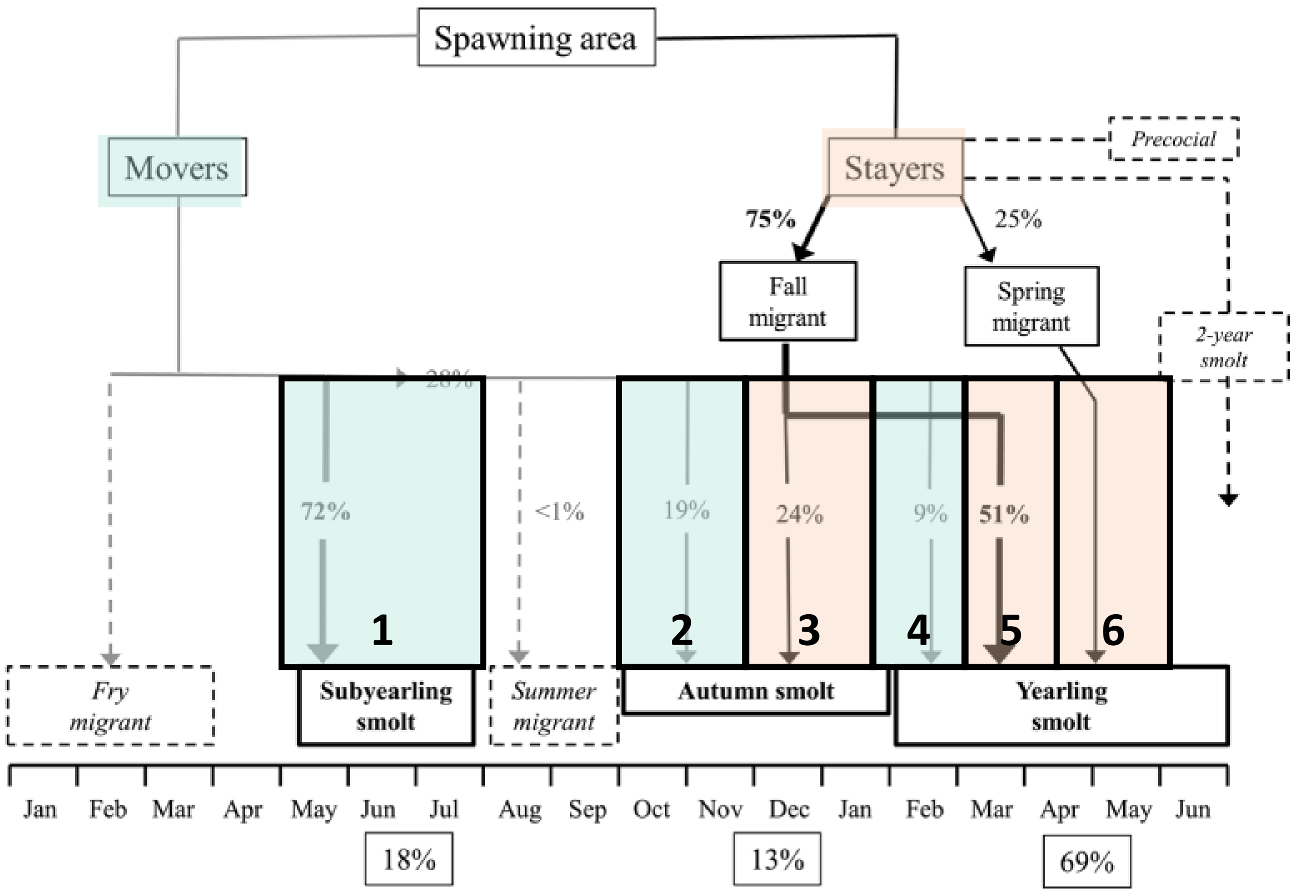

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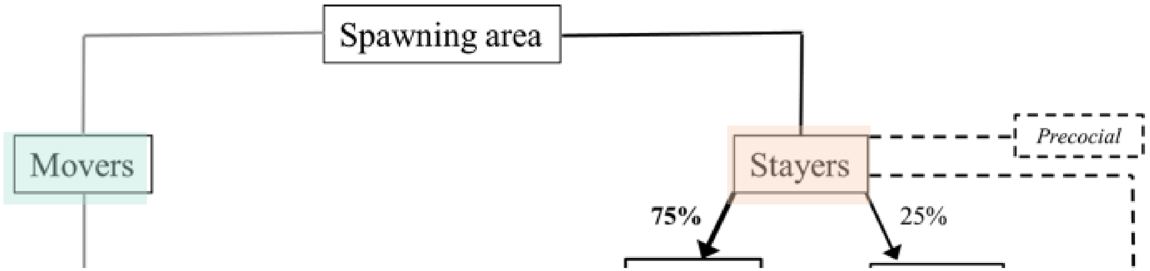


These six types apply to below-dam juveniles:
What about above-dam fish whose migration patterns can be impacted by dam passage alternatives?

Modelling dam passage's effect on JMT diversity

To model EIS alternatives: designated six juvenile migrant types (JMTs)

- Stage 1: **age at which fish leave spawning areas**
- Stage 2: **age at which fish smolt and migrate to sea**

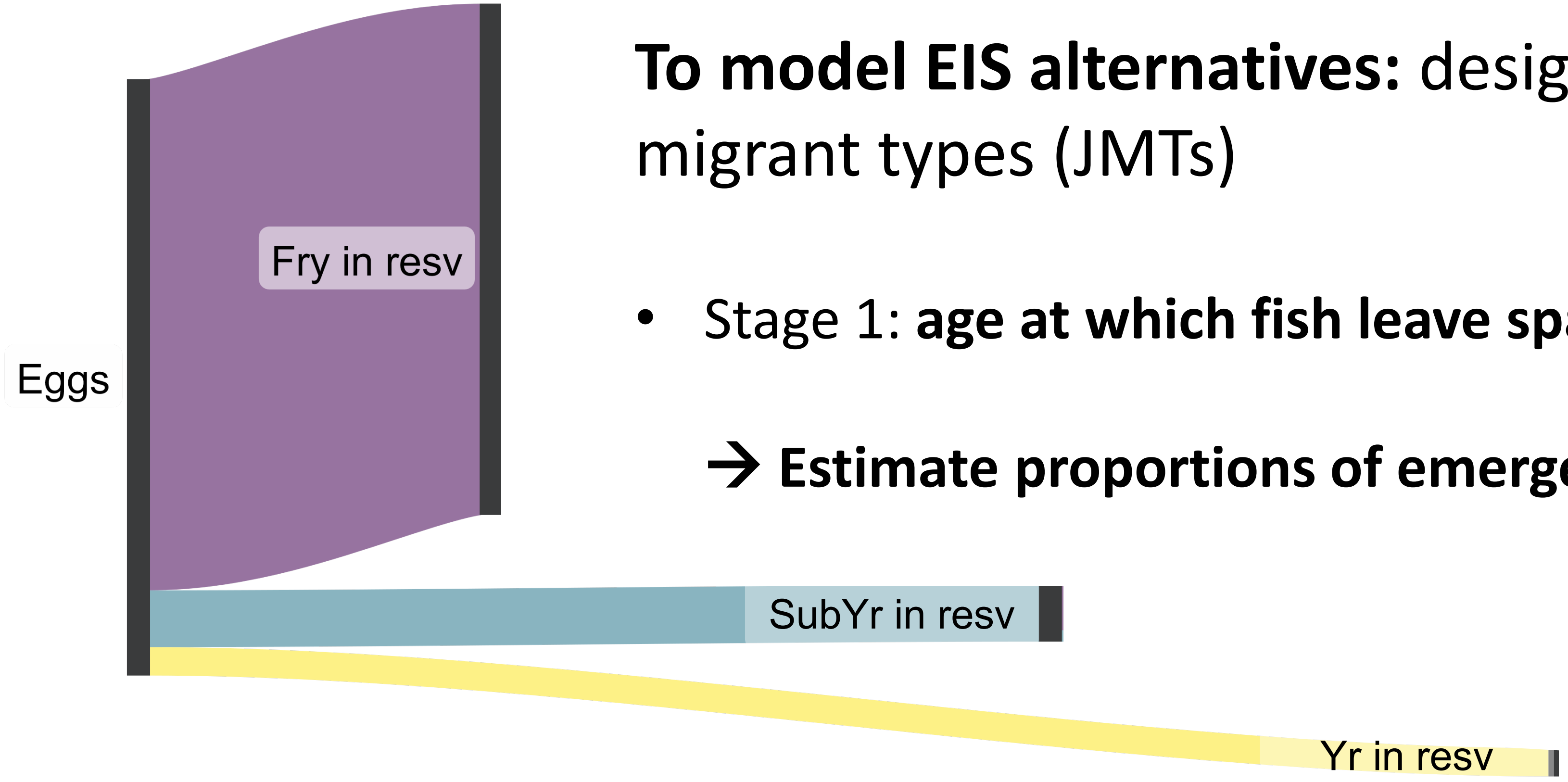
Modelling dam passage's effect on JMT diversity

To model EIS alternatives: designated six juvenile migrant types (JMTs)

- Stage 1: **age at which fish leave spawning areas**
  1. **Fry** migrate to reservoir directly
  2. **Subyearlings** rear in spawning areas over summer
  3. **Yearlings** rear in spawning areas over summer & winter

Same types as those used by the Fish Benefits Workbook to estimate dam passage survival and efficiency under different EIS alternatives

Modelling dam passage's effect on JMT diversity



To model EIS alternatives: designated six juvenile migrant types (JMTs)

- Stage 1: **age at which fish leave spawning areas**

  → Estimate proportions of emergent fry of each type

Migrant types from rotary screw trap (RST)

- Outmigration monitoring (e.g. Monzyk et al. 2011; Romer et al. 2012-2017)
  - Juvenile fish captured in RSTs at heads of reservoirs in each subbasin

Image credit: US Army Corps of Engineers

Monzyk et al. 2011, *Pilot Head-of-Reservoir Juvenile Salmonid Monitoring* (ODFW report); Romer et al. 2012-2017, *Juvenile Salmonid Outmigration Monitoring at Willamette Valley Project Reservoirs* (ODFW reports)

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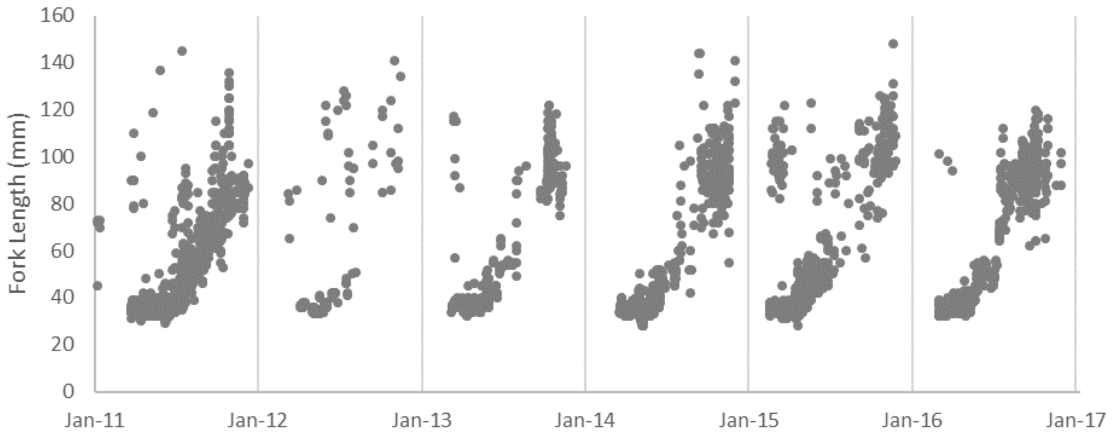

Data from RST at Detroit dam head of reservoir, North Santiam

Image credit: US Army Corps of Engineers

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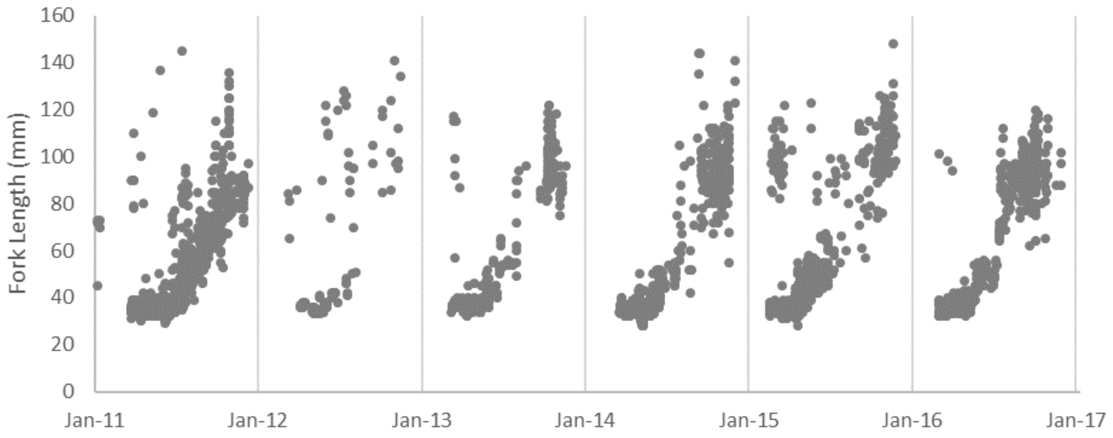
IPA team applied **date and size-based rules** informed by growth curve estimates:

Fry: Fork length <60mm

Yearlings: Fork length >60mm & migrating in January after emergence



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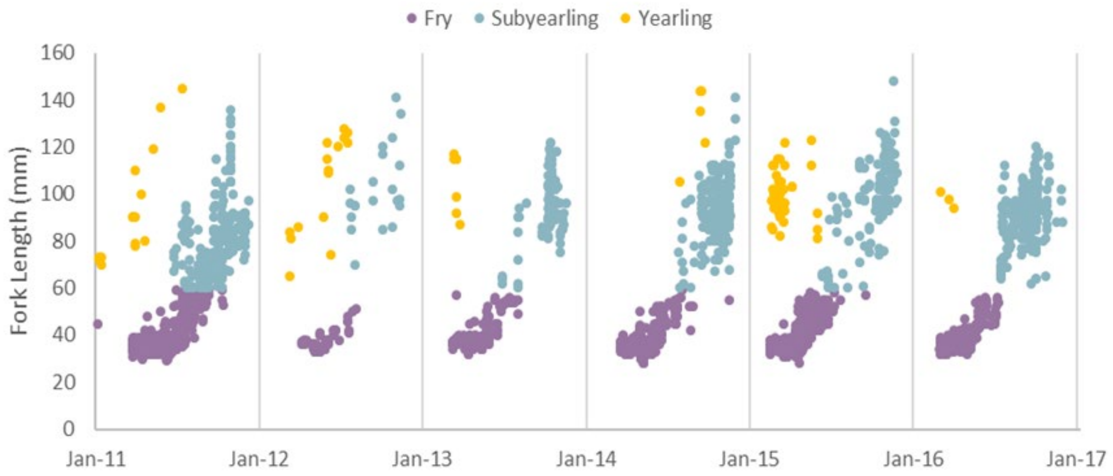


Data from RST at Detroit dam head of reservoir, North Santiam

IPA team applied **date and size-based rules** informed by growth curve estimates:

Fry: Fork length <60mm

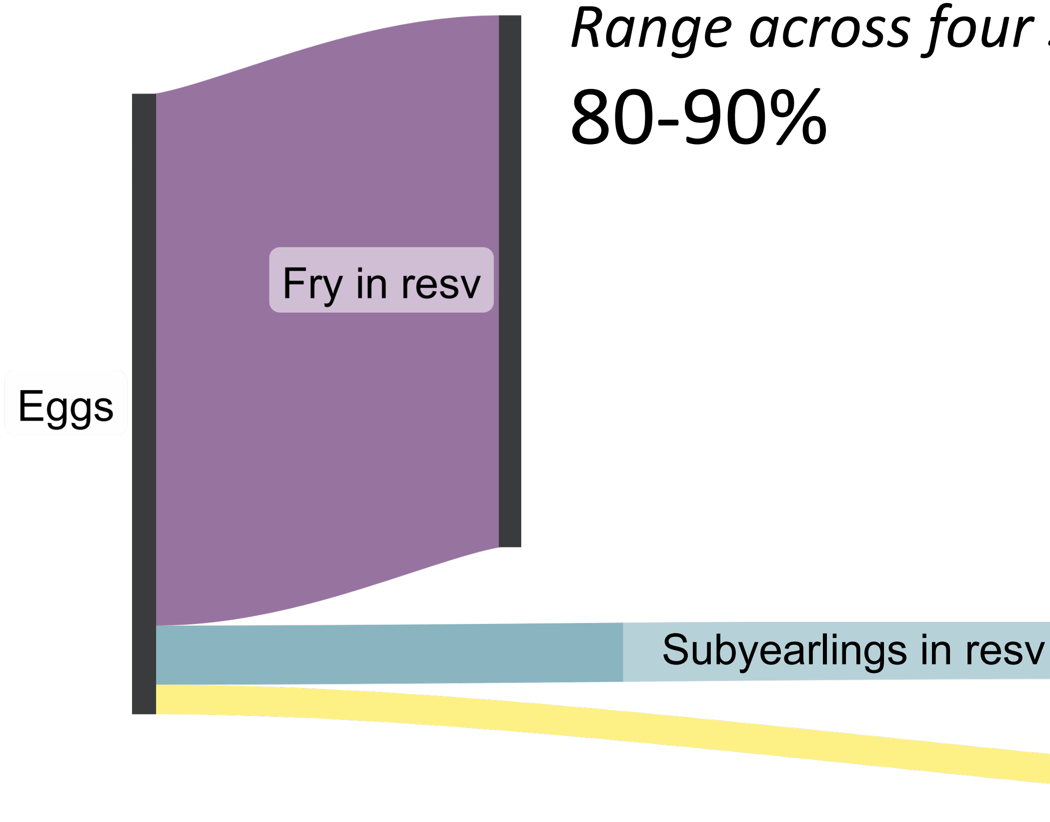
Subyearlings: *all others*

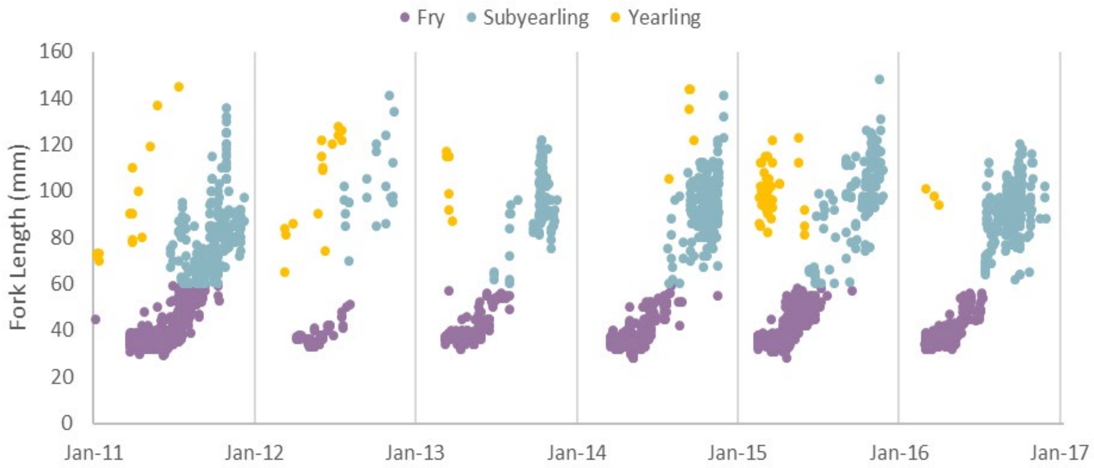
Yearlings: Fork length >60mm & migrating in January after emergence

Migrant types from rotary screw trap (RST)

Range across four subbasins:

80-90%



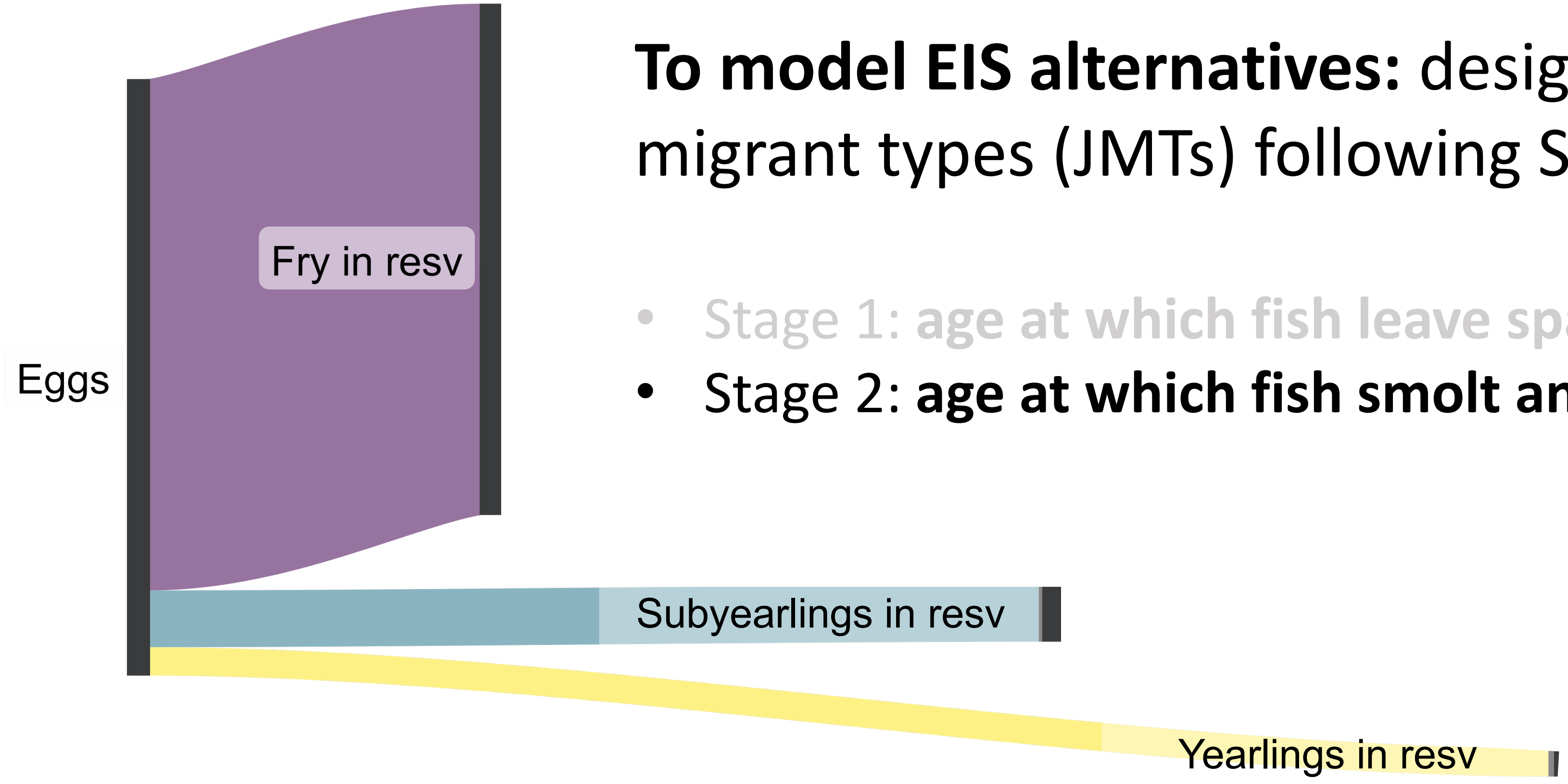


10-20%

1-5%

*Note: No incorporation of **inter-year variation** in proportions moving to reservoir at each stage*

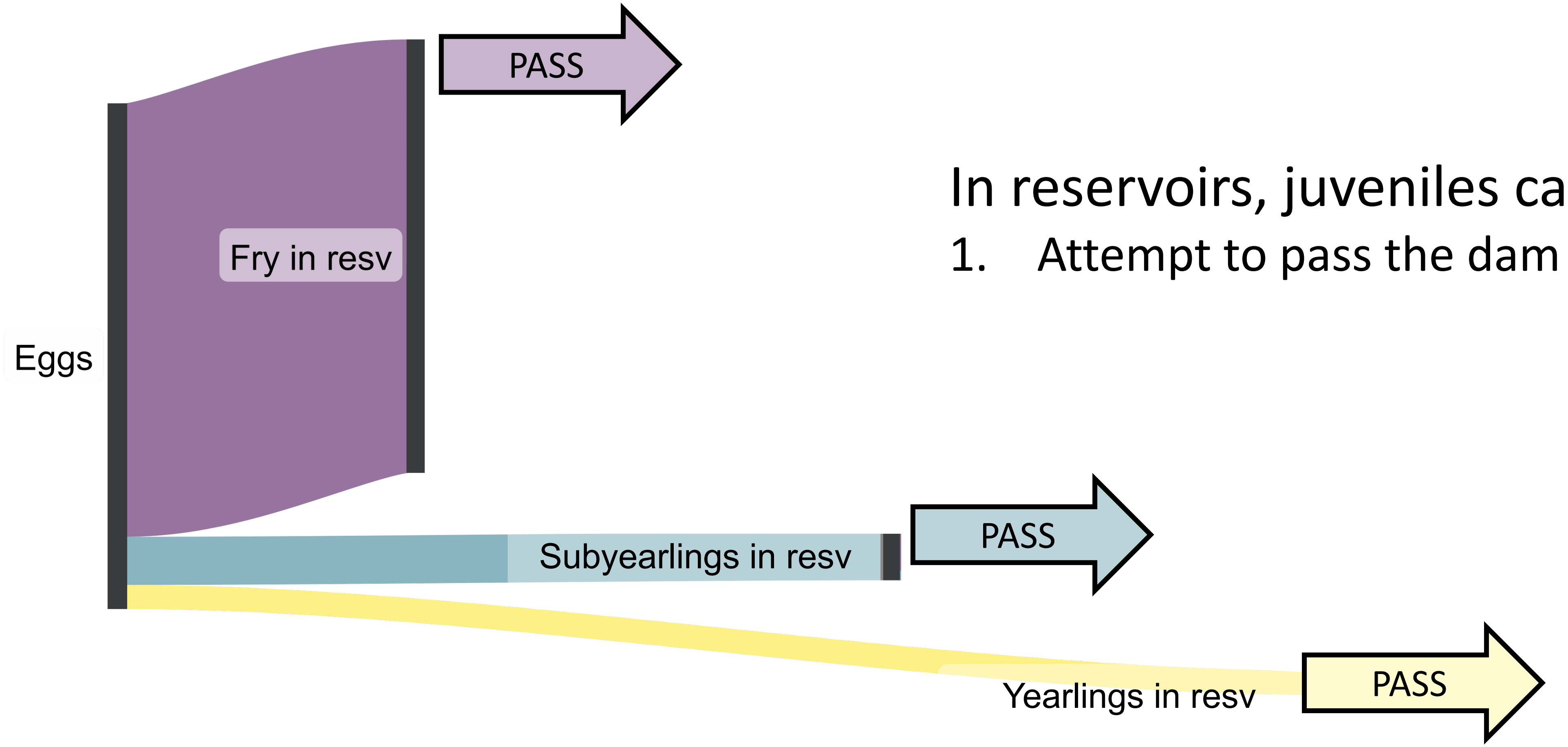
Modelling dam passage's effect on JMT diversity



To model EIS alternatives: designated six juvenile migrant types (JMTs) following Schroeder 2016

- Stage 1: **age at which fish leave spawning areas**
- Stage 2: **age at which fish smolt and migrate to sea**

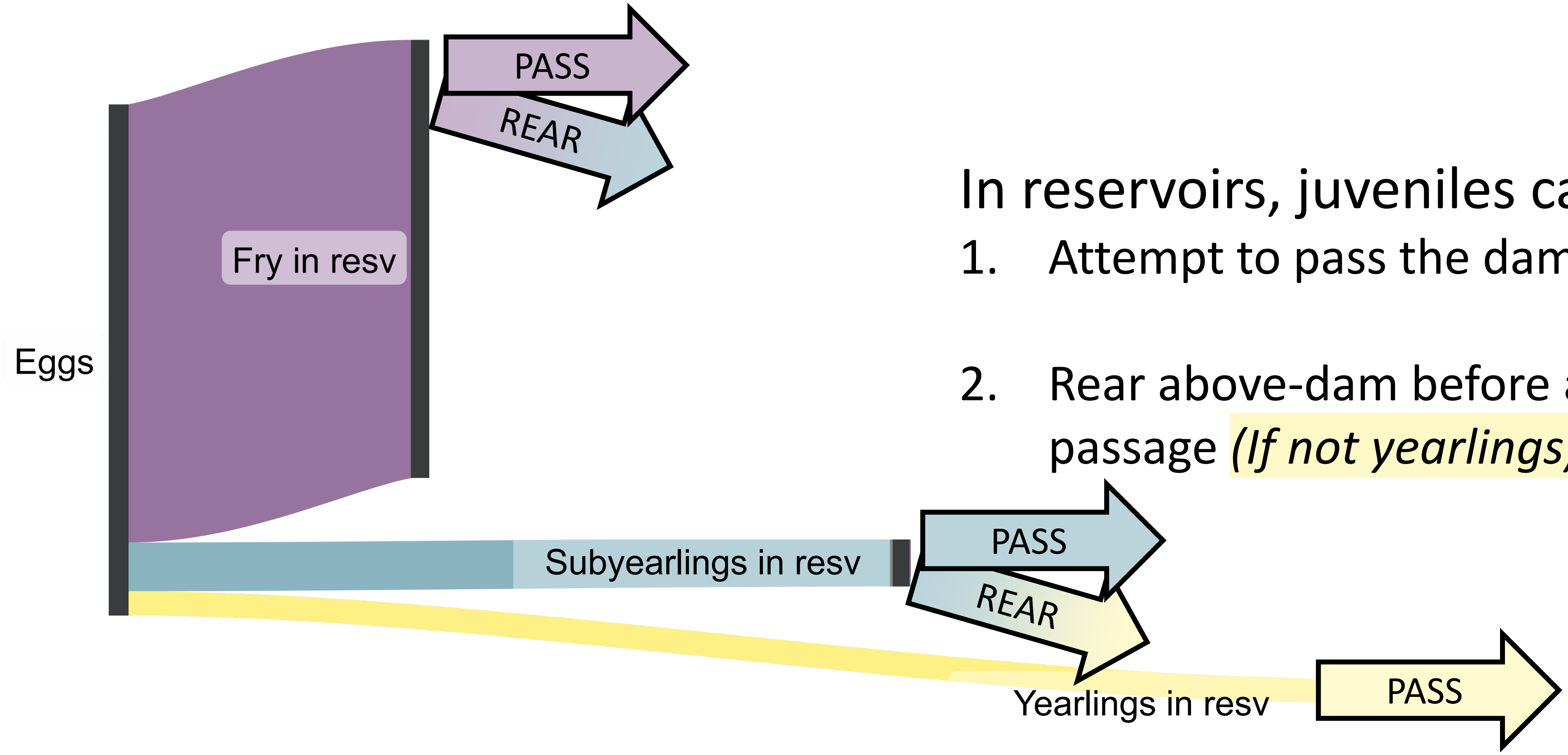
Dam passage and reservoir rearing



In reservoirs, juveniles can:

1. Attempt to pass the dam

Dam passage and reservoir rearing

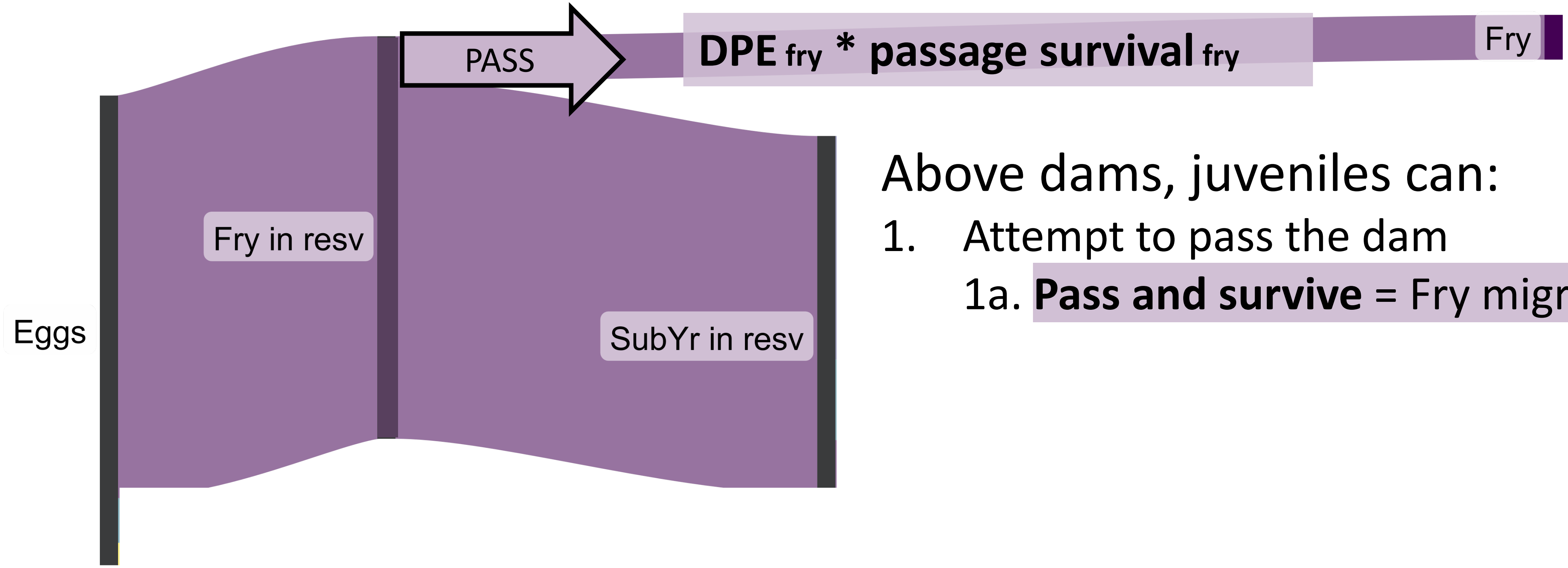


In reservoirs, juveniles can:

1. Attempt to pass the dam

2. Rear above-dam before attempting passage *(If not yearlings)*

Dam passage and reservoir rearing



Above dams, juveniles can:

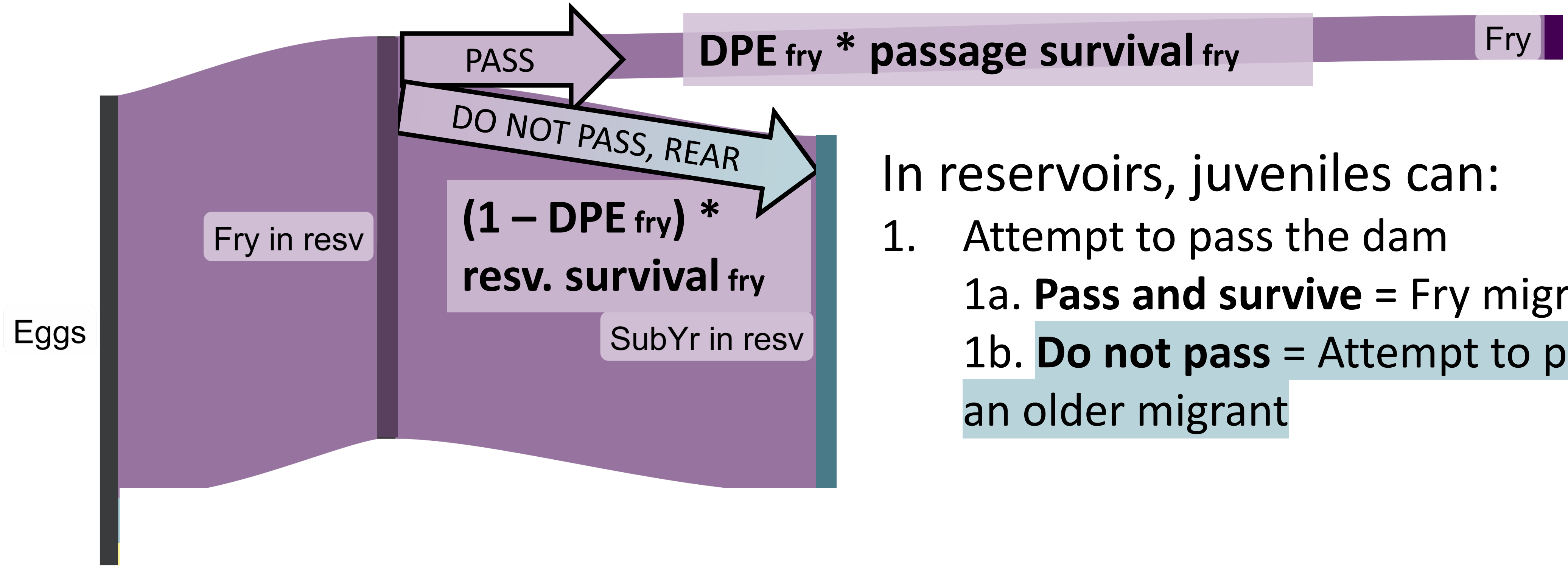
1. Attempt to pass the dam

    1a. **Pass and survive** = Fry migrants

DPE and passage survival estimates from Fish Benefits Workbook;
Reservoir survival estimates from expert workshops (e.g., COP 2015)

Zabel et al. 2015 (NWFS Report)

Dam passage and reservoir rearing



In reservoirs, juveniles can:

1. Attempt to pass the dam

   1a. **Pass and survive** = Fry migrants

   1b. **Do not pass** = Attempt to pass as an older migrant

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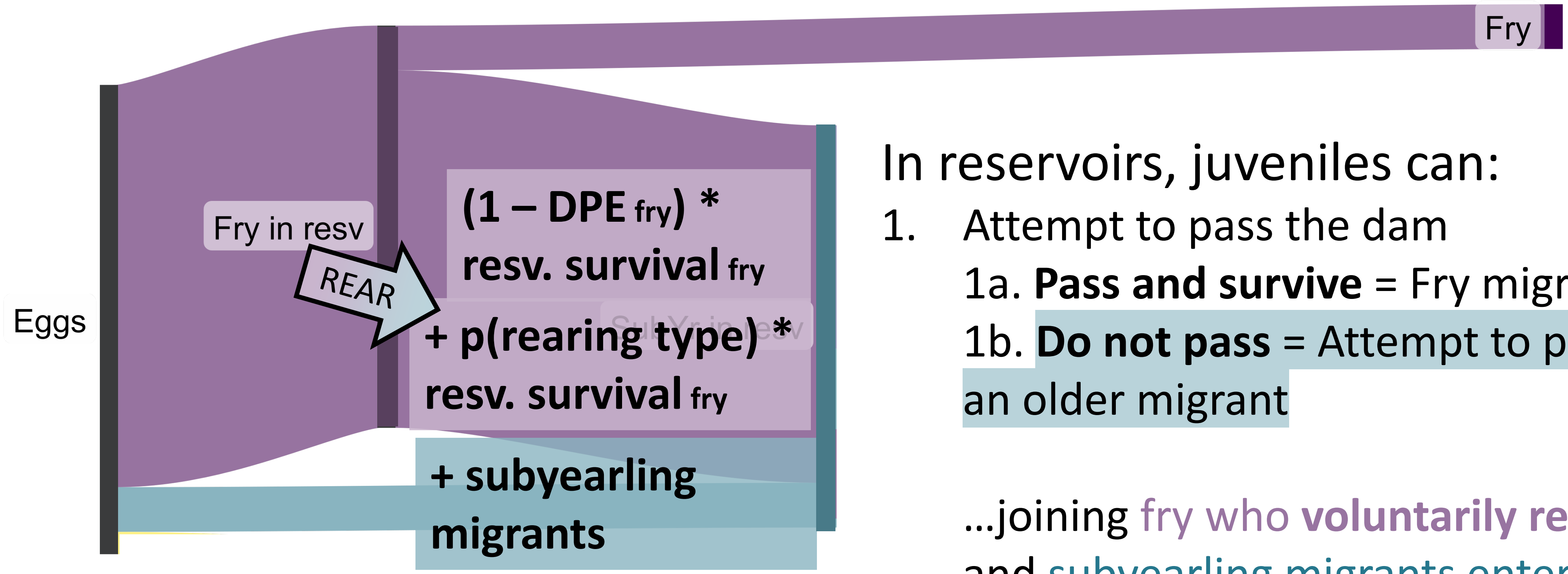
Dam passage and reservoir rearing



In reservoirs, juveniles can:

1. Attempt to pass the dam
   1a. **Pass and survive** = Fry migrants
   1b. **Do not pass** = Attempt to pass as an older migrant

…joining fry who **voluntarily reared** and subyearling migrants entering the reservoir

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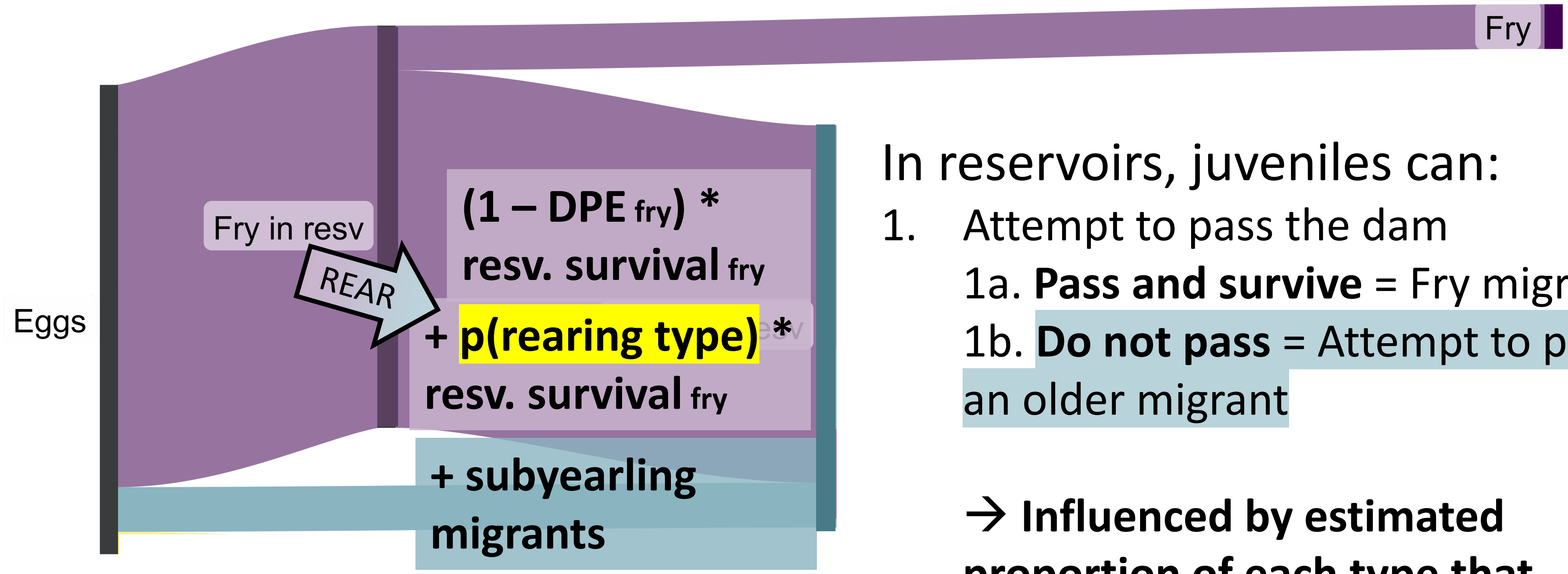
Dam passage and reservoir rearing



In reservoirs, juveniles can:

1. Attempt to pass the dam
   1a. **Pass and survive** = Fry migrants
   1b. **Do not pass** = Attempt to pass as an older migrant

→ **Influenced by estimated proportion of each type that volitionally rears** (from expert workshops)

DPE and passage survival estimates from Fish Benefits Workbook; Reservoir survival estimates from expert workshops (e.g., COP 2015)

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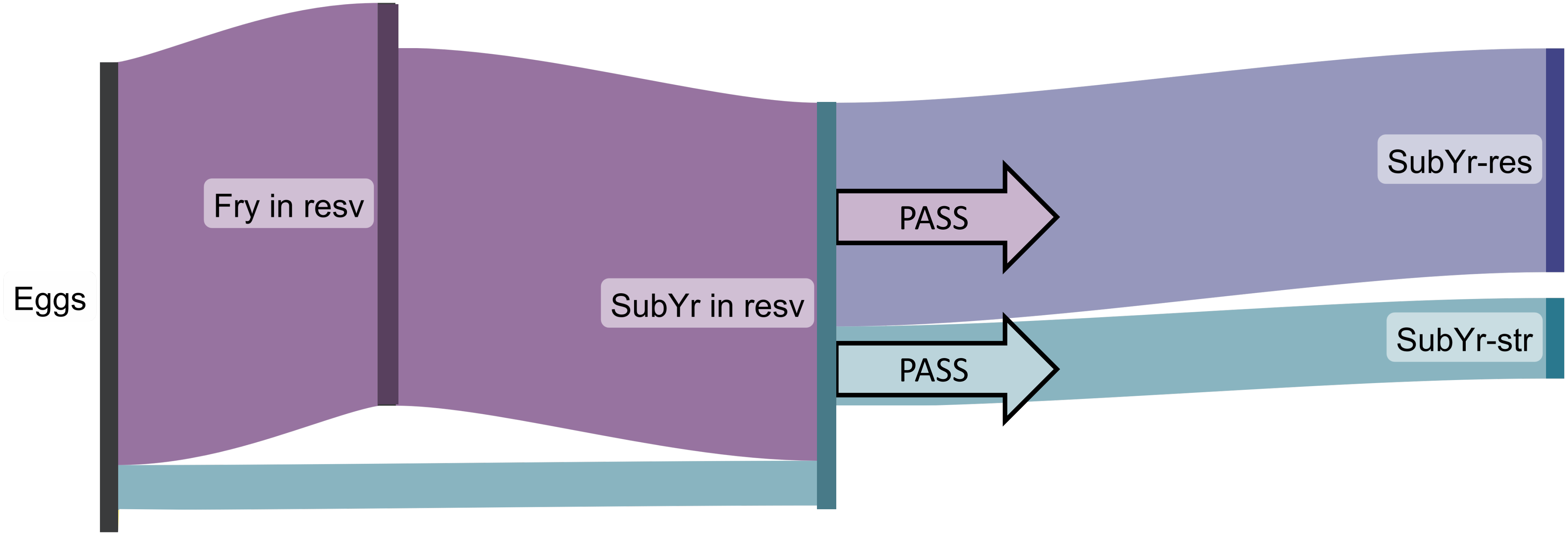
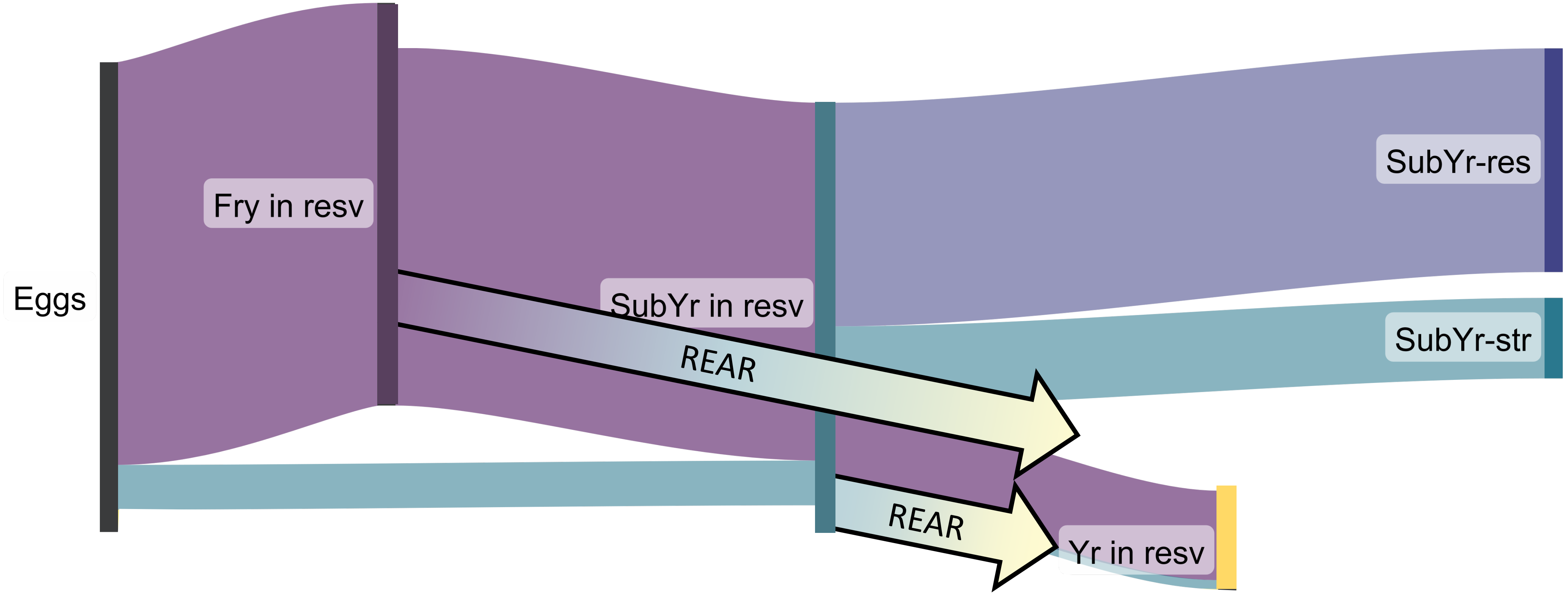
Dam passage and reservoir rearing



Dam passage and reservoir rearing



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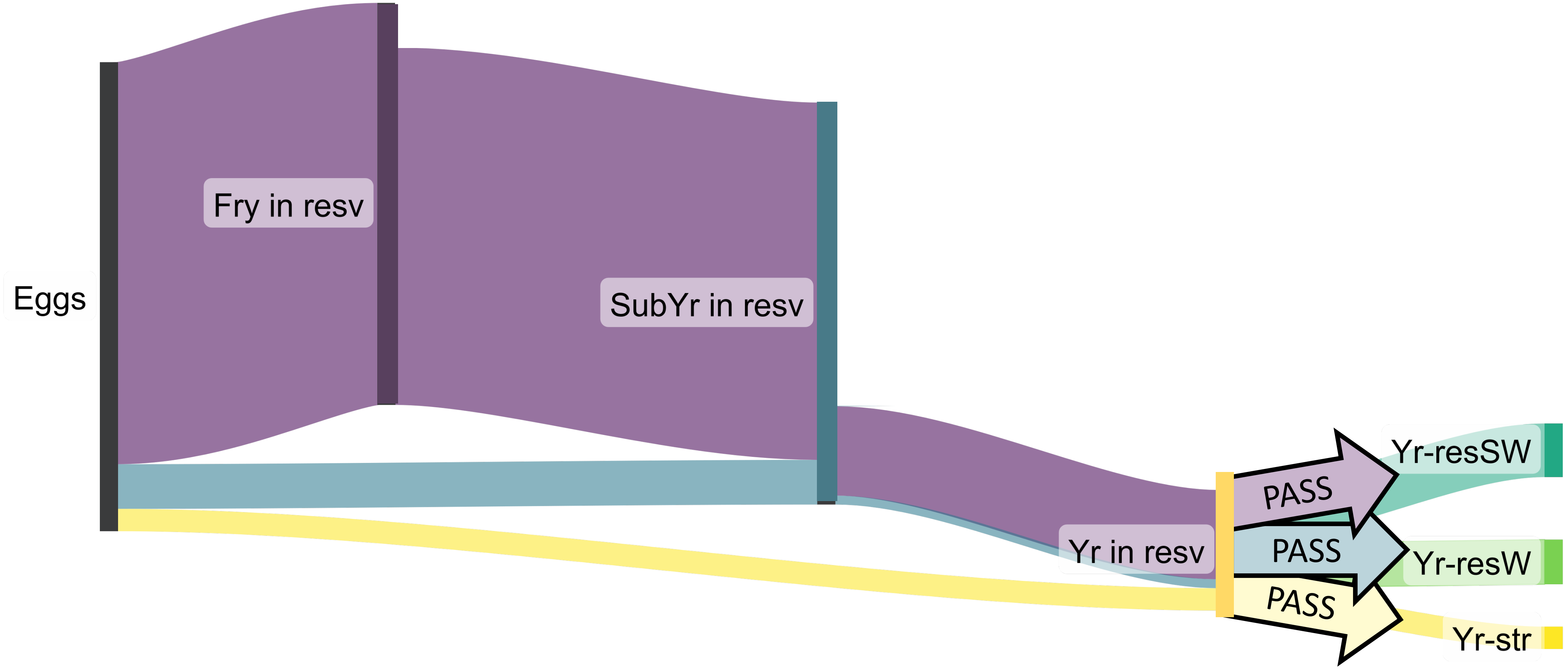
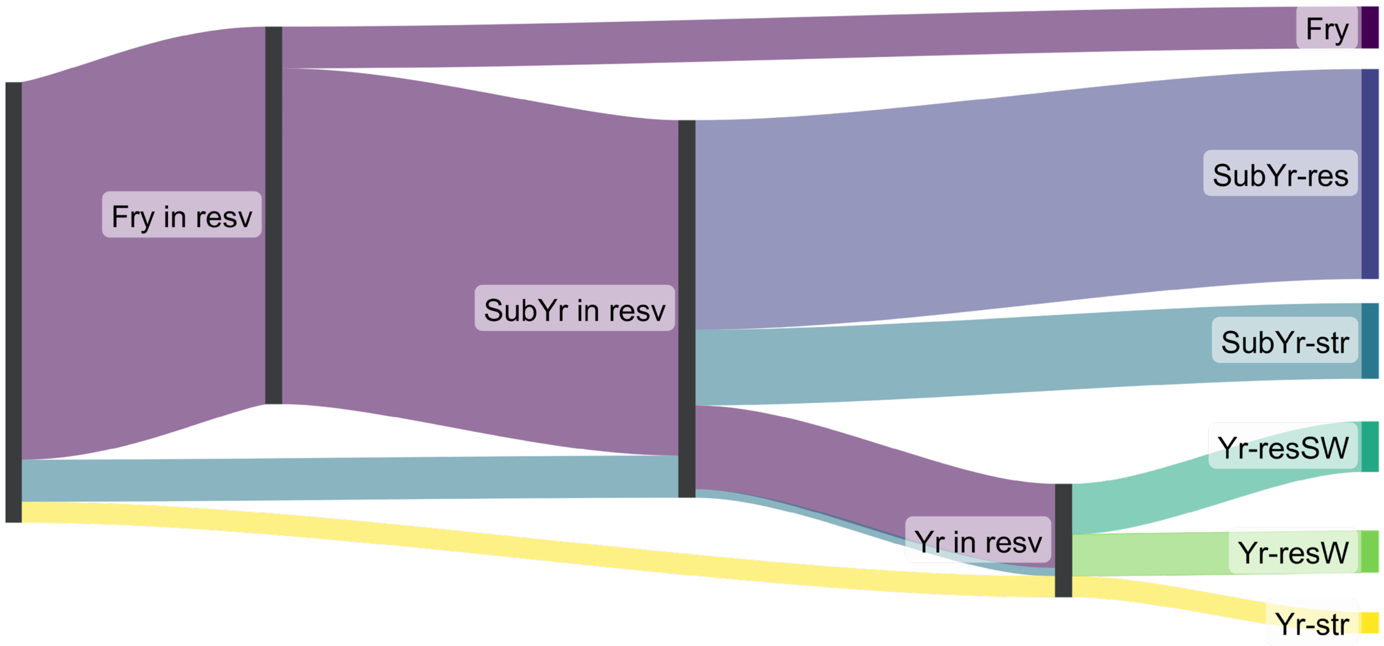


Six migratory types, impacted by split of fry/subyearling/yearlings and rearing patterns



Fry migrant

Reservoir-reared subyearling

Stream-reared subyearling

Reservoir-reared yearling

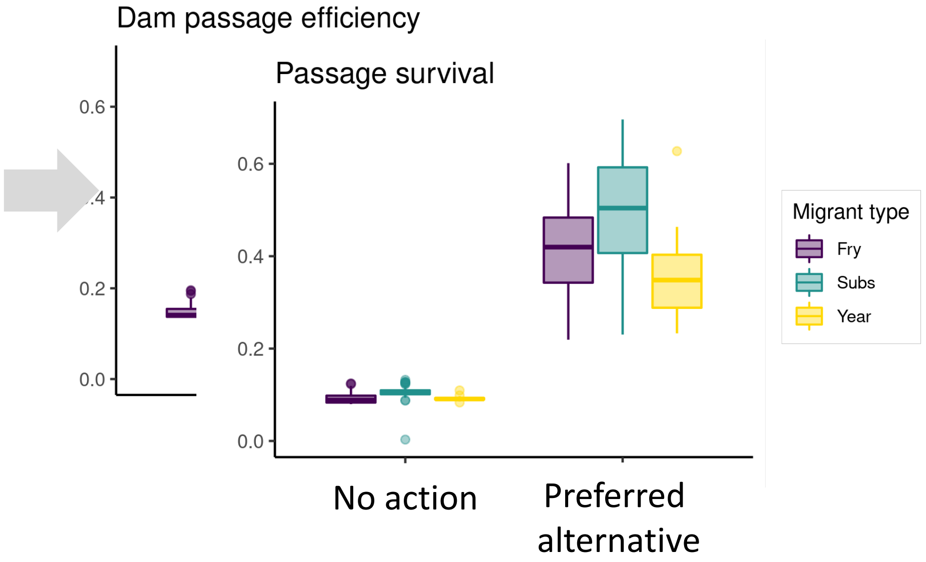
Stream- & reservoir-reared yearling

Stream-reared yearling

JMT diversity: Life cycle model predictions

Estimated DPE and passage survival
from the Fish Benefits Workbook

% fry,
subyearling,
yearling



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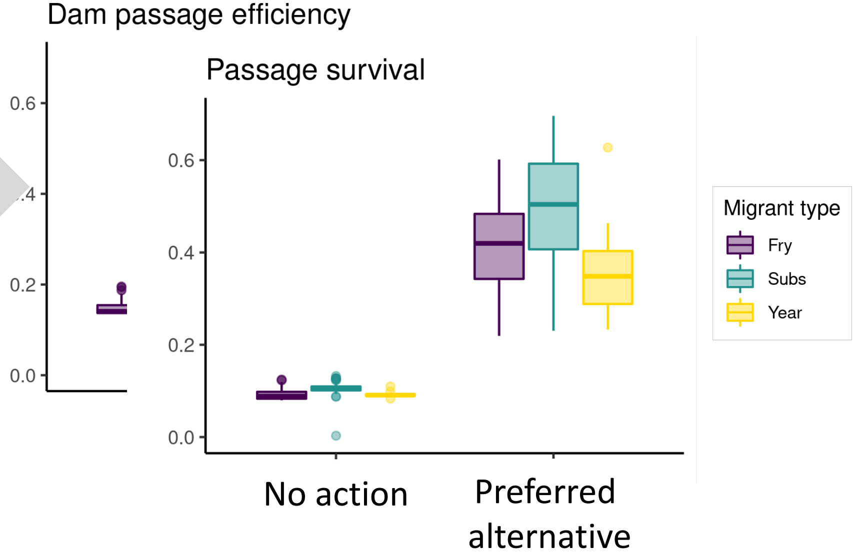
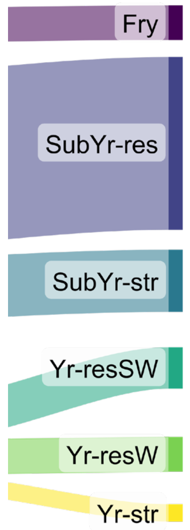


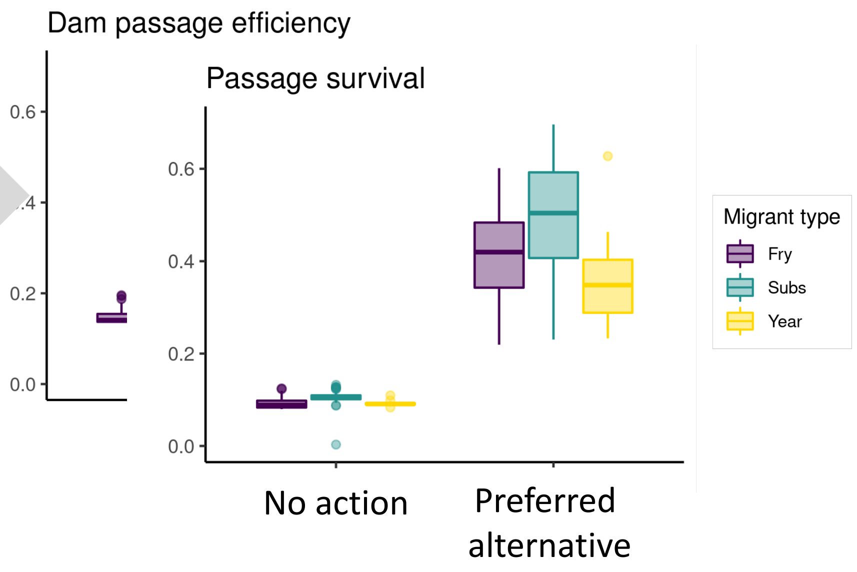
Six JMTs after passing the dam



JMT diversity: Life cycle model predictions

% fry, subyearling, yearling

Estimated DPE and passage survival from the Fish Benefits Workbook



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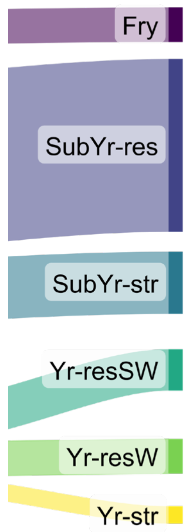


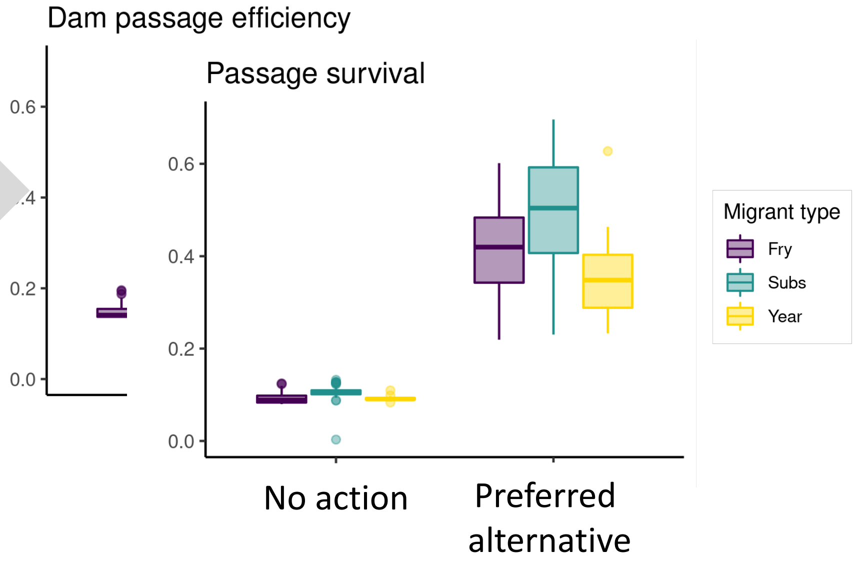
* In-river survival estimates from expert workshops

Zabel et al. 2015 (NWFS Report)

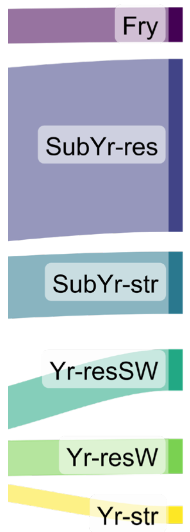
JMT diversity: Life cycle model predictions

% fry, subyearling, yearling

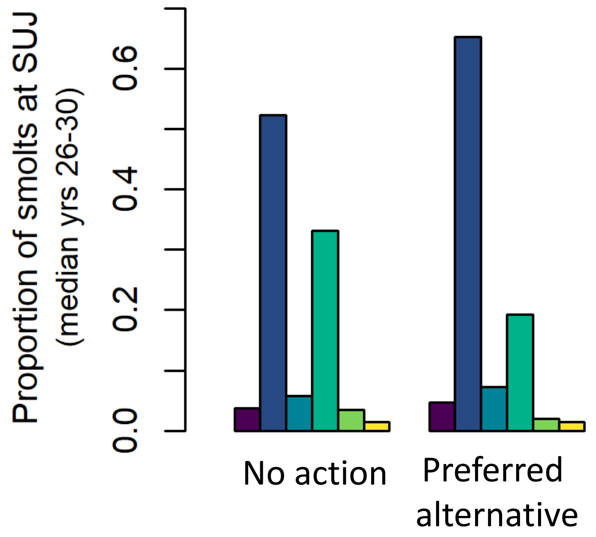
Estimated DPE and passage survival from the Fish Benefits Workbook



Six JMTs after passing the dam



= proportion of smolts of each type predicted to pass Sullivan Detection Centre (SUJ)

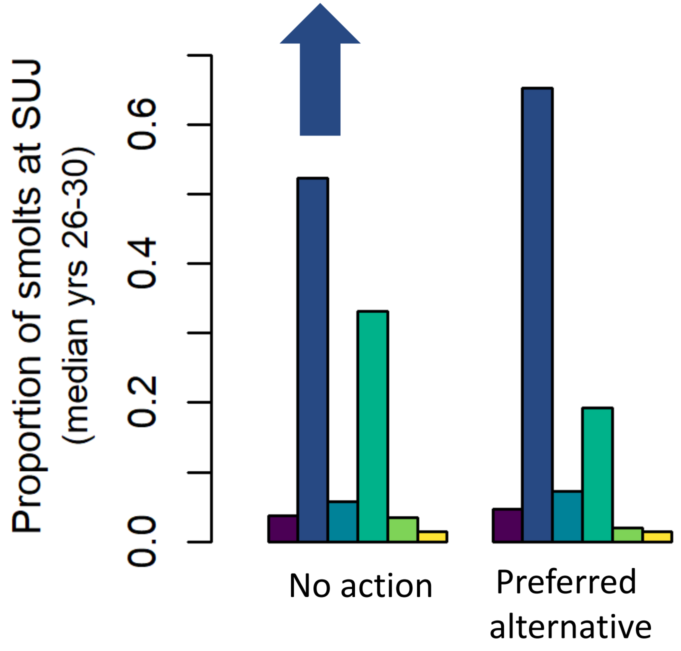


Zabel et al. 2015 (NWFS Report)

JMT diversity: Life cycle model predictions

In the McKenzie river: Changes to DPE/DPS at Cougar dam increases JMT that **enters the reservoir as fry and passes the dam as a subyearling**

Subyr-res: Fry migrants who rear in-reservoir then **pass as subyearlings**



JMT diversity: Life cycle model predictions

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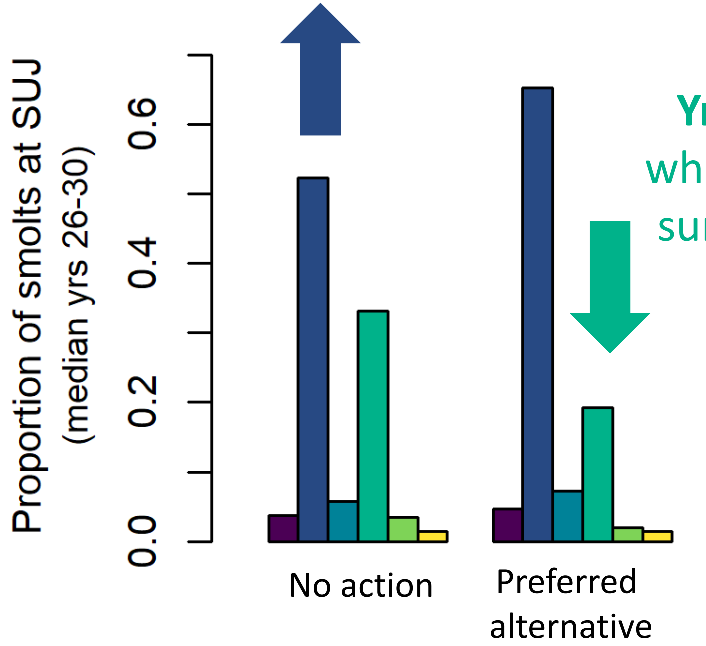
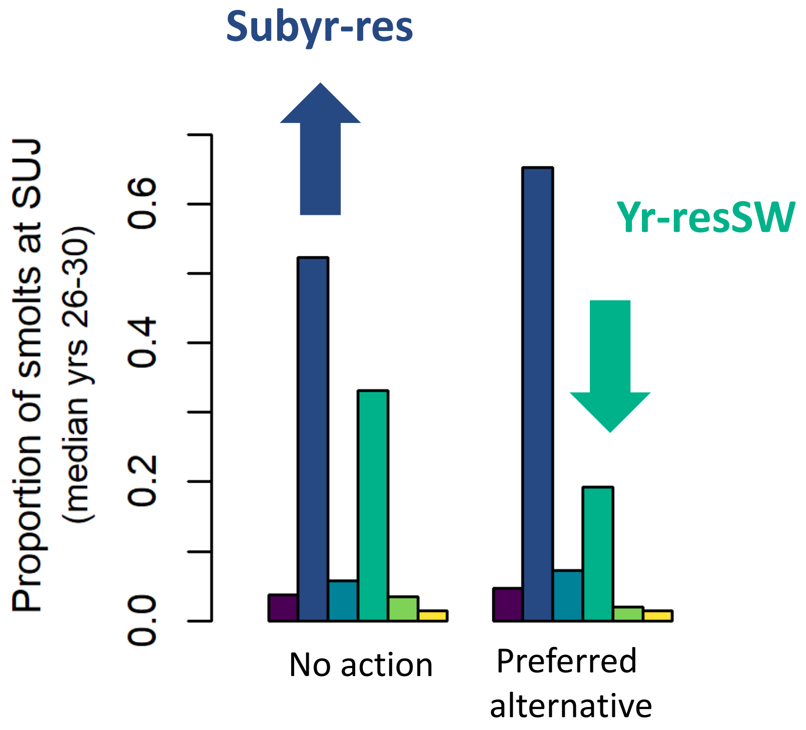
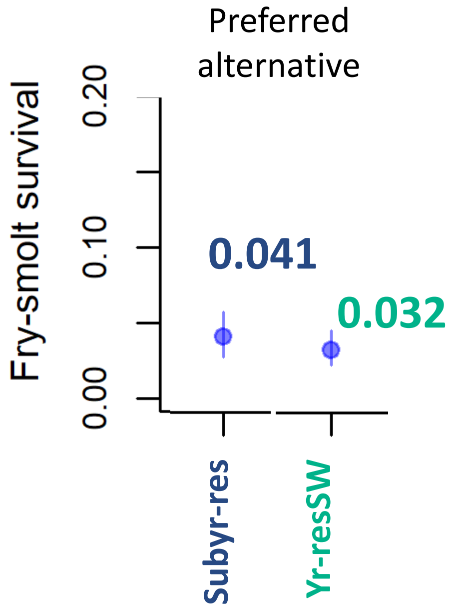


Yr-resSW: Fry migrants who rear in-reservoir over summer and winter then **pass as yearlings**

JMT diversity: Life cycle model predictions

In the McKenzie river: Changes to DPE/DPS at Cougar dam increases JMT that **enters the reservoir as fry and passes the dam as a subyearling**



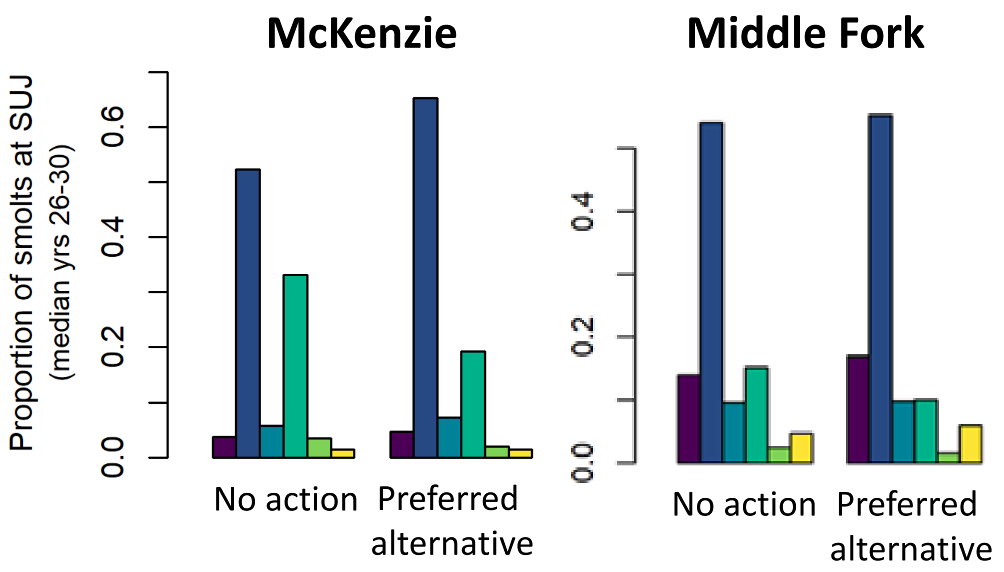


Favors JMT with higher fry-to-smolt survival

Alternatives that favor the **Subyr-res JMT** in the McKenzie have lower projected extinction risk

JMT diversity: Life cycle model predictions

***Note:** JMT diversity outcomes are subbasin specific*



In both McKenzie and Middle Fork, lowest extinction risk when **Subyr-res** is dominant

JMT diversity: Life cycle model predictions

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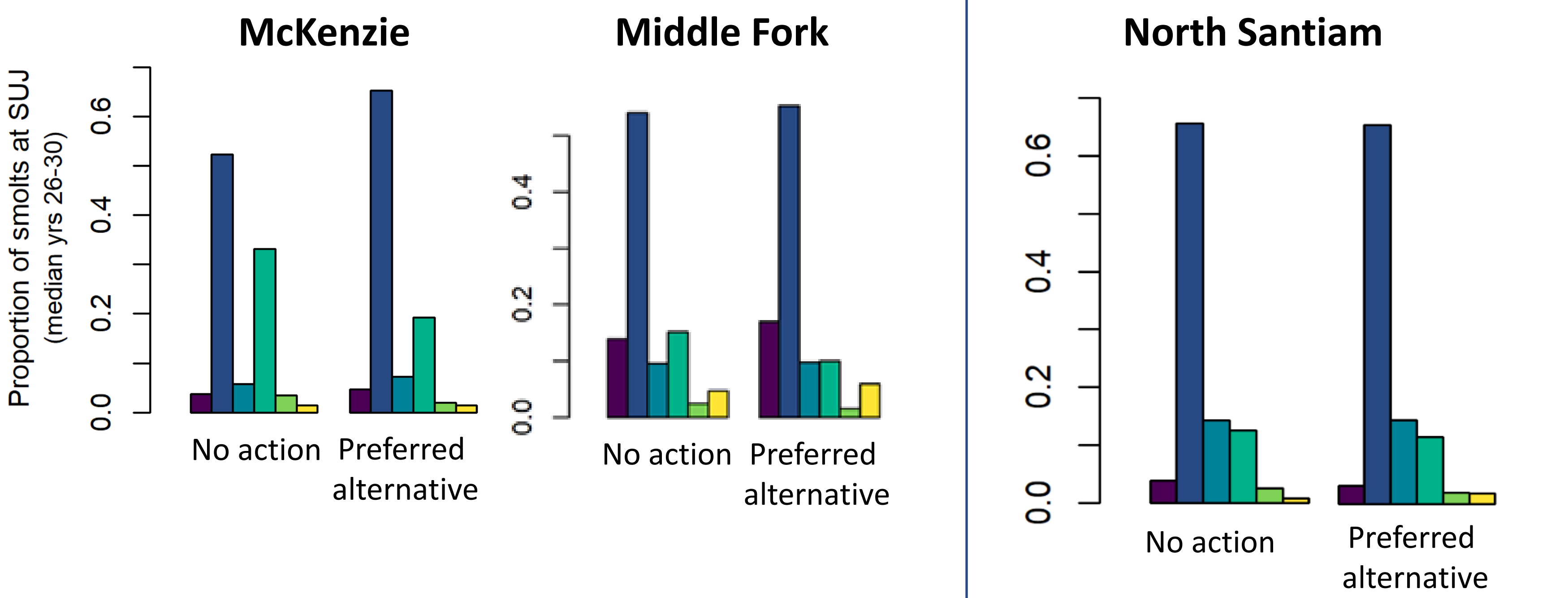
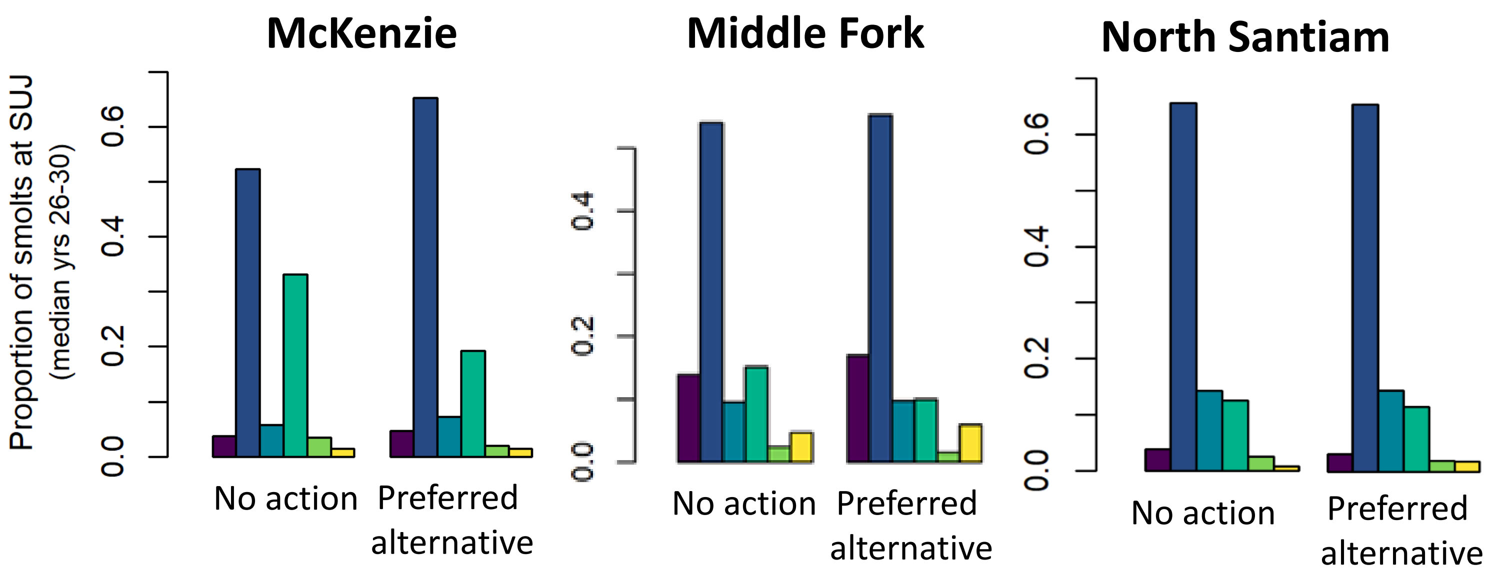
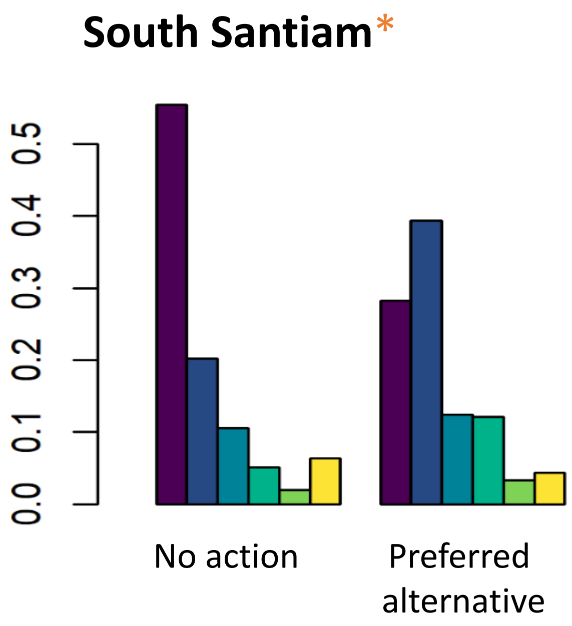


In N Santiam, minor effect of alternative on JMT diversity

JMT diversity: Life cycle model predictions

Note: *JMT diversity outcomes are subbasin specific*





In S Santiam, alternatives with highest returns favor **older types**

*but outcomes influenced by changes to outplanting rules above Green Peter

JMT diversity: Limitations and assumptions

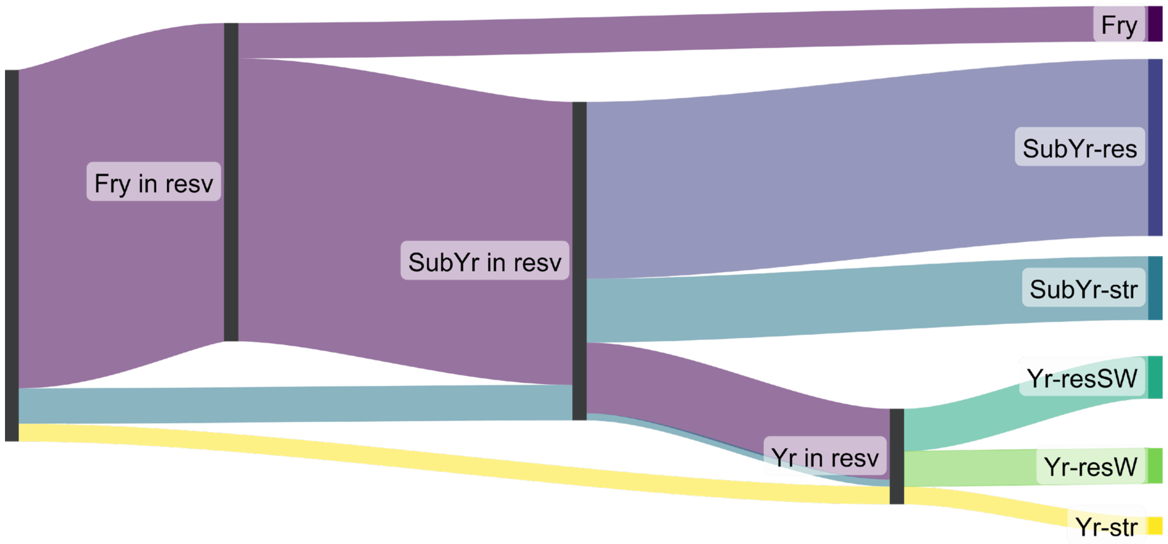
- Limitations:
  - Screw trap data cannot distinguish migrants who **choose** to rear from those that were diverted back to the reservoir by the dam
    - Could be informed by, e.g., 3D acoustic telemetry

- Proportion of fry/subyearling/ yearling migrant types influenced by other factors
  - e.g., density-dependent processes (Zimmerman et al. 2015)
  - e.g. evolution in response to dams (Waples et al. 2017)

Waples et al. 2017, doi:10.1111/eva.12468; Zimmerman et al. 2015, doi:10.1080/00028487.2015.1017658

Conclusions

- Changes to dam passage efficiency and outplanting can have large impacts on JMT diversity, but not universally
  - Long-term impacts depend on relative productivity of migrant types, future conditions

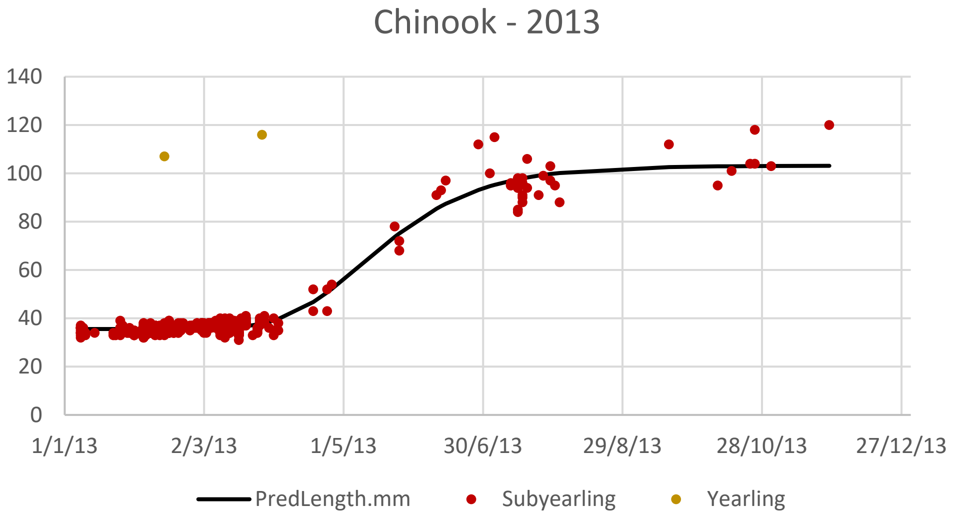


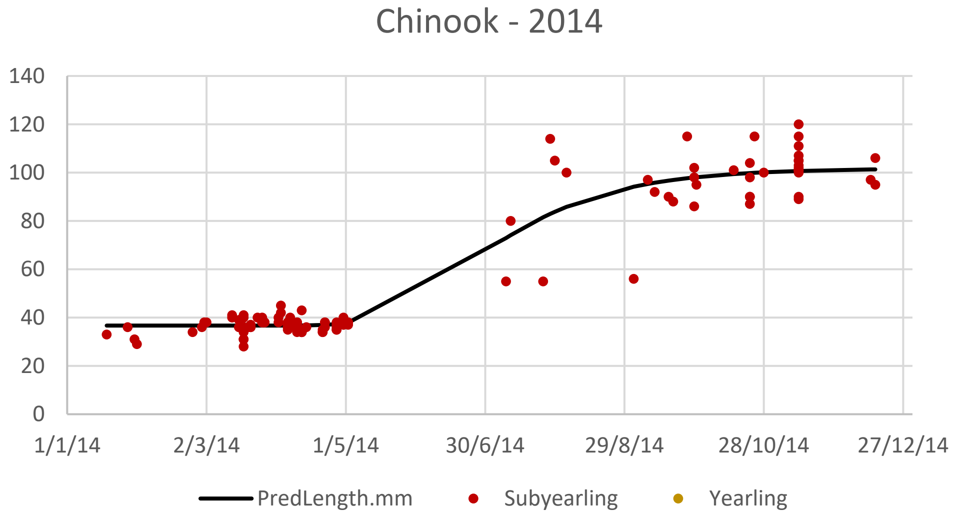
- Despite trade-offs between migrant types; diversity itself is advantageous

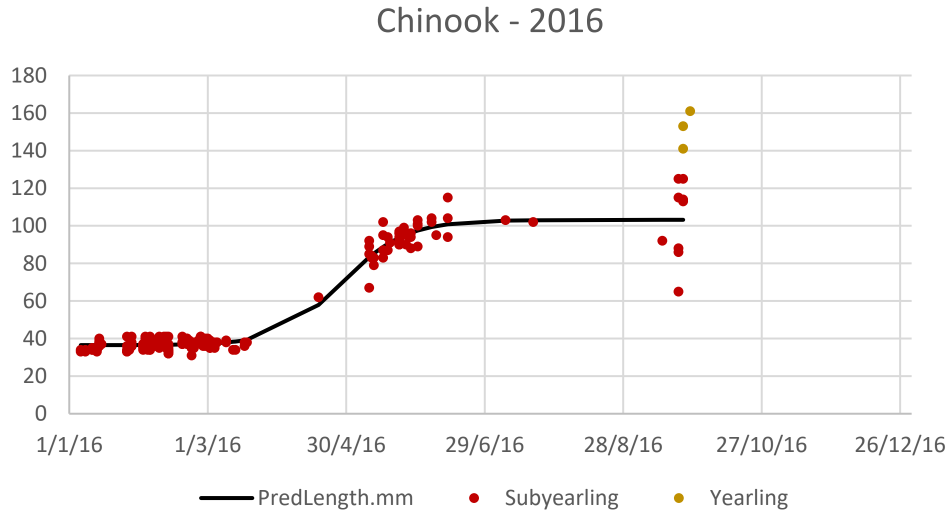
Definition of the juvenile migrant types used in the UBC Chinook life cycle model compared to the JMTs documented by Schroeder et al. (2016).

Juvenile migrant type (life stage – rearing location before smolting)	**Schroeder et al. (2016) life history type** (migrant type – smolt type)
Fry	**Mover** – spring subyearling
Subyearling – reservoir rearing in summer	**Mover** – fall subyearling
Subyearling – spawning area rearing in summer	**Stayer-fall migrant** – autumn subyearling
Yearling – reservoir rearing in summer & winter	**Mover** – spring yearling
Yearling – spawning area in summer, reservoir in winter	**Stayer-fall migrant** – spring yearling
Yearling – spawning area rearing in summer & winter	**Stayer-spring migrant** – spring yearling

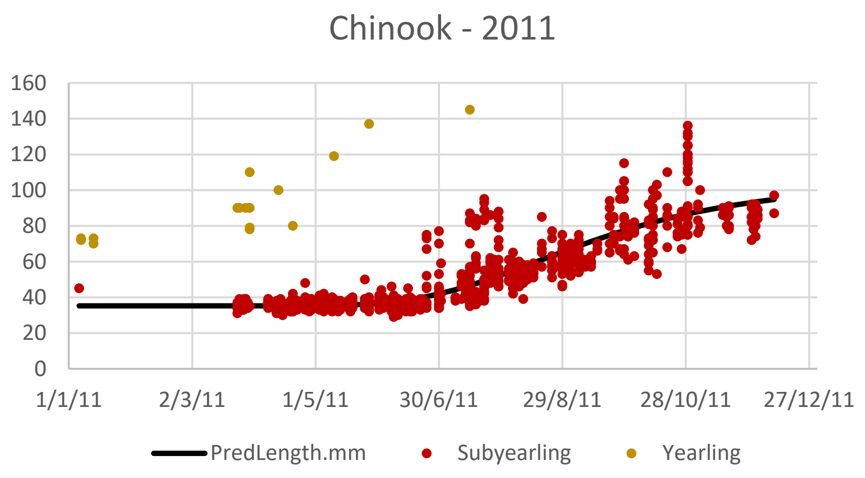
Observed growth from RST data: South Santiam above Foster

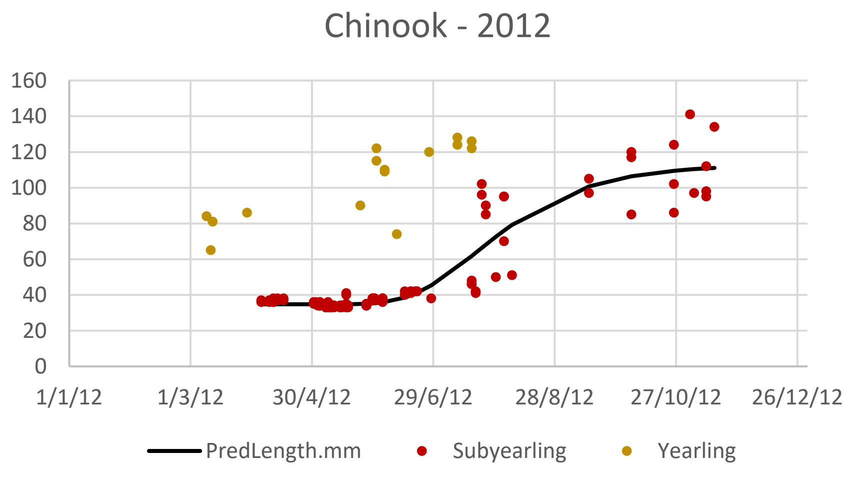


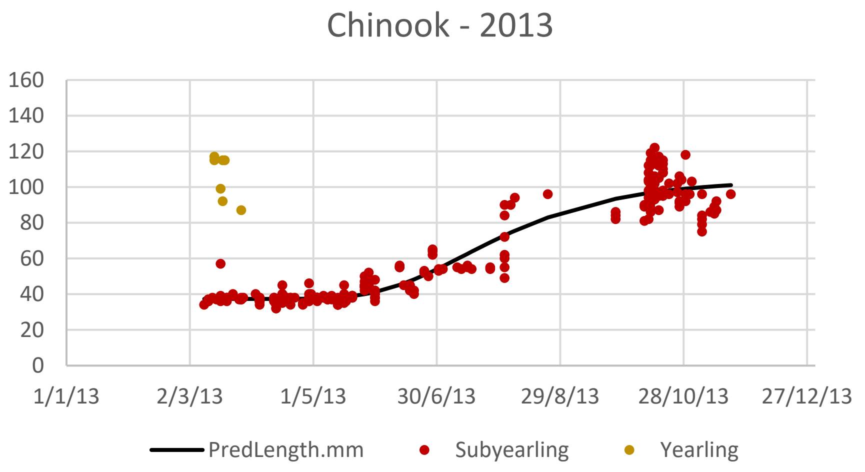


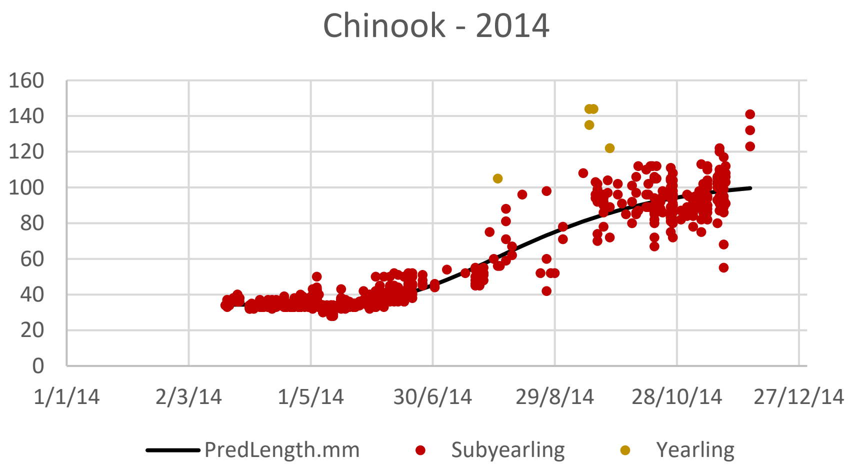


Observed growth from RST data: North Santiam above Detroit

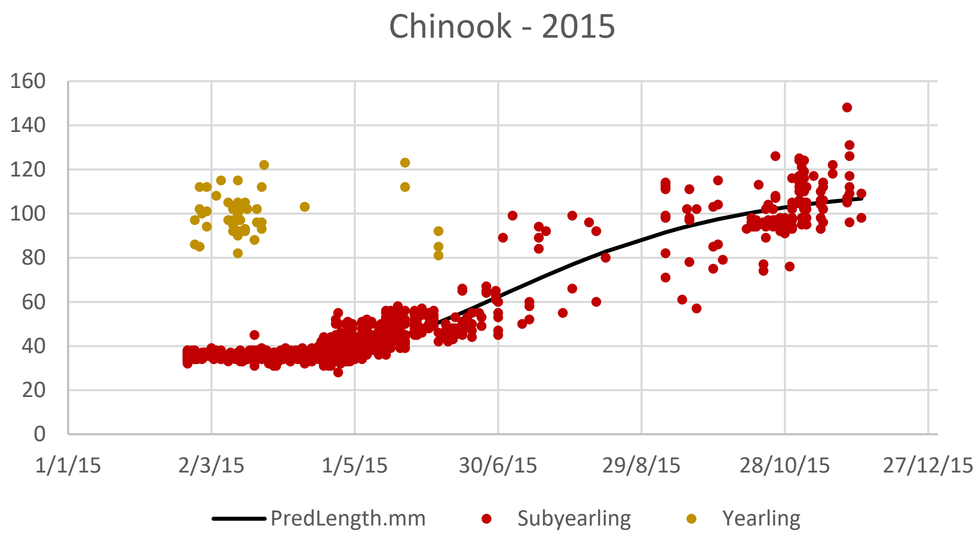


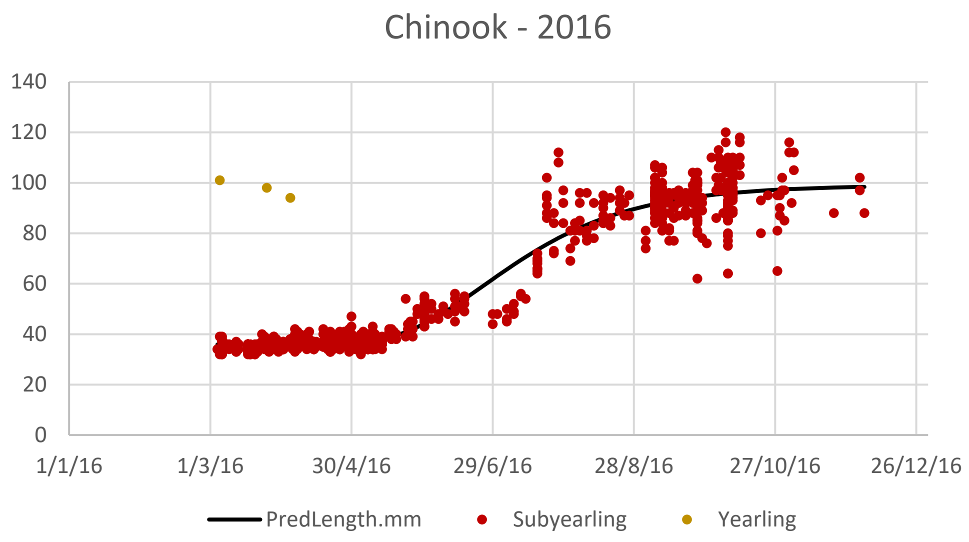






Observed growth from RST data: North Santiam above Detroit





Chinook size in Detroit reservoir by life history growth group

AIM: to get mean size at passage of each life history growth type under each Alternative

0.8125 (mm/day)

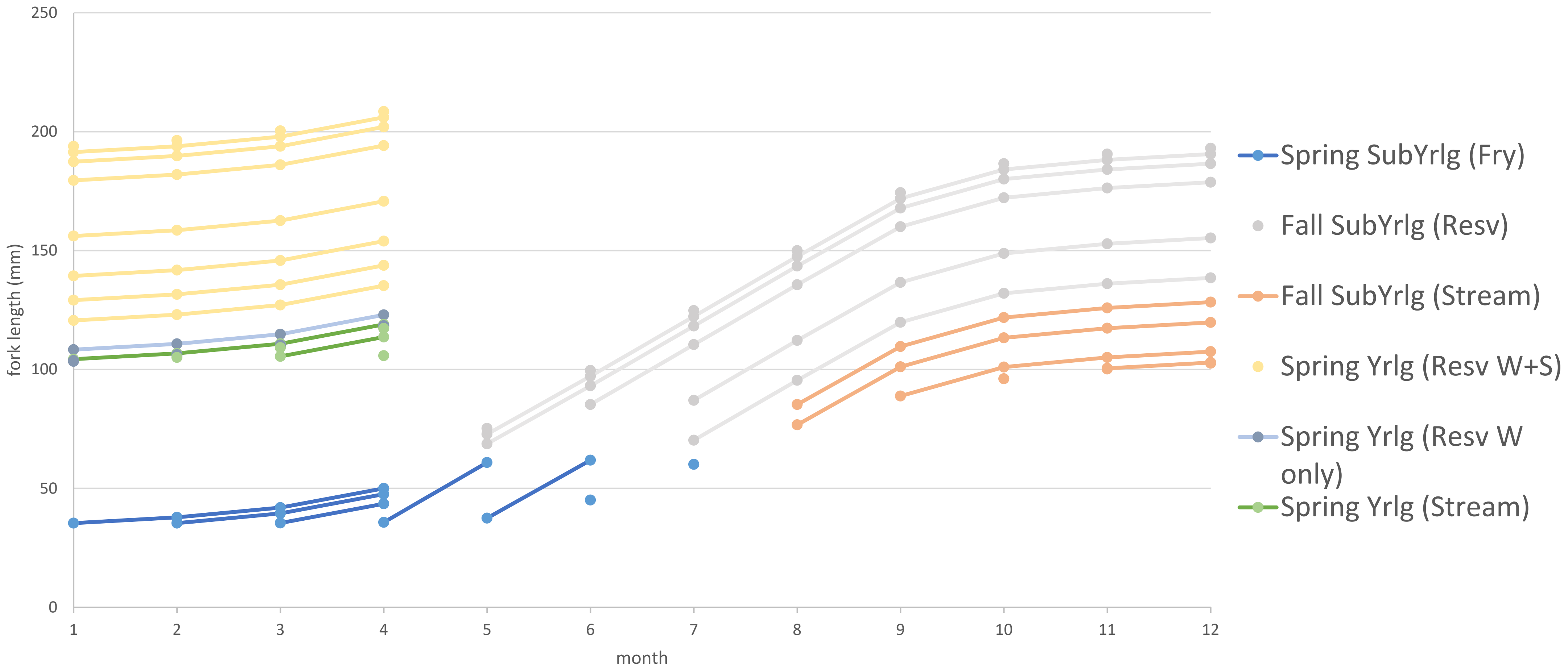
Mon_Yr	Growth days	Jan_0	Feb_0	Mar_0	Apr_0	May_0	Jun_0	Jul_0	Aug_0	Sep_0	Oct_0	Nov_0	Dec_0	Jan_1	Feb_1	Mar_1	Apr_1
Yr0-Jan	1	35															
Yr0-Jan	3	38	35														
Yr0-Feb	5	42	39	35													
Yr0-Mar	10	50	48	44	36												
Yr0-Apr	31	75	73	69	61	37											
Yr0-Jun	30	100	97	93	85	62	45										
Yr0-Jul	31	125	122	118	110	87	70	60									
Yr0-Aug	31	150	148	143	136	112	95	85	77								
Yr0-Sep	30	174	172	168	160	137	120	110	101	89							
Yr0-Oct	15	187	184	180	172	149	132	122	113	101	96						
Yr0-Nov	5	191	188	184	176	153	136	126	117	105	100	100					
Yr0-Dec	3	193	191	187	179	155	139	128	120	108	103	103	103				
Yr1-Jan	1	194	191	187	180	156	139	129	121	108	103	104	104	104			
Yr1-Feb	3	196	194	190	182	159	142	132	123	111	106	106	106	107	105		
Yr1-Mar	5	200	198	194	186	163	146	136	127	115	110	110	110	111	109	106	
Yr1-Apr	10	208	206	**202**	194	171	154	144	135	123	118	118	118	119	117	114	106

Spring SubYrlg (Fry)
Fall SubYrlg (Resv)
Fall SubYrlg (Stream)
Spring Yrlg (Resv W+S)
Spring Yrlg (Resv W only)
Spring Yrlg (Stream)

Chinook size in Detroit reservoir by life history growth group

AIM: to get mean size at passage of each life history growth type under each Alternative

0.8125 (mm/day)



Observed growth from RST data

Generalised logistic function

From Wikipedia, the free encyclopedia

The **generalized logistic function** or **curve**, also known as **Richards' curve**, originally developed for growth modelling, is an extension of the logistic or sigmoid functions, allowing for more flexible S-shaped curves:

$$Y(t) = A + \frac{K - A}{(C + Qe^{-Bt})^{1/\nu}}$$

where Y = weight, height, size etc., and t = time.

It has five parameters:

- A: the lower asymptote;
- K: the upper asymptote when $C = 1$. If $A = 0$ and $C = 1$ then K is called the carrying capacity;
- B: the growth rate;
- $\nu > 0$: affects near which asymptote maximum growth occurs.
- Q: is related to the value $Y(0)$
- C: typically takes a value of 1. Otherwise, the upper asymptote is $A + \frac{K - A}{C^{1/\nu}}$

Parameters for North Santiam above Detroit

	2011	2012	2013	2014	2015	2016
lower	35.2702635	34.7700743	37.3574169	34.3568932	34.6631158	35.9129187
upper	103.293968	112.927676	103.916528	104.843003	112.627744	99.0211348
b	0.01754927	0.03166386	0.0240977	0.02045229	0.01701698	0.02849059
v	0.00457926	0.00100911	0.00314983	0.0038431	0.00590044	0.00244563
q	0.25629108	0.60253626	0.34330681	0.29197036	0.13354944	0.37871153
n.obs	1479	155	306	1097	1590	1253
SS	84201.6493	10684.5048	15022.3563	45416.6636	41367.1013	32602.7521