An ecosystem-science approach to support salmon management: **How ocean sampling can help modeling efforts**

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How ocean sampling can help modeling efforts

1) Conceptual models representing the contemporary understanding of the ecosystem
2) Improving understanding of salmon behavior, growth, and mortality rates at sea,
3) Improve salmon assessment models based on research of ecosystem processes,
4) Life-cycle models to evaluate tradeoffs associated with management alternatives.
5) Looking to the future

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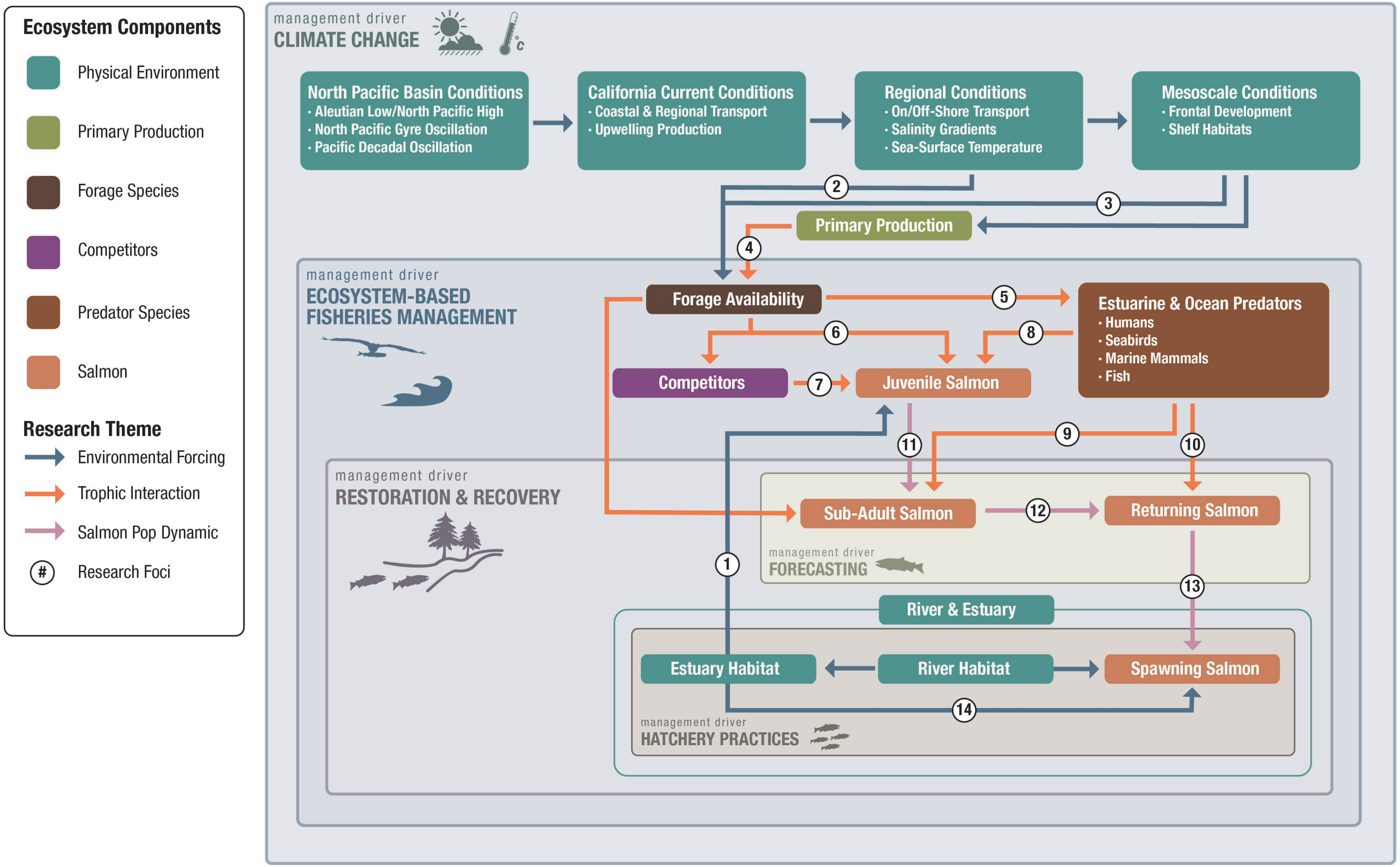
1) Designing purpose-built conceptual models



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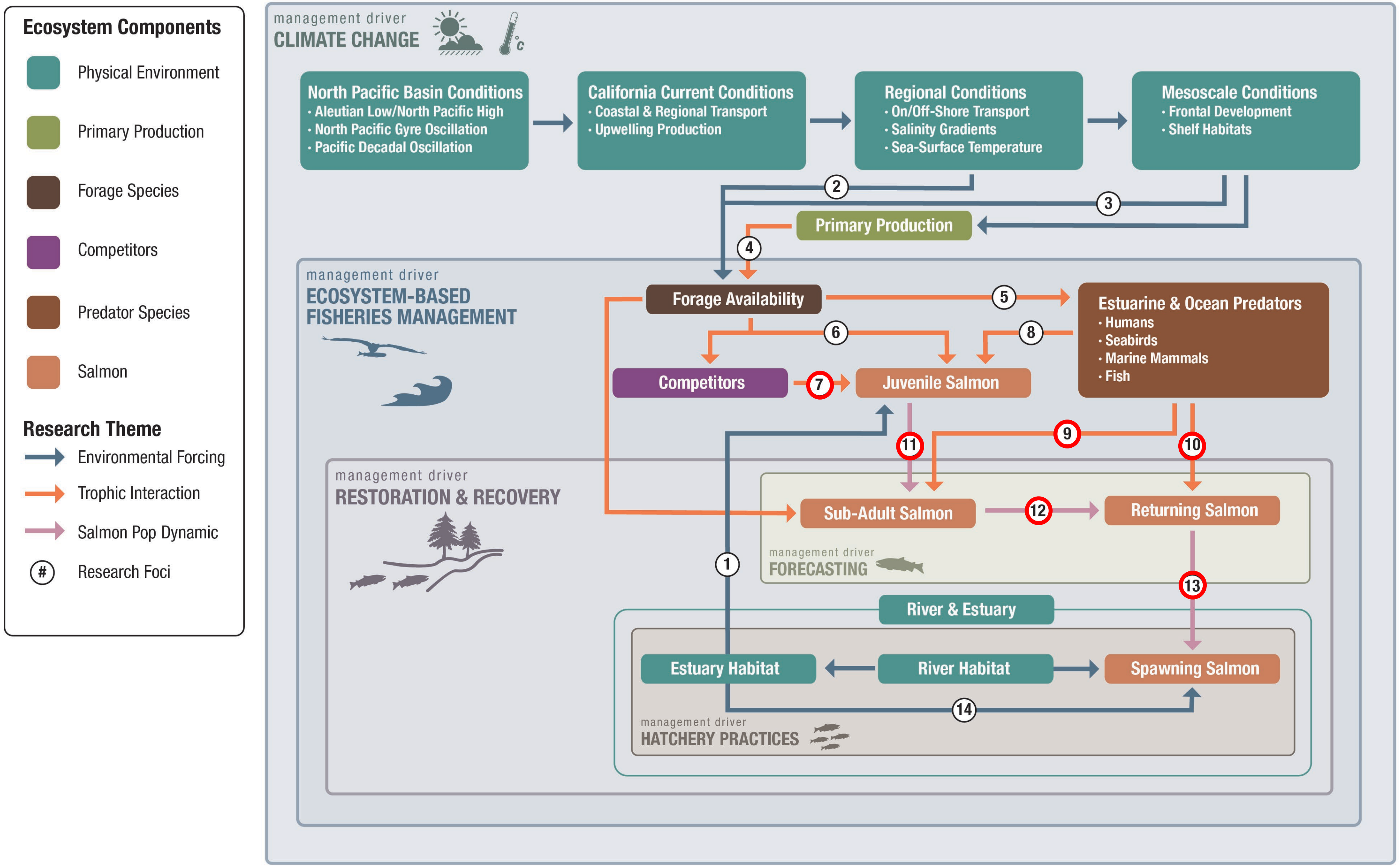

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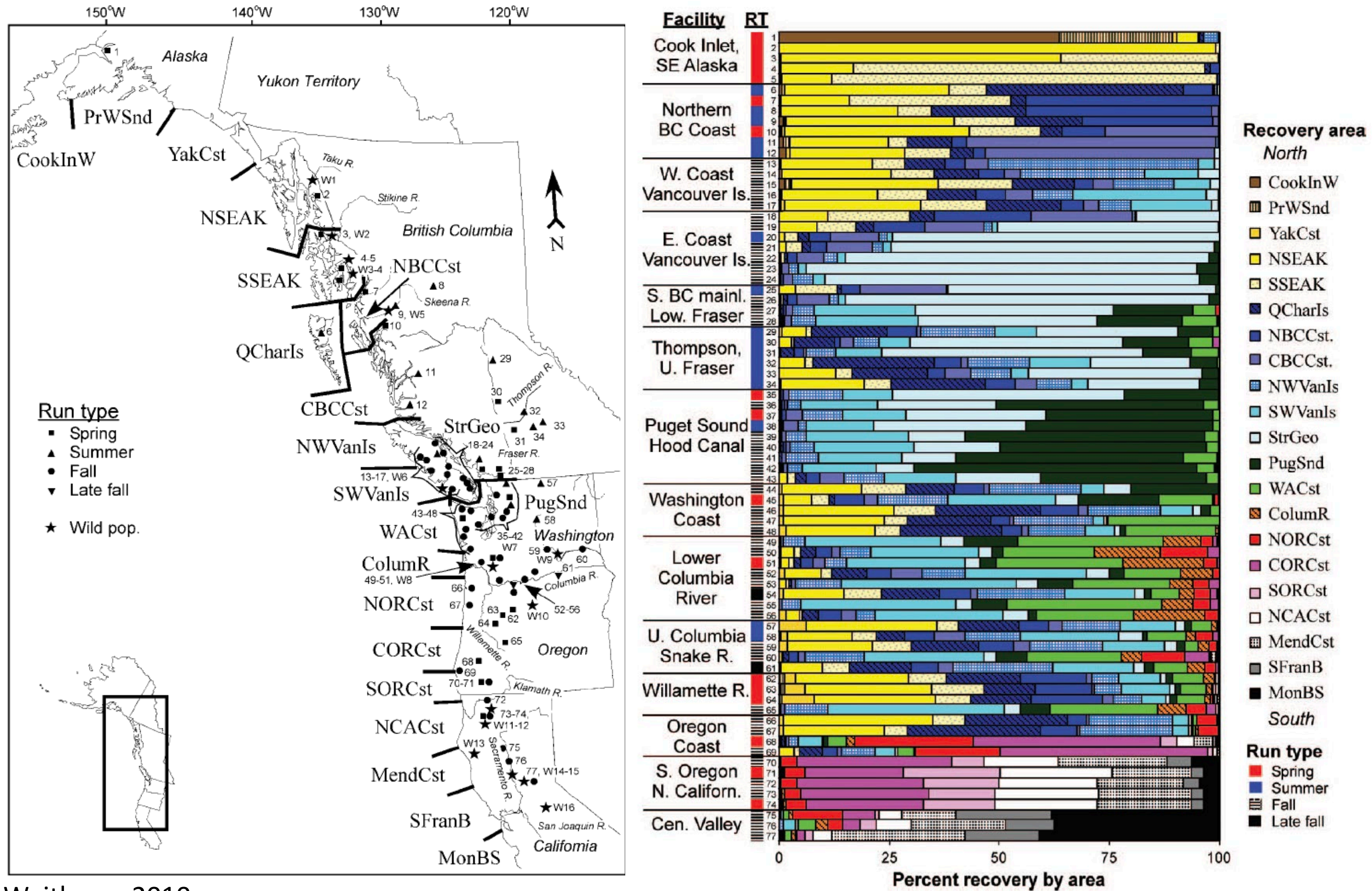
2) Improving our understanding of salmon at sea

As the fish age through their life cycle we need to consider their distributions

Tagging studies and spatiotemporally expanded survey efforts can be used to address this.

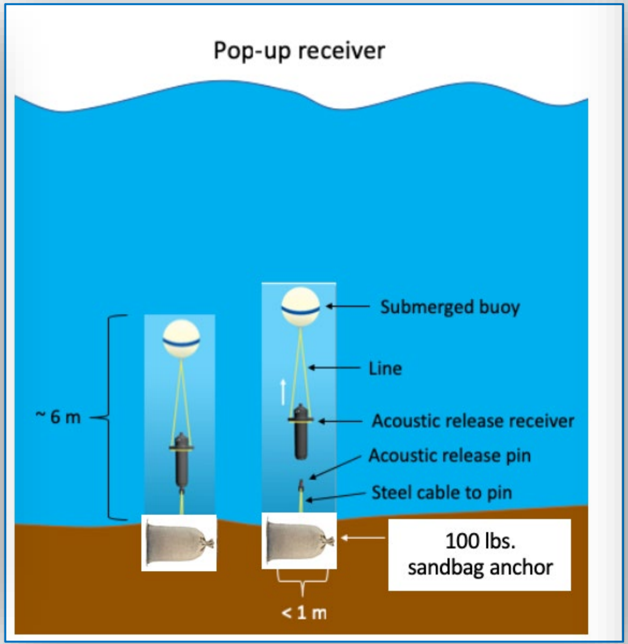


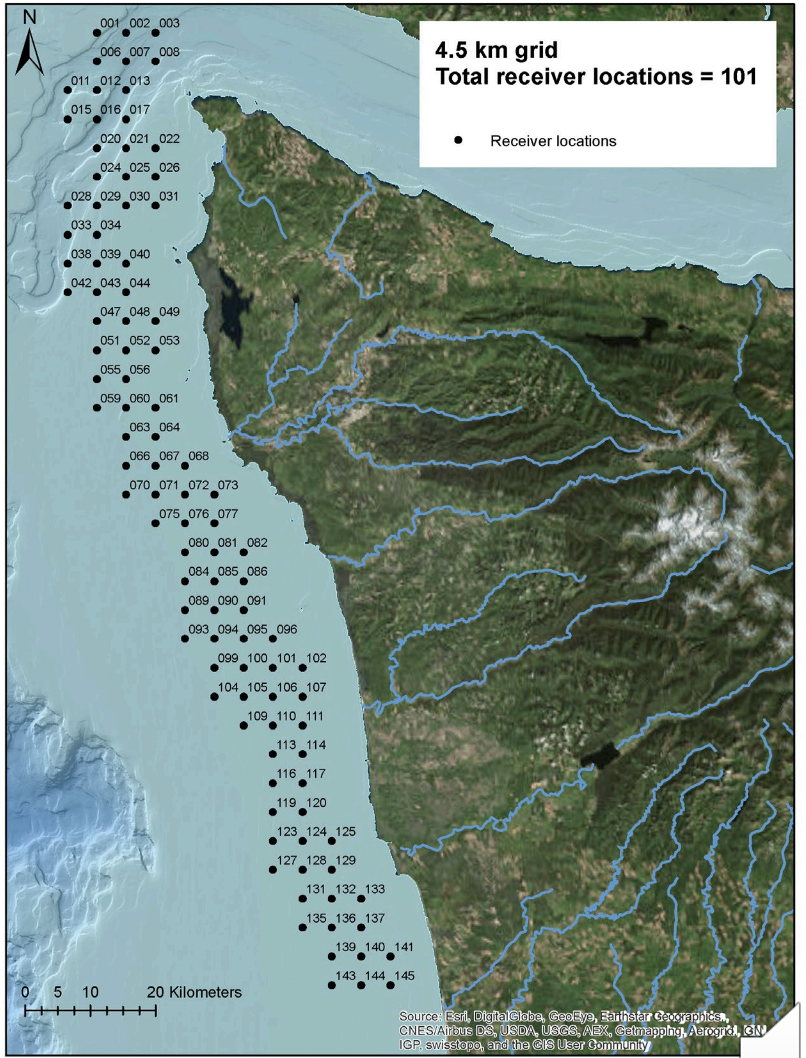
Weitkamp 2010

2) Improving our understanding of salmon at sea

Ocean acoustic arrays can inform behavior

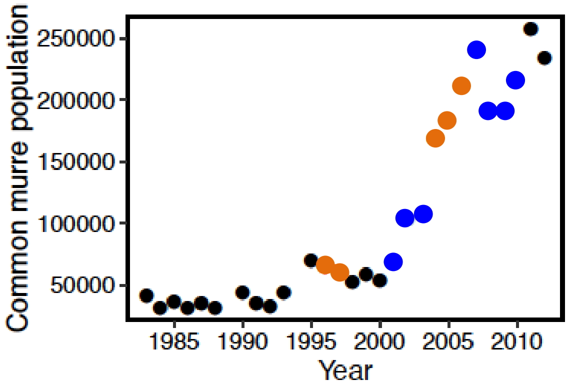
Behavioral studies can inform these models

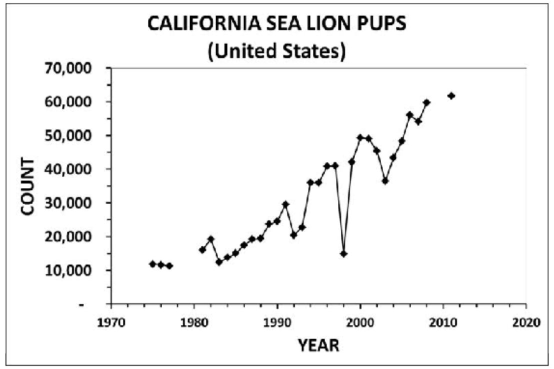


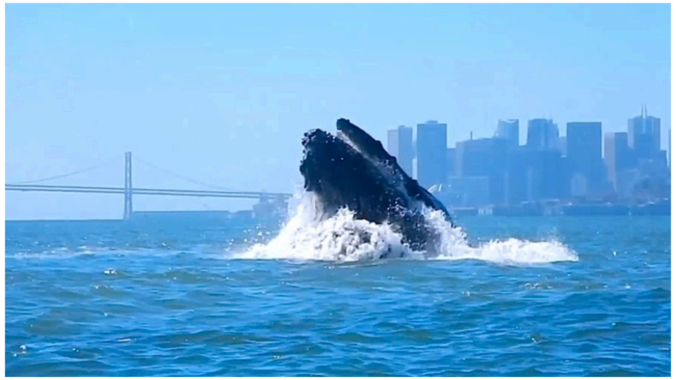


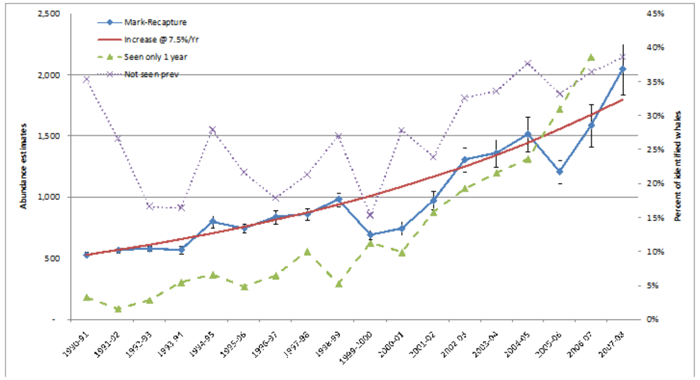
J. Smith and D. Huff, Salmon Ocean Behavior and Distributi

Much of morality at sea is due to predation









More process studies need to be conducted to understand the role of predators on salmon mortality.

EBFM

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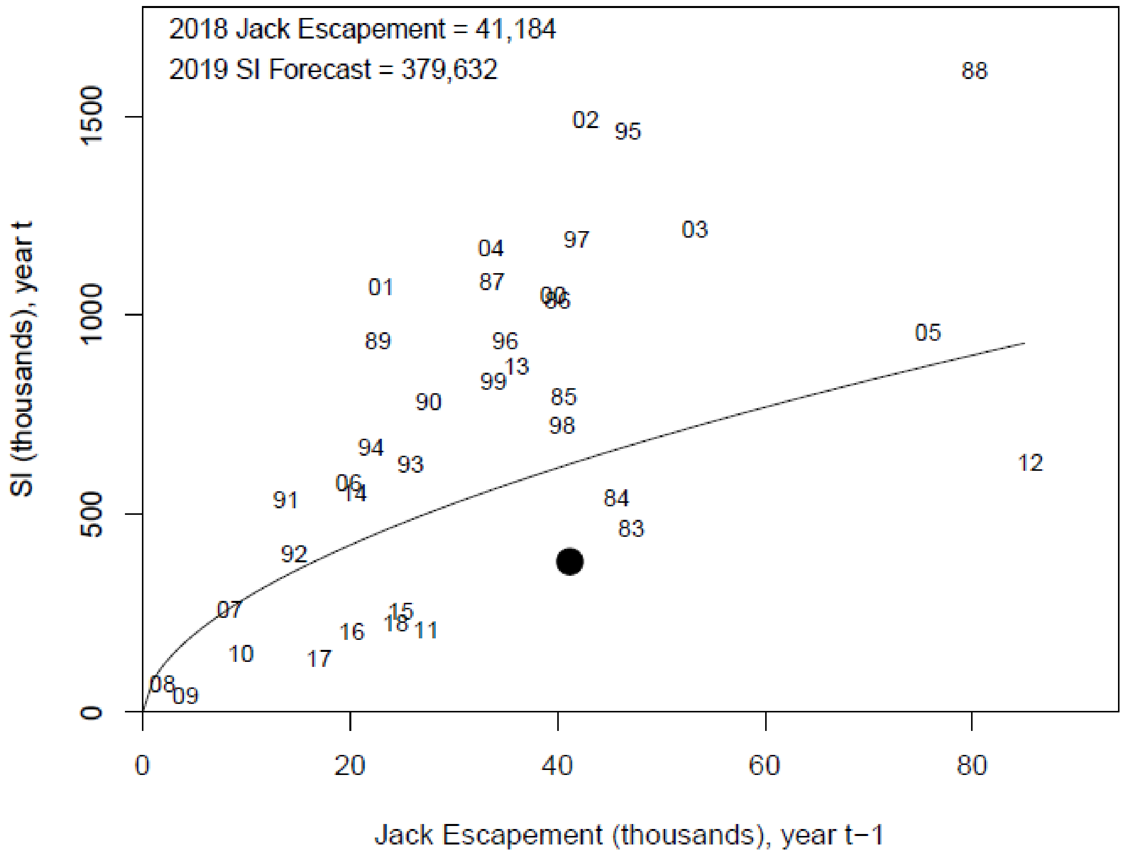
3) Improvements to salmon assessment models

Harvestable adults at sea = # of jacks returning

This assumes *constant maturation* and *natural mortality* rates – *Solution: Ocean sampling of older fish*.



3) Improvements to salmon assessment models

Pink salmon assessments are exploring *inclusion of ocean processes*

Namely, ocean abundance is estimated from juvenile at-sea CPUE in the context of assumed environmental relationships to mortality. As well, at-sea abundance of predators is included

$$Harvest = Ln(CPUE\ juvs) + env1 + env2 + \ldots env_n$$

Parameter	***r***	***P*-value**
Juvenile pink salmon abundance		
$CPUE_{cal}$	**0.78**	**<0.001**
$CPUE_{ttd}$	**0.74**	**<0.001**
Seasonality	**-0.55**	**0.019**
Percentage of Juvenile Pinks	**0.55**	**0.010**
Juvenile pink salmon growth and condition		
Pink Salmon Size July 24	0.05	0.847
Condition Index	-0.05	0.856
Energy Content	-0.01	0.958
Percent Stomach Contents	-0.08	0.745
Predator Indexes		
Adult Coho Abundance	-0.27	0.273
Adult Coho Abundance/$CPUE_{cal}$	**-0.80**	**<0.001**
Zooplankton standing crop		
June/July Average Zooplankton Total Water Column	0.12	0.624
Local-scale physical conditions	-	
May 20-m Integrated Water Temperature	0.01	0.978
June 20-m Integrated Water Temperature	-0.24	0.343
Icy Strait Temperature Index (ISTI)	-0.18	0.488
June Mixed-layer Depth	-0.03	0.906
July 3-m Salinity	0.00	0.995
Basin-scale physical conditions		
Pacific Decadal Oscillation (PDO, y-1)	0.01	0.983
Northern Pacific Index (NPI, y)	**0.62**	**0.007**
ENSO Multivariate Index (MEI, Nov (*y-1*)-March (*y*))	0.25	0.326
North Pacific Gyre Oscillations	0.30	0.234
Ecosystem Indicators Rank Index (ERI)	**-0.83**	**<0.001**

Wertheimer et al 2017

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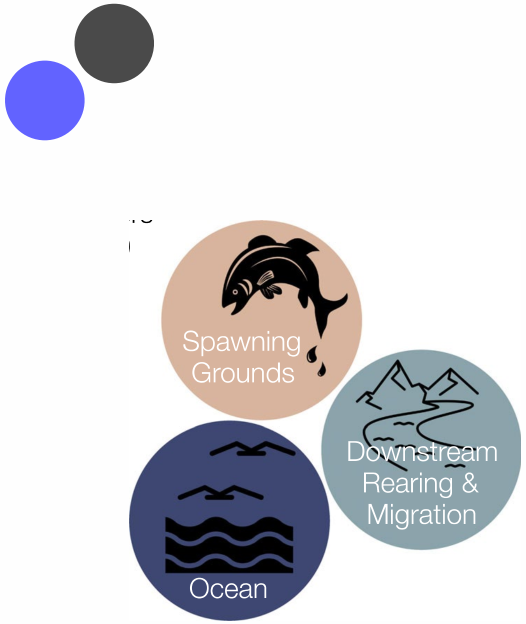
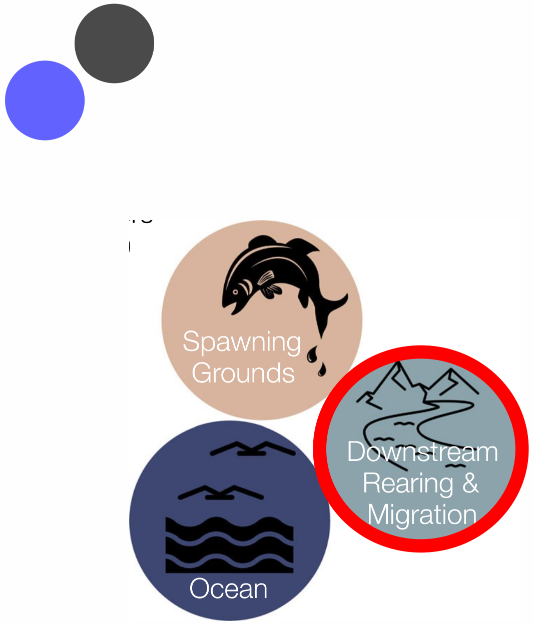
4) Development of life-cycle models to evaluate tradeoffs



Friedman et al. 2019

4) Development of life-cycle models to evaluate tradeoffs



Carry-over effects (e.g., size at emigration, timing, diversity) are directly related to freshwater experiences and relate to survival and maturation at sea. *These are levers in our control. Can be studied with early sampling and hatchery manipulations.*

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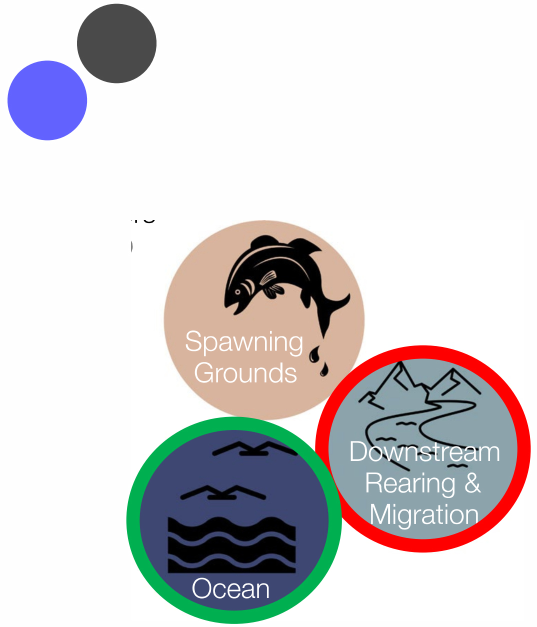

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Life-history transitions are dependent on entry demographics, ocean conditions, and selective predation. *Ocean surveys of older fish provide parameterization*

4) Development of life-cycle models to evaluate tradeoffs

Successful spawning depends on return dynamics and freshwater habitat. *The ocean has influence on age and timing of spawning and can inform habitat management. Sampling fish on return can be used here.*

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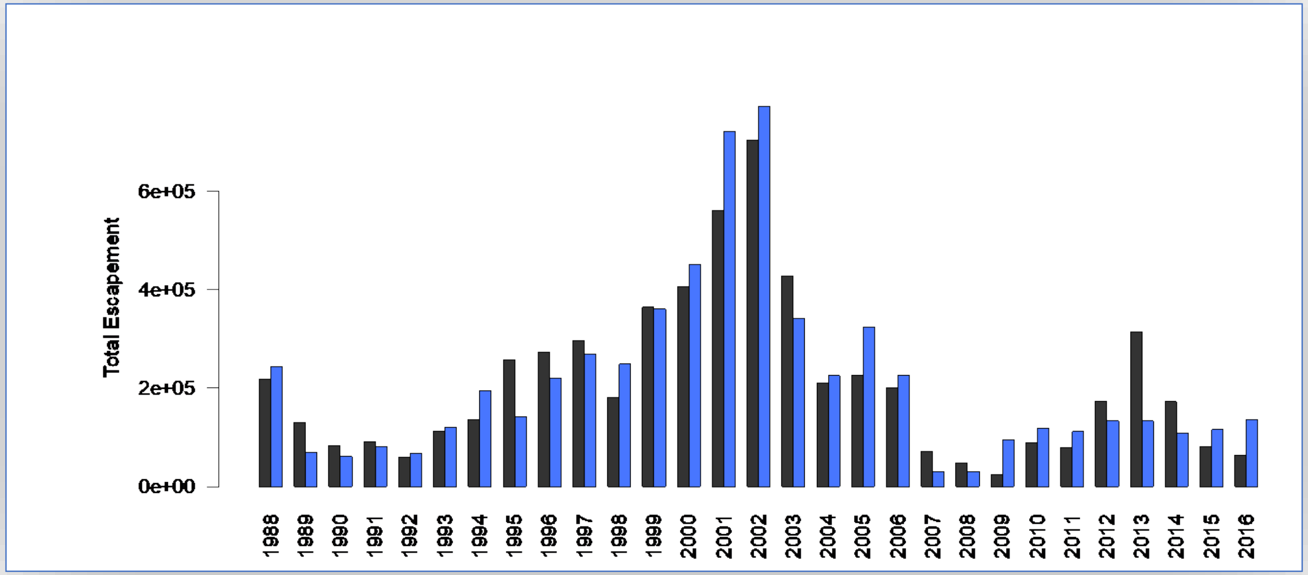

The key is that ocean influences (e.g., predation) were parameterized in the context of all examined influences across the full life cycle. *Therefore, any managerial decisions considered, such as flow-dependent emigration size or timing, can be evaluated properly in the context of predation at sea.*

Friedman et al. 2019

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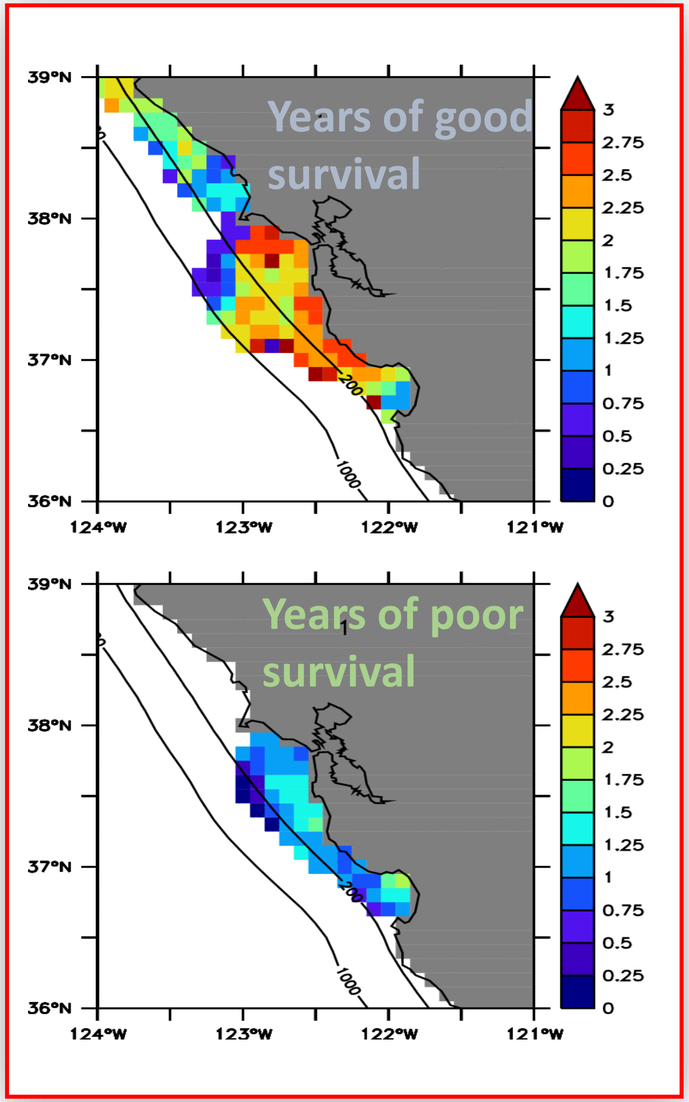
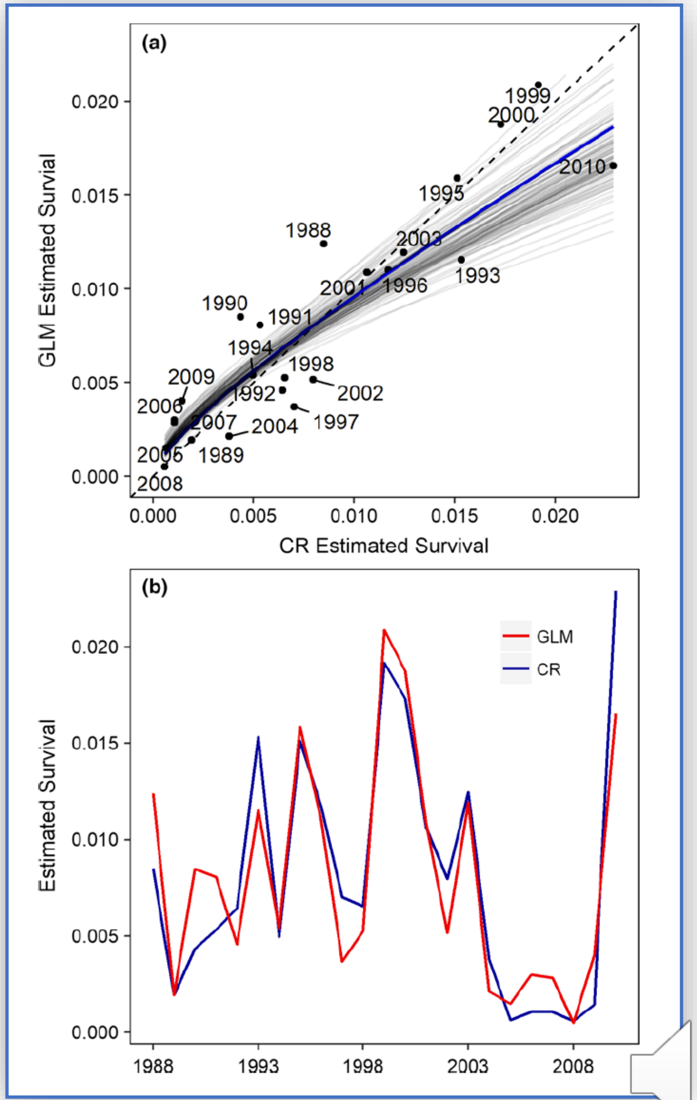


Fiechter et al. 2015

Survey data is used to parameterize ecosystem-level models where there is need to incorporate behavior, distribution, prey dynamics and ocean state.

To the left is modeled growth of salmon at sea in different ocean states and to the right is modeled early survival related to growth



Henderson et al. 2018

How ocean sampling can help modeling efforts

1) Designing purpose-built conceptual models can guide research and management
2) Salmon dynamics after early ocean entry are poorly understood
3) Improved understanding of at-sea dynamics could improve assessments,
4) Life-cycle models can be used to evaluate additive and cumulative effects across life
5) To rebuild stocks we need simulation approaches that incorporate and allow discovery of processes.