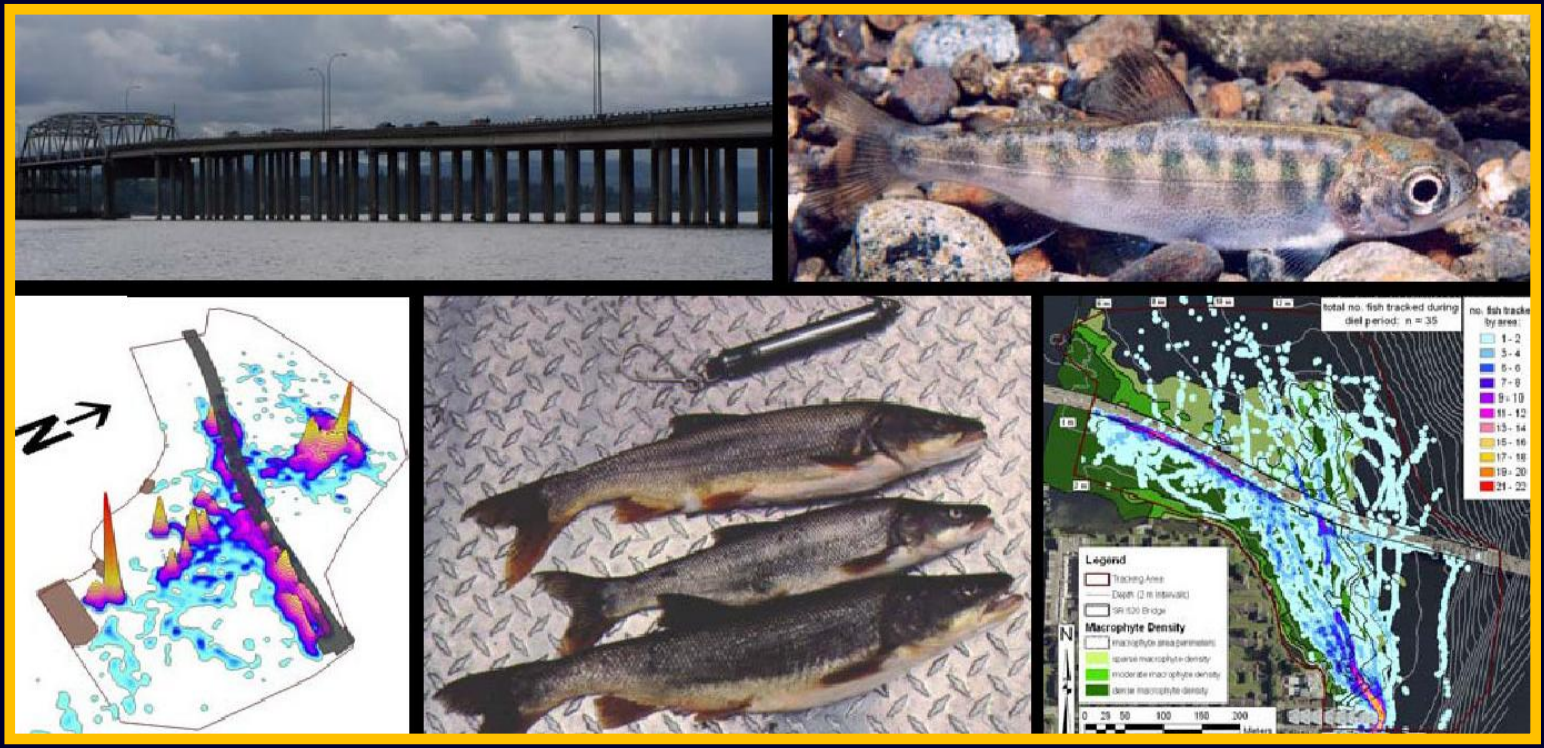
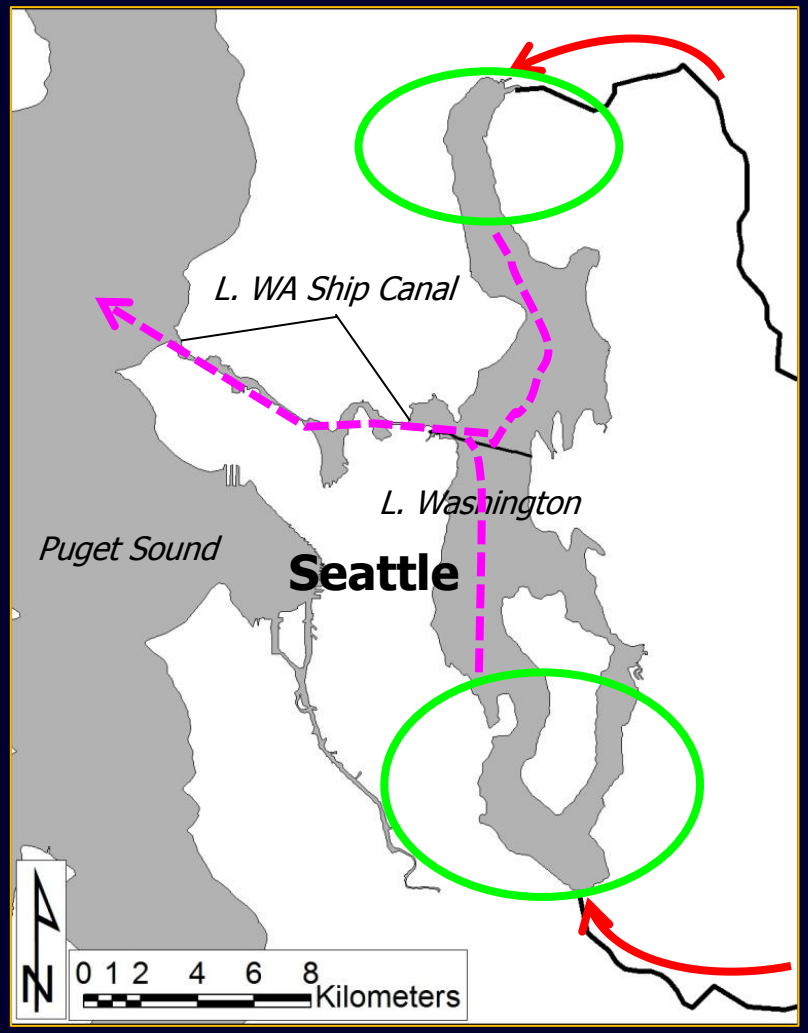
Chinook Salmon Smolt Behavior in Lake Washington and the Ship Canal: 2004-2008 Acoustic Tracking Studies



Mark T. Celedonia & Roger A. Tabor

U.S. Fish & Wildlife Service
Washington Fish & Wildlife Office
510 Desmond DR., SE
Lacey, WA 98503

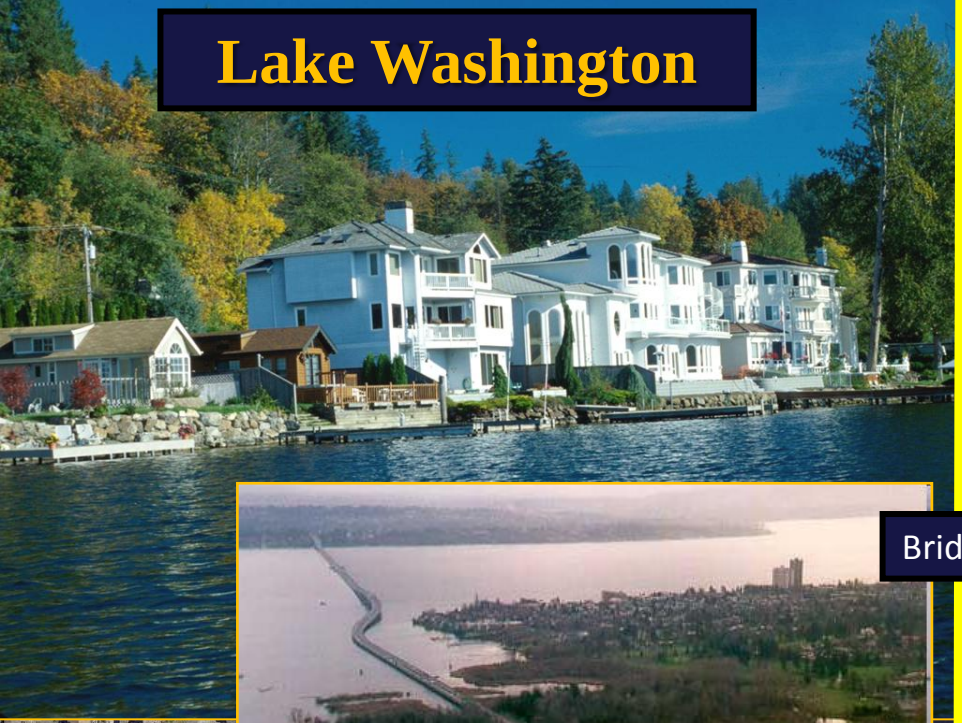
Background



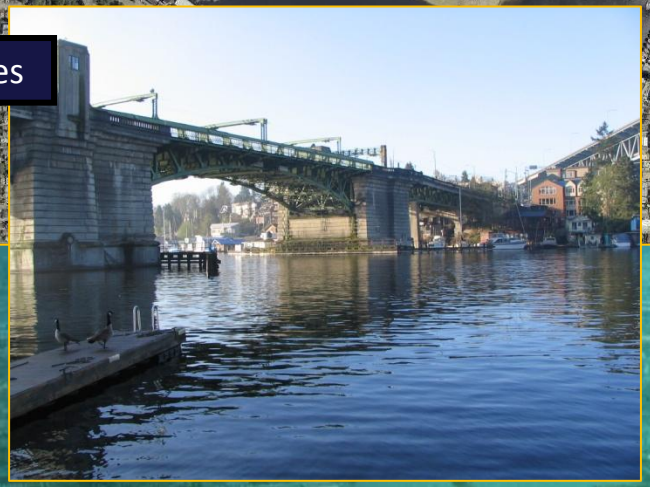
- February: peak fry migration into Lake WA
- Feb. thru mid-May: inhabit nearshore areas in southern & northern parts
- mid-May thru early July: smolts outmigrate into Puget Sound

Lake Washington

Ship Canal



Bridges

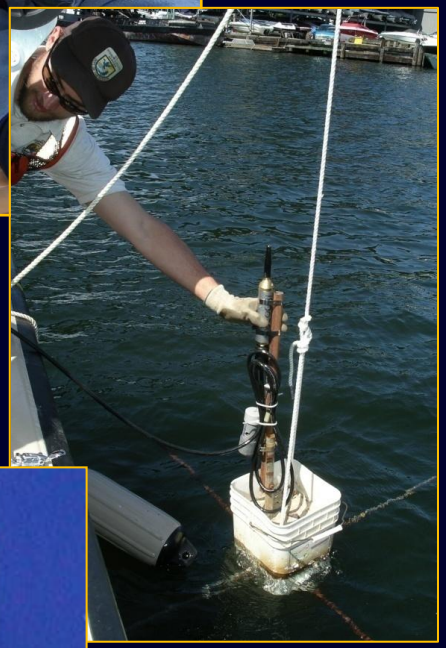


Residential docks & marinas

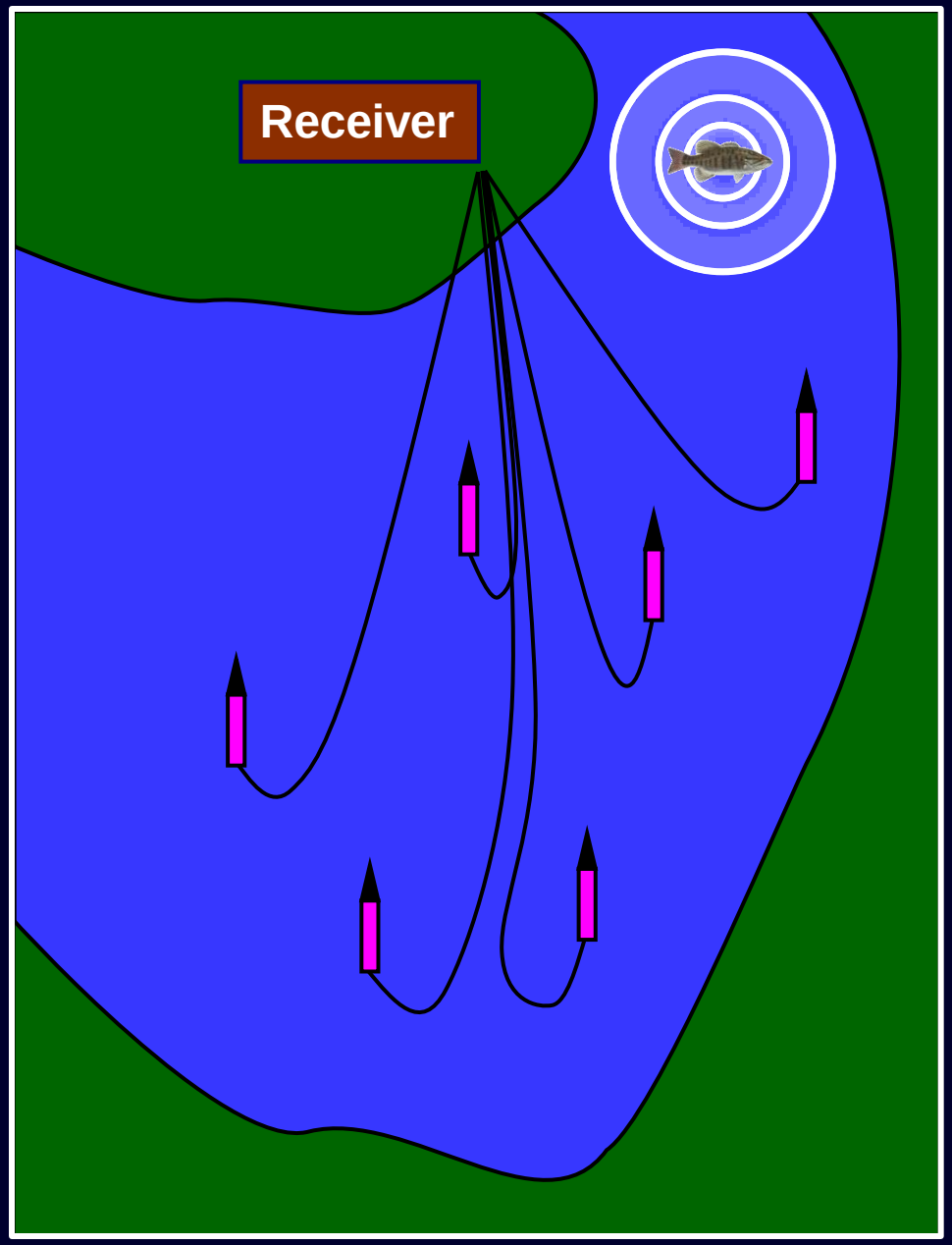
Commercial & industrial shipyards, etc.

Tracking Method

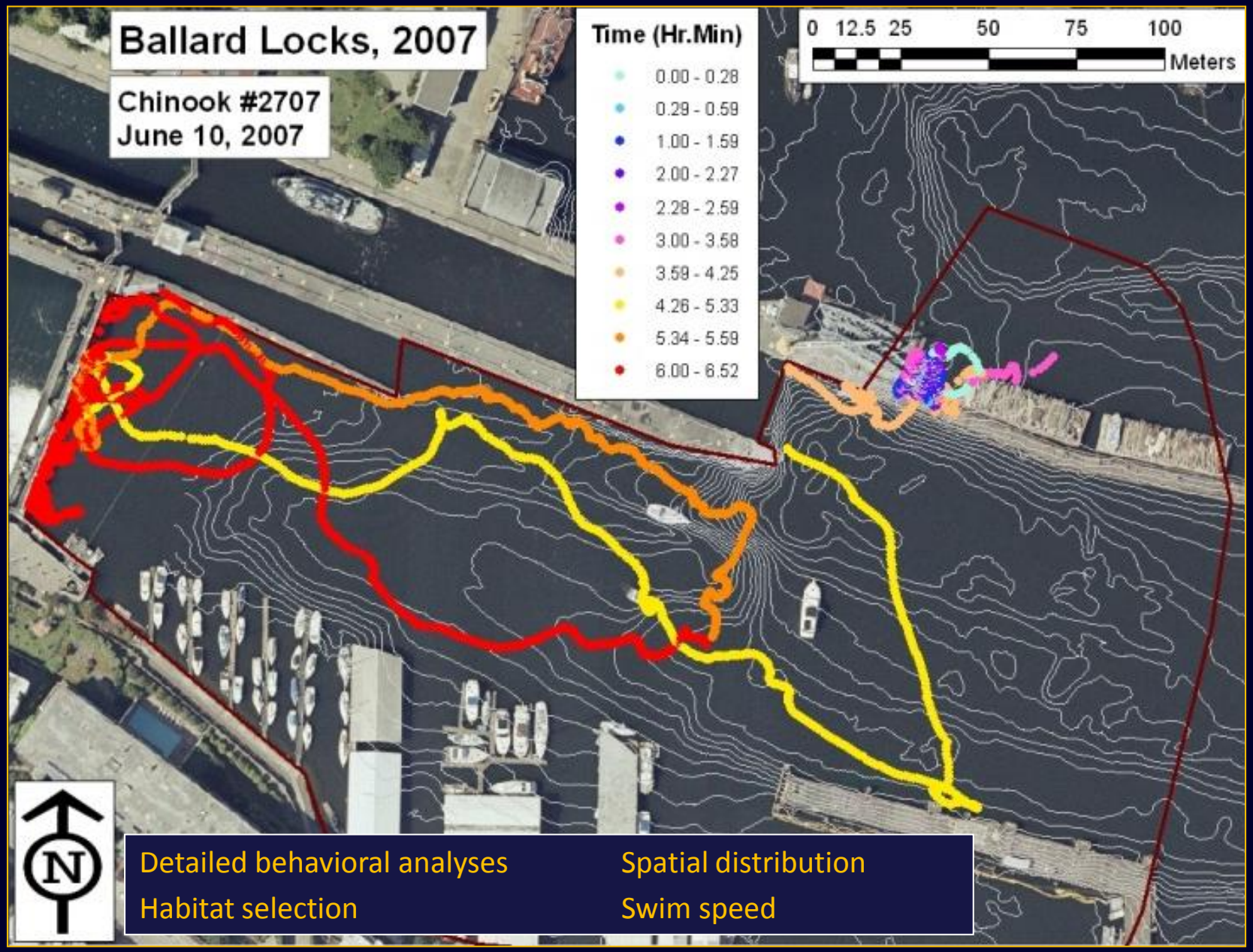
- Fine-scale acoustic tracking (1 m)
- Hydroacoustic Technology, Inc. (HTI)



0.65 g & 0.75 g



Tracking Product



Detailed behavioral analyses
Habitat selection
Spatial distribution
Swim speed

Study Sites

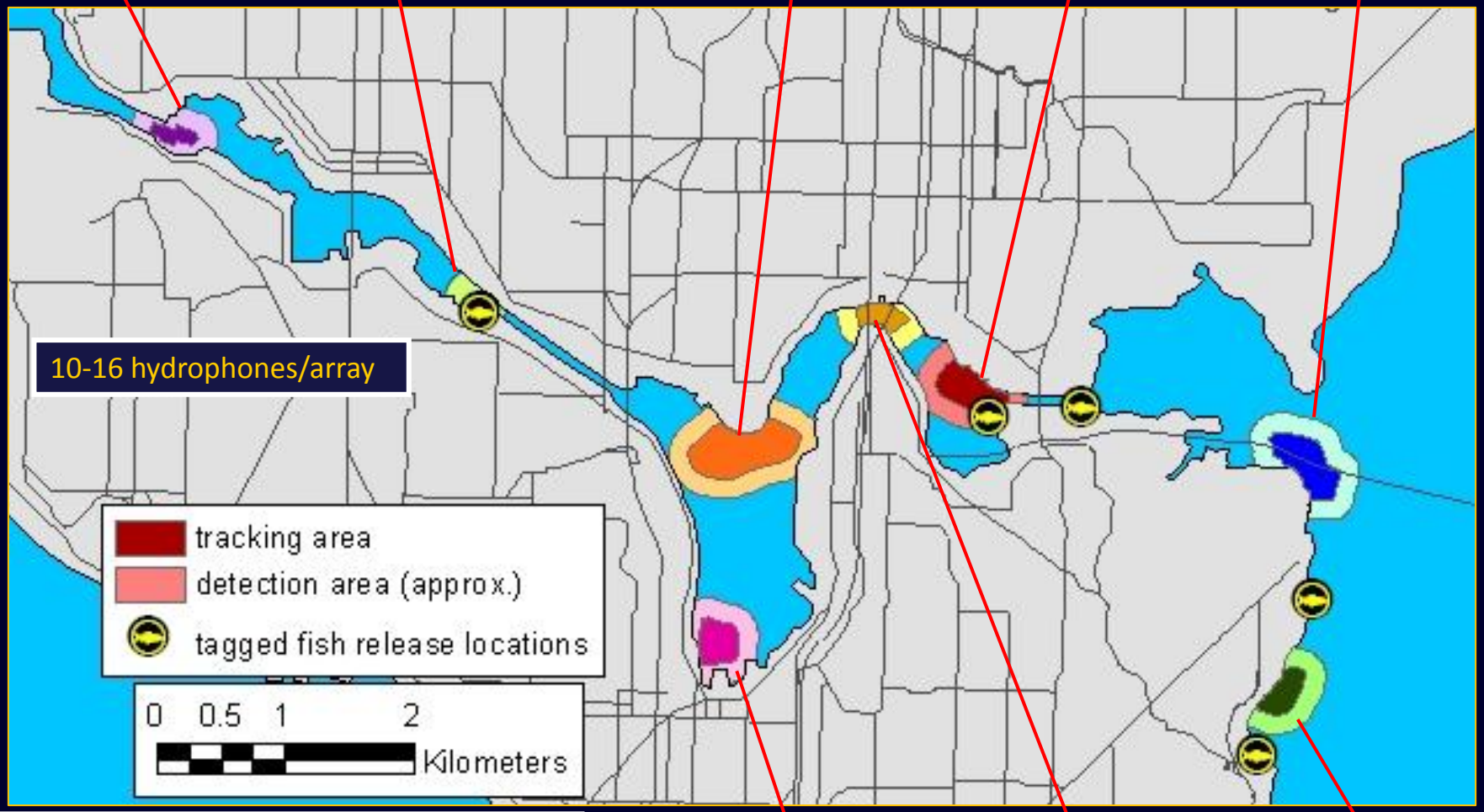
Ballard Locks
(2007-2008)

Fremont Cut
(2007-2008)
[P/A only]

N. Lake Union/
Gas Works Park
(2005-2008)

Portage Bay
(2004-2005)

SR 520 Bridge
(2007-2008)



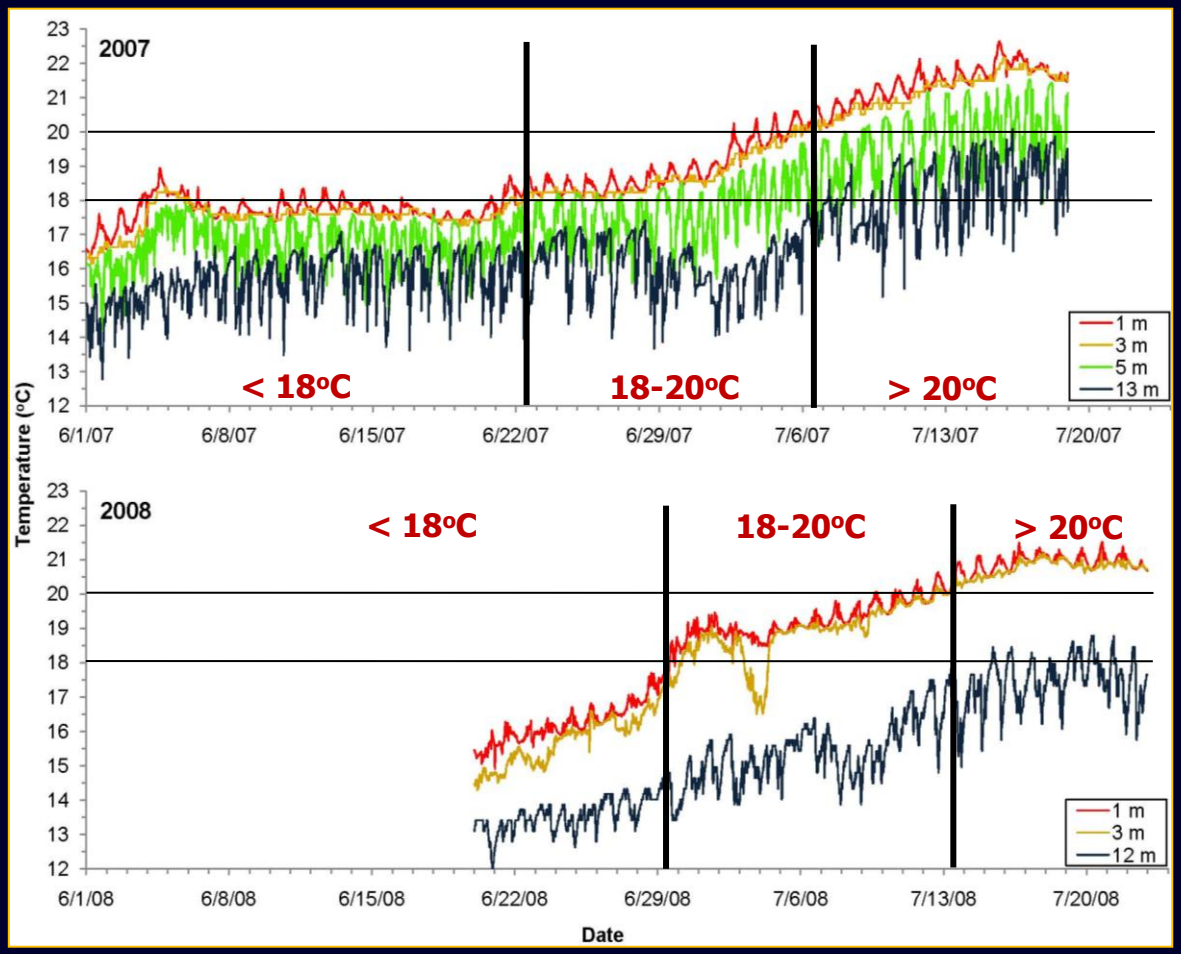
Multi-spatial scale analysis:
- Site-scale
- Broad, LWSC scale (esp. 2007 & 2008)

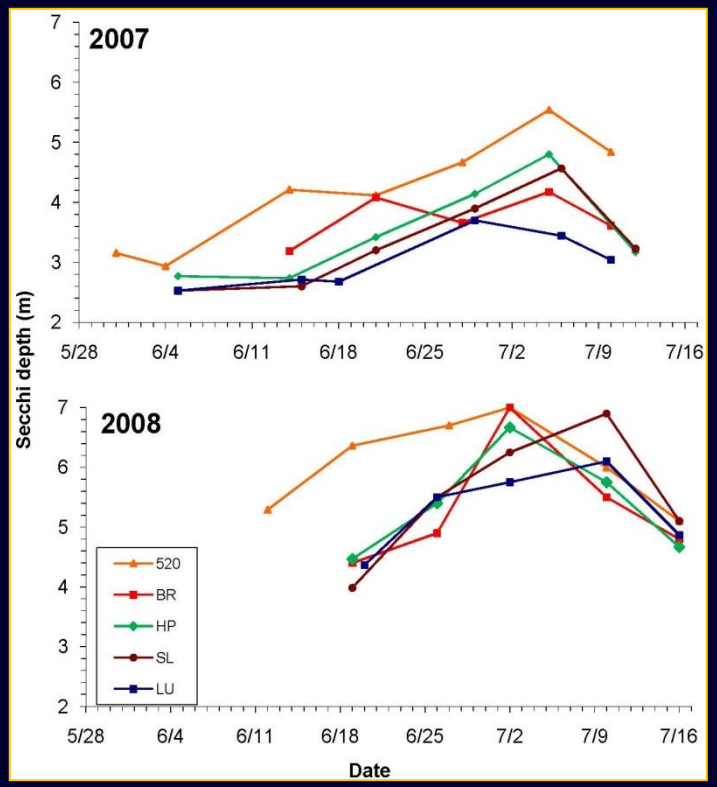
S. Lake Union
(2007-2008)

University &
I5 Bridges
(2007-2008)

Seattle Tennis Club
(2005)

2007-2008 Water Temperature & Turbidity





- 2007 warmer much earlier than in 2008
- 2007 was more turbid than in 2008 (weekly Secchi depth readings at each site).
- 2007 = “warm, turbid”; 2008 = “cool, clear.”
- Divided study period into 3 temperature regimes based on temperature at 1 m depth.

Fish tagging & release

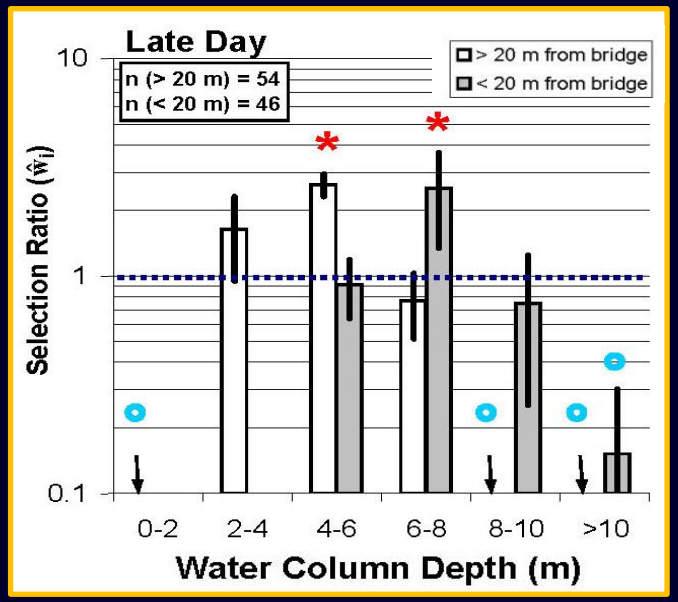
- 100-114 mm FL; 10.5-17 g (tag:fish weight ratio ≤ 6%)
- Upper end of size range; smaller sizes not represented
- Mostly surgical implant (some gastric in 2004-2005)
- Released in groups of 9-68 fish during study period (mid-May to early-June)
- 10-14 day tag battery life

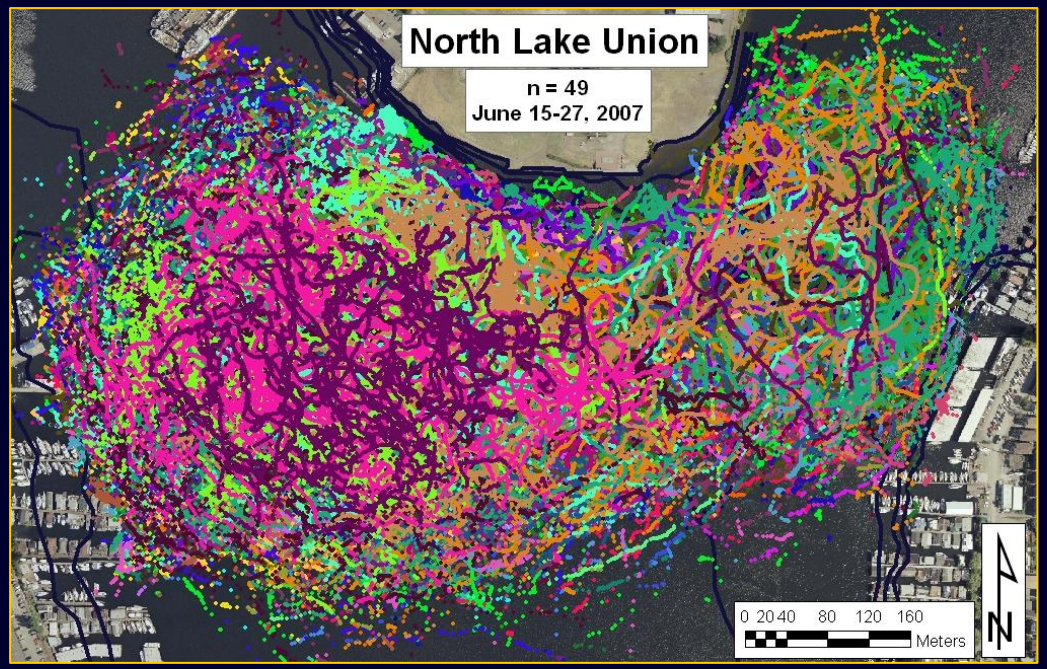
	Origin	# tagged	# fish/group	% detected
2004-2005	Cedar R. natural (50%) Hatchery (50%) [UW & Issaquah]	140	9-17	53-80%
2007-2008 (SPU)	Issaquah Hatchery	335	21-60	74-92%
2007-2008 (DOT)	Issaquah Hatchery	352	27-68	79-98%

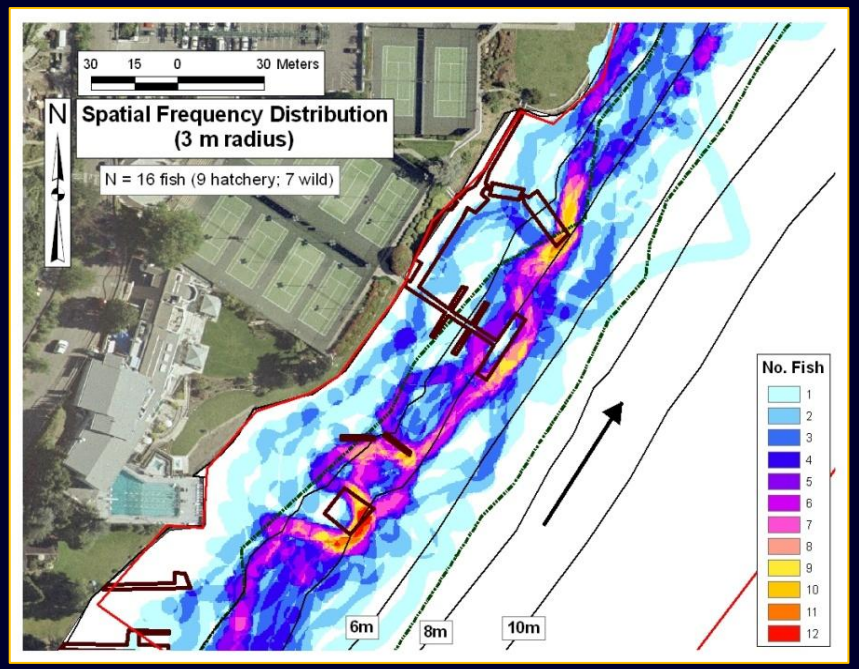
Broad similarity between wild and hatchery fish in travel times, residence times, spatial distribution, and habitat use

Analytical methods

- Fish tracks (ArcGIS)
- "Heat maps" combine all fish into 1 graphic (ArcGIS):
  - Density plots
  - Spatial frequency distributions
- Habitat selection ratios (Manly et al. 2002):
  - Habitat types (proximity to structure, veg)
  - Bottom depth
  - Vertical position in water column





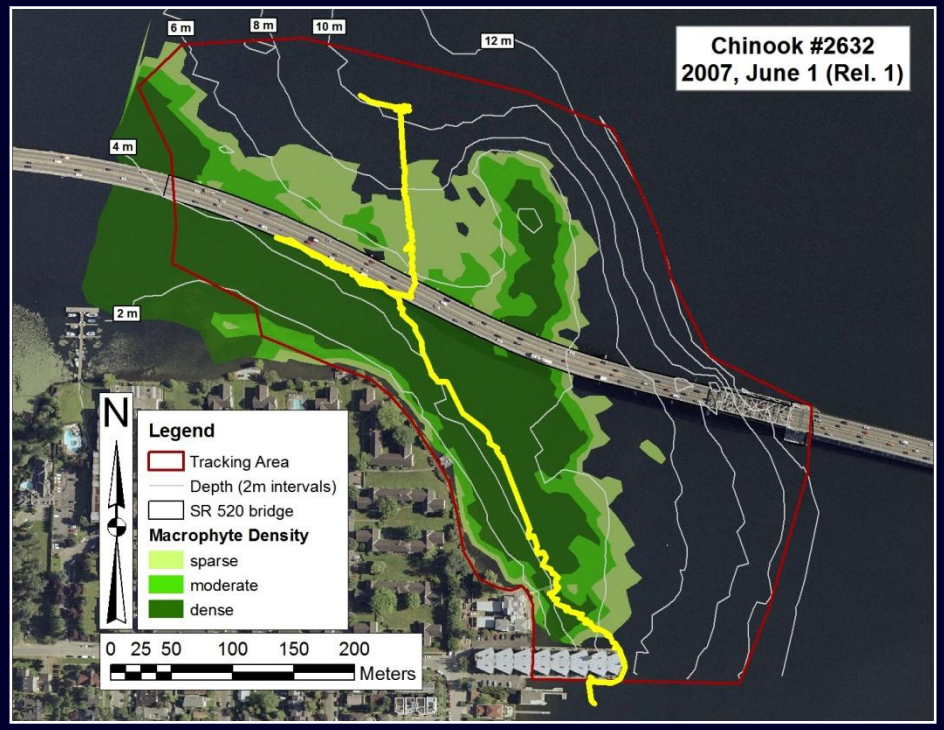


Topics

- Migratory behaviors & site-specific migratory functions
- Chinook movement into LWSC from Lake Washington
- Importance of south Lake Union
- Horizontal distribution in Lake WA vs. LWSC
- Macrophytes
- Influence of overwater structures
- Passage through Ballard Locks
- Chinook vertical distribution
- Influence of artificial lighting
- Influence of warming temperature

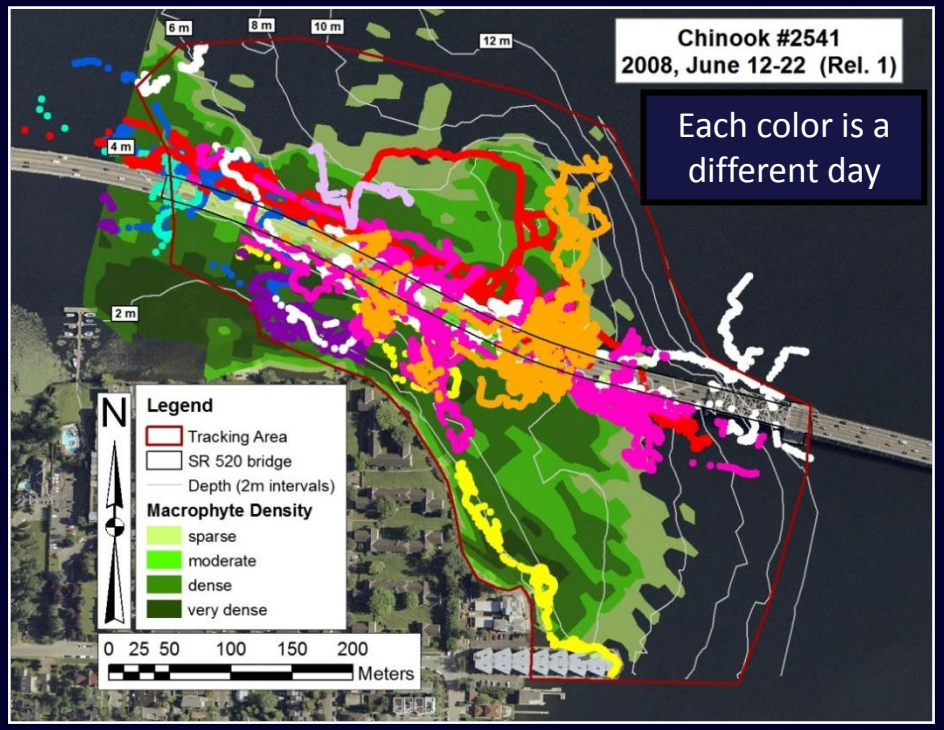
Two main migrational behaviors observed

Actively migrating



- Direct movement toward Puget Sound
- Fast swim speeds (4.5 BL/s)
- Observed mostly during day, sometimes at dawn (different from Columbia R.)

Holding



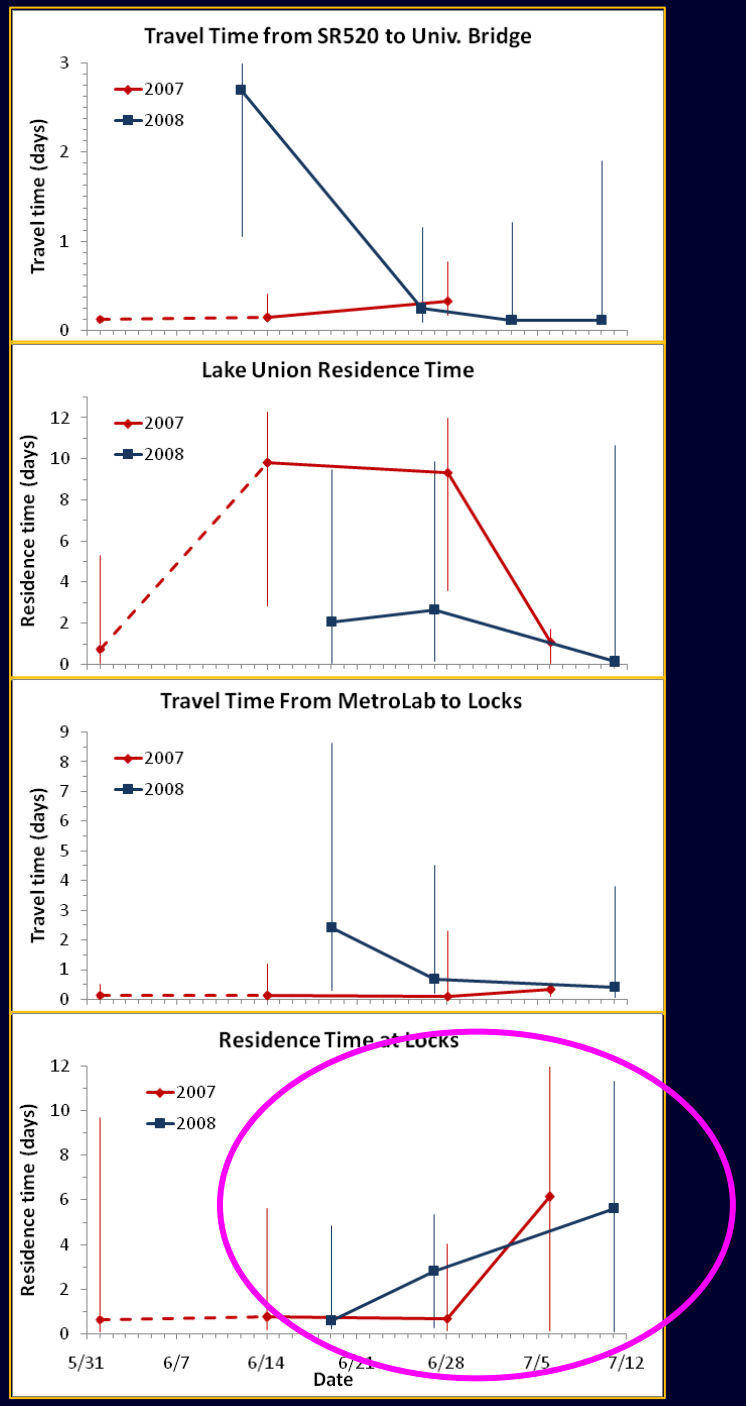
- Milling/meandering; lacking direction
- Slow swim speeds (1.5-2.1 BL/s)
- Observed during all time periods (dawn, day, dusk, and night)
- Break down into short-term (few hours) and long-term (overnight) holding

- Each behavior was observed in at least some fish at all sites
- Some behaviors were more prevalent at some sites

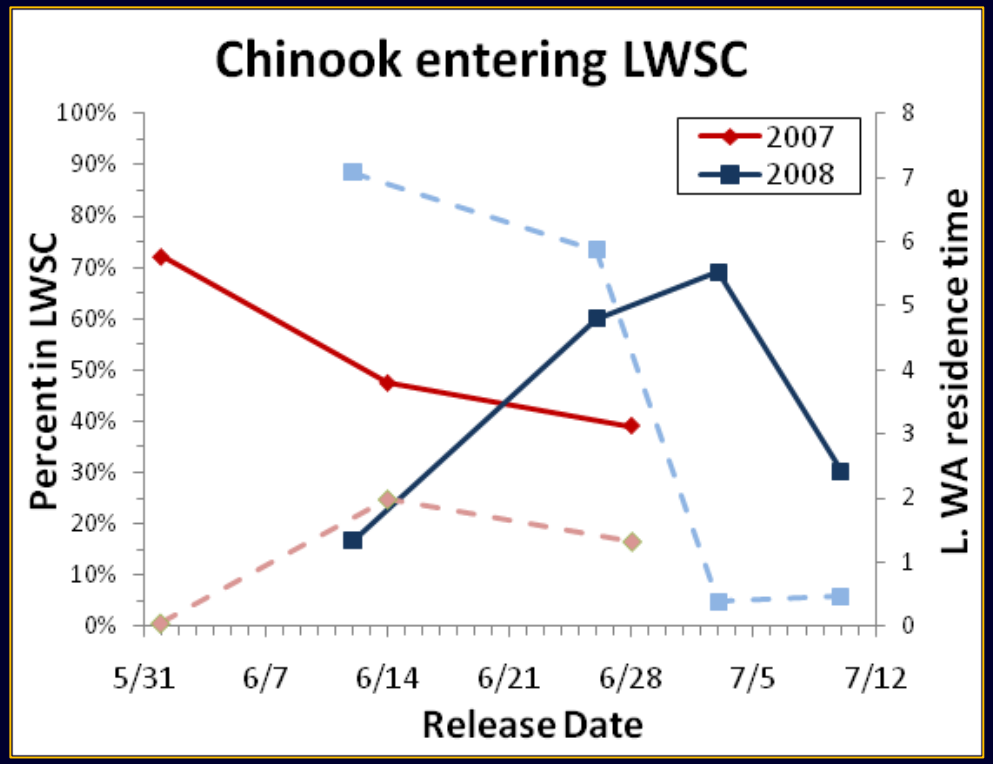
Migratory functions

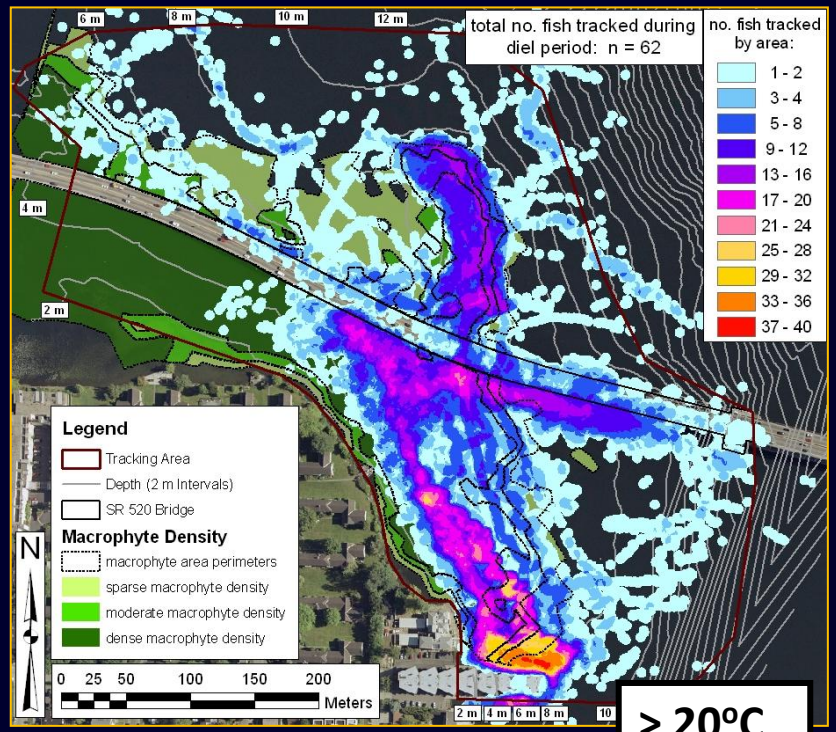
	Primary migratory function	Time spent in area
Lake WA		
Lake WA, littoral (Tennis Club)	Migratory corridor; short-term holding	< 1 h
Lake WA, littoral + pelagic	Varies? Migratory corridor to long-term holding	???
Transition		
Union Bay / adjacent Lake WA	Varies: migratory corridor to long-term holding	< 1 h to 1 week or more
Ship Canal		
Montlake Cut	Migratory corridor; Short-term holding	< 24 h
Portage Bay	Migratory corridor; short-term holding	< 24 h
Lake Union	Short- to long-term holding	1-2 days to 2 weeks or more
Fremont Cut	Migratory corridor	< 24 h
Salmon Bay / Ballard Locks	Short- to long-term holding	a few hours to 1 week or more

- **Medians**
- **Error bars are 10th & 90th percentiles**
- **Note variability**

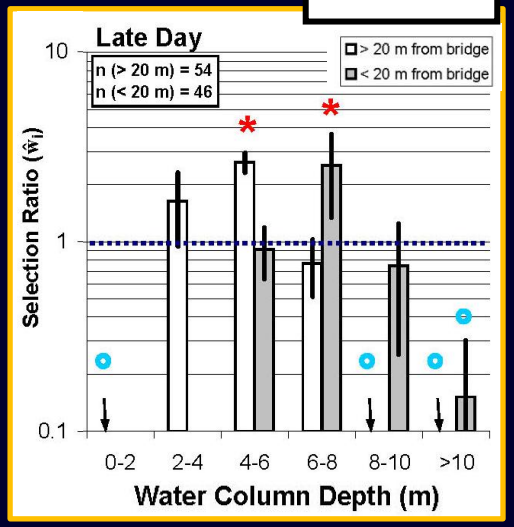


Chinook movement into LWSC



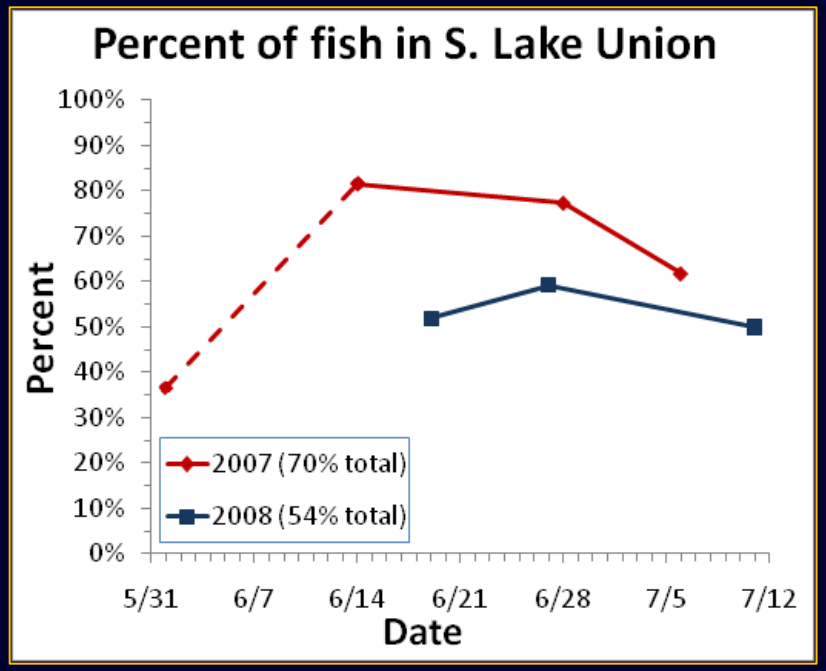


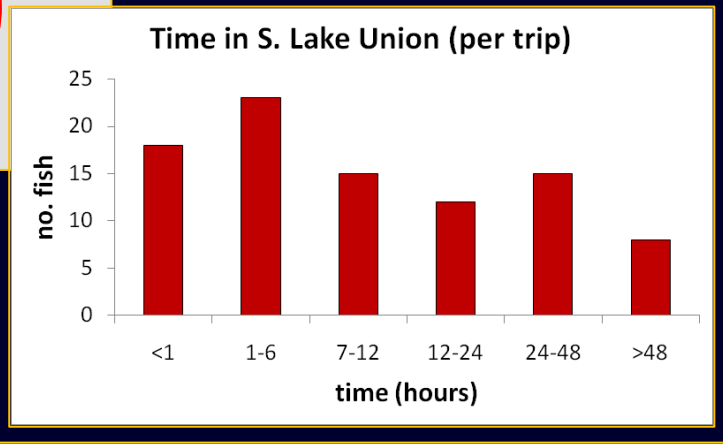
> 20°C



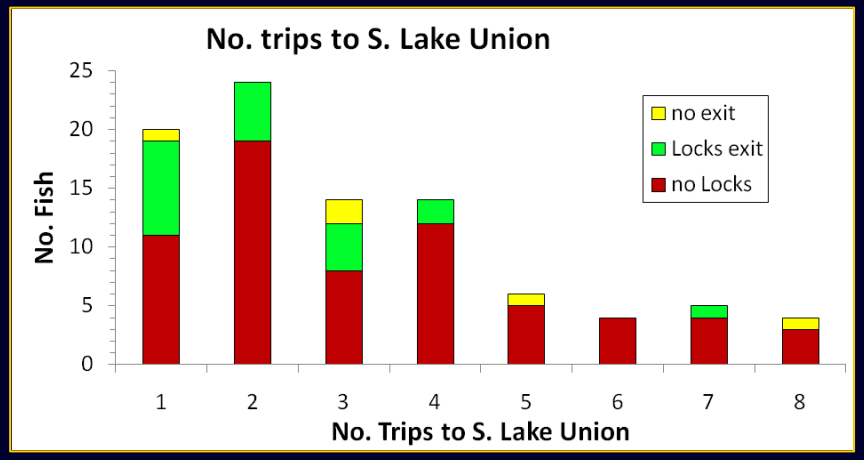
- Decline from 520 to U. Br.; but not from Portage Bay to U. Bridge
- Decline in late-season entrance:
  - Desmoltification & residualism
  - Predation/predation threat
  - Thermal barrier (but select for < 6 m despite elevated temps)
  - Lack of suitable migratory corridor? (shallow water; vegetation)

South Lake Union is important



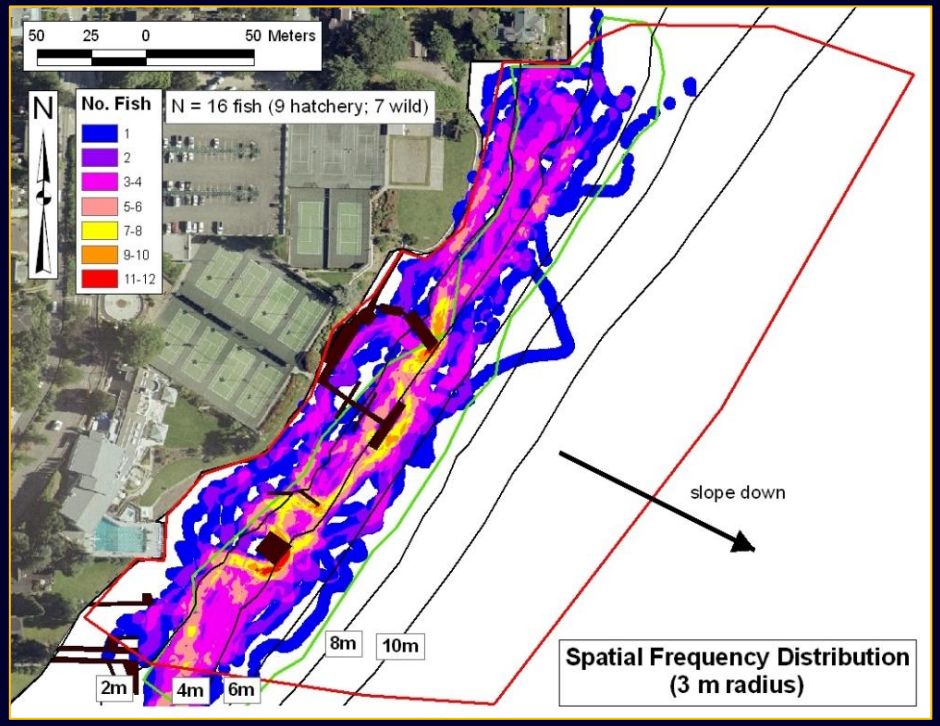


- Sizeable proportions of Chinook used south L. Union.
- Many made numerous "trips" between north & south L. Union.
- Fish usually spent several hours to a few days in south L. Union per trip.
- Subsampled 91 fish from 2007 that were detected in S. Lake Union:
  - 25 (27%) were detected at Locks
  - 20 (22%) exited locks
  - Rest - ??? – tag battery life, predation, residualism.



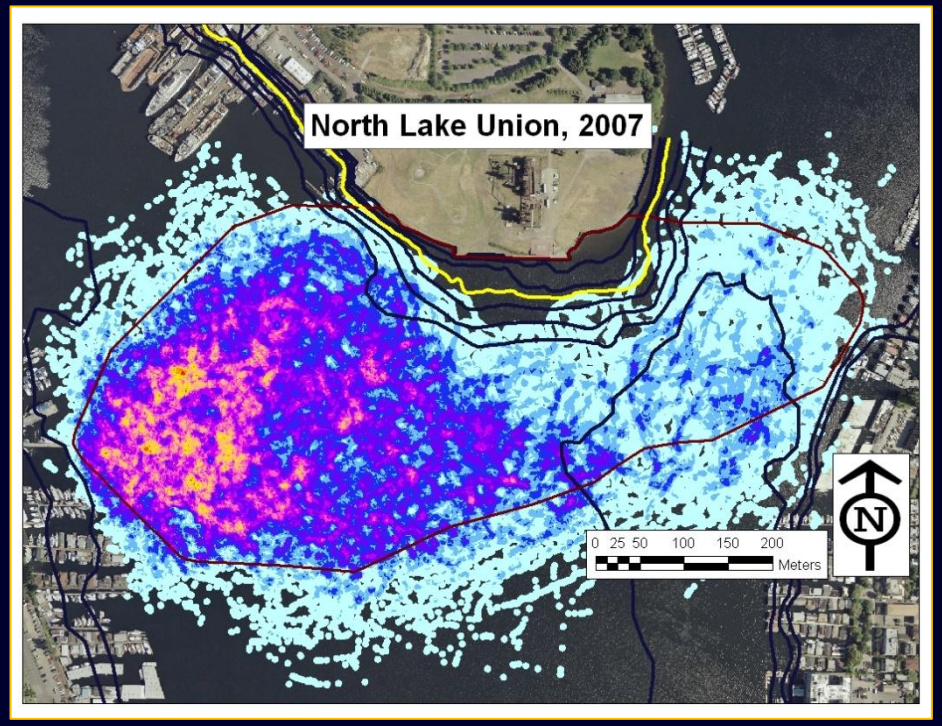
Daytime horizontal distribution is very different in the LWSC vs. Lake WA

Lake Washington (day)



- **Select for bottom depths of 1.5-5 m**
- **Little use of areas > 8 m**
- except near deepwater structures
- 1.5-2 m w/o macrophytes; 3-5 m w/ macrophytes

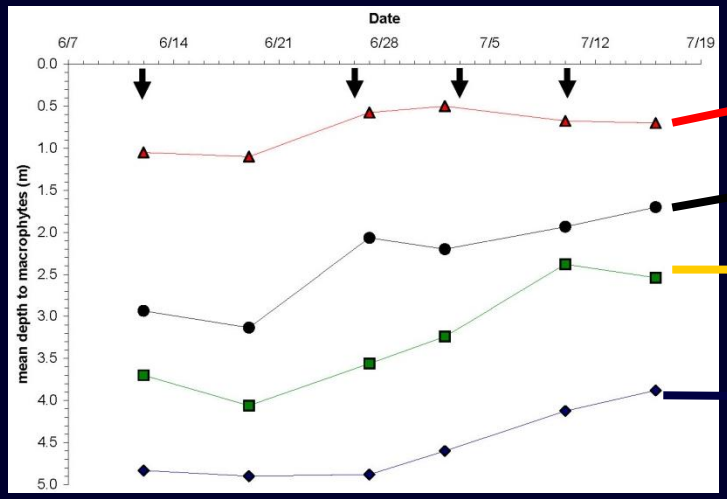
Ship Canal (day)

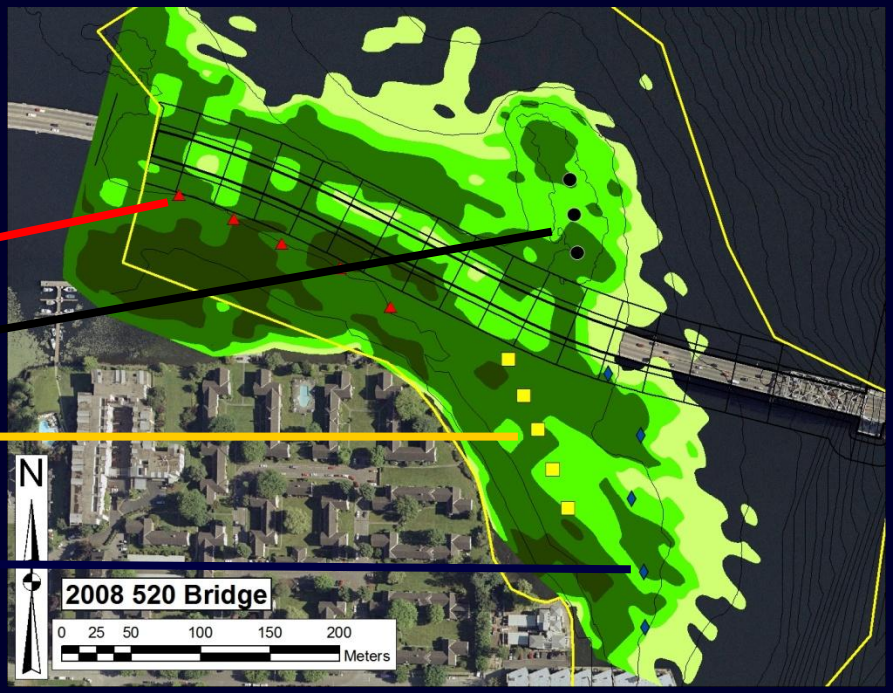


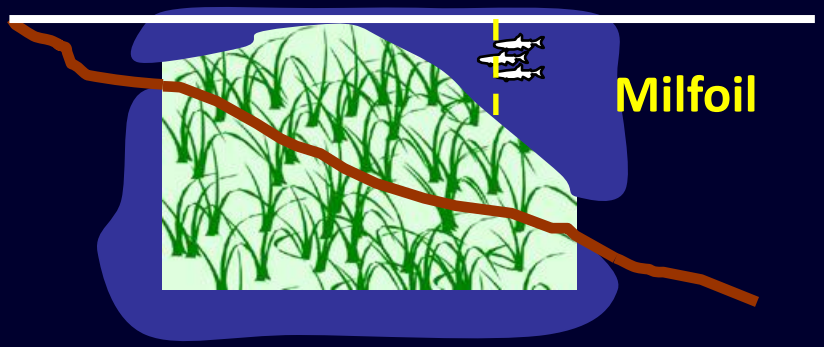
- **Select for bottom depths > 8 m**
- **Proportional selection for 2-8 m**
- Varied by site, time of year, & year

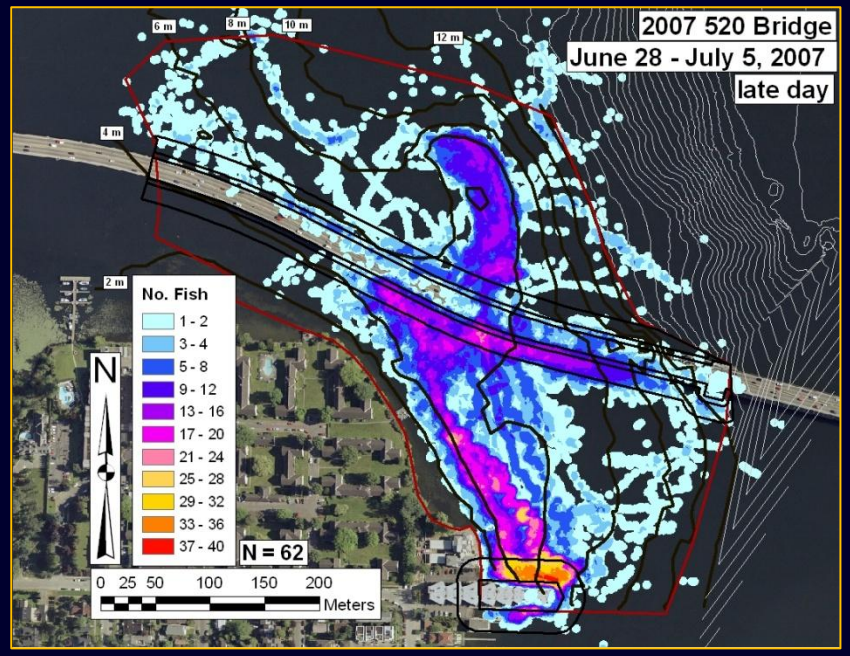
- Overwater structures may influence migration and habitat use in both Lake WA & LWSC, but influence may look different
- Nighttime distribution is similar – offshore, deeper water

- Milfoil functions as false bottom
- Fish avoid areas where milfoil is w/in ~ 1m of water surface



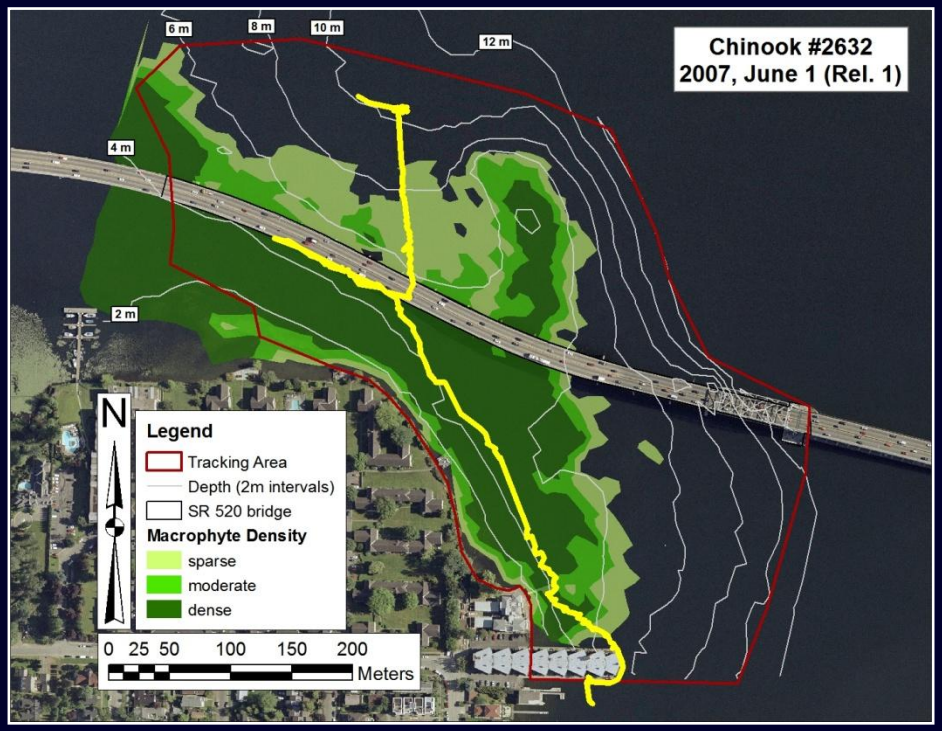






Response to structure depends on fish migrational status

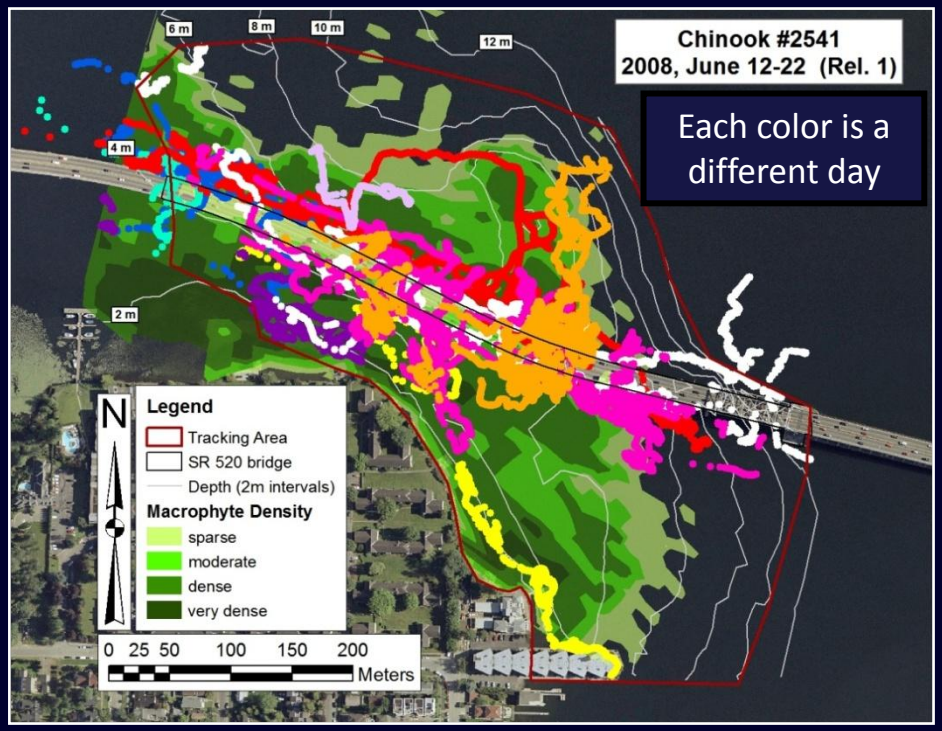
Actively migrating fish



Structure as something to be avoided (i.e., hindrance/barrier to migration)

Kemp et al. 2005, Seaward migrating subyearling Chinook Salmon avoid overhead cover, JFB 67:1381-1391

Holding fish



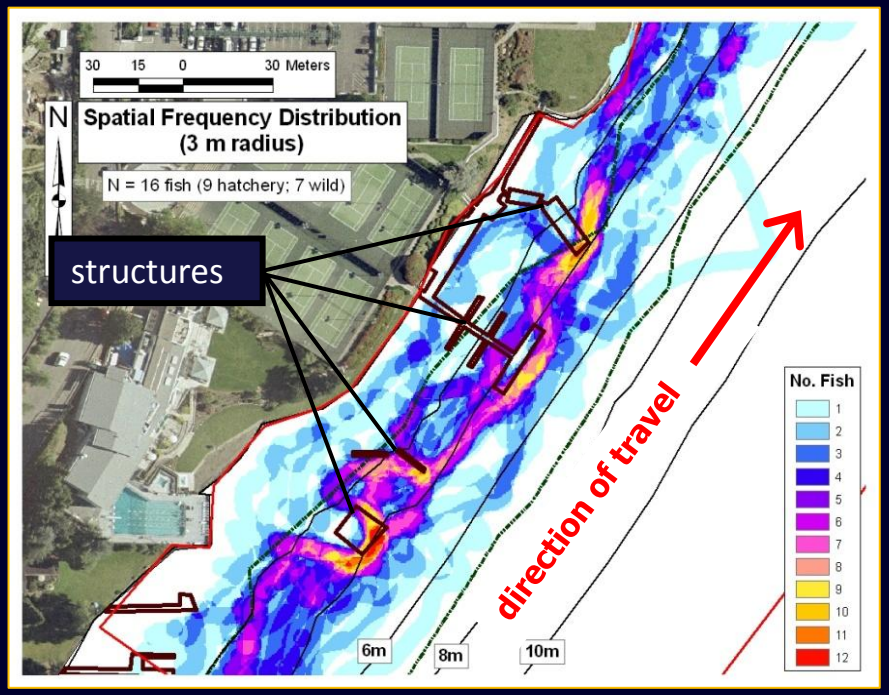
Structure as attractant

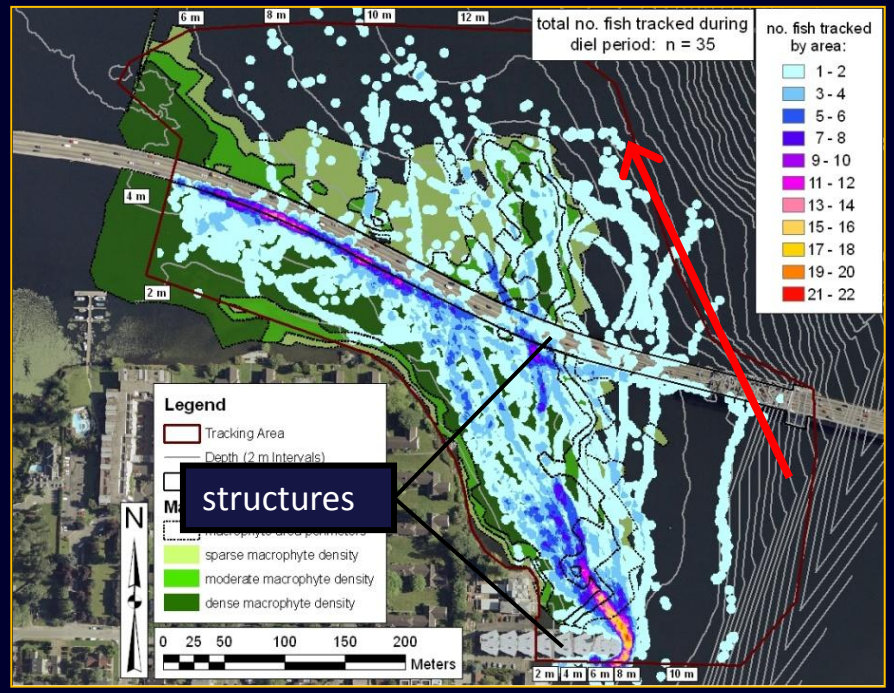
Toft et al. 2007, Fish distribution, abundance, and behavior along city shoreline types in Puget Sound, NAJFM 27:465-480. (marine)

Friesen et al. 2007, Outmigration of juvenile Chinook Salmon in the lower Willamette River, OR, NS 81:173-190.

Concerns: migrational delay; predation

Migratory corridor is narrower & (usually) deeper at structure edges

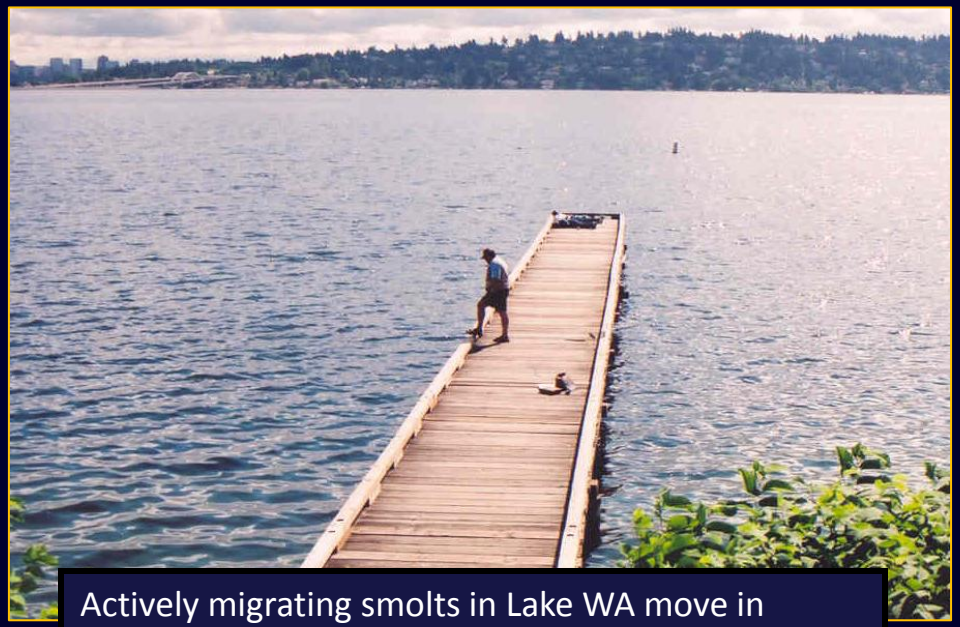




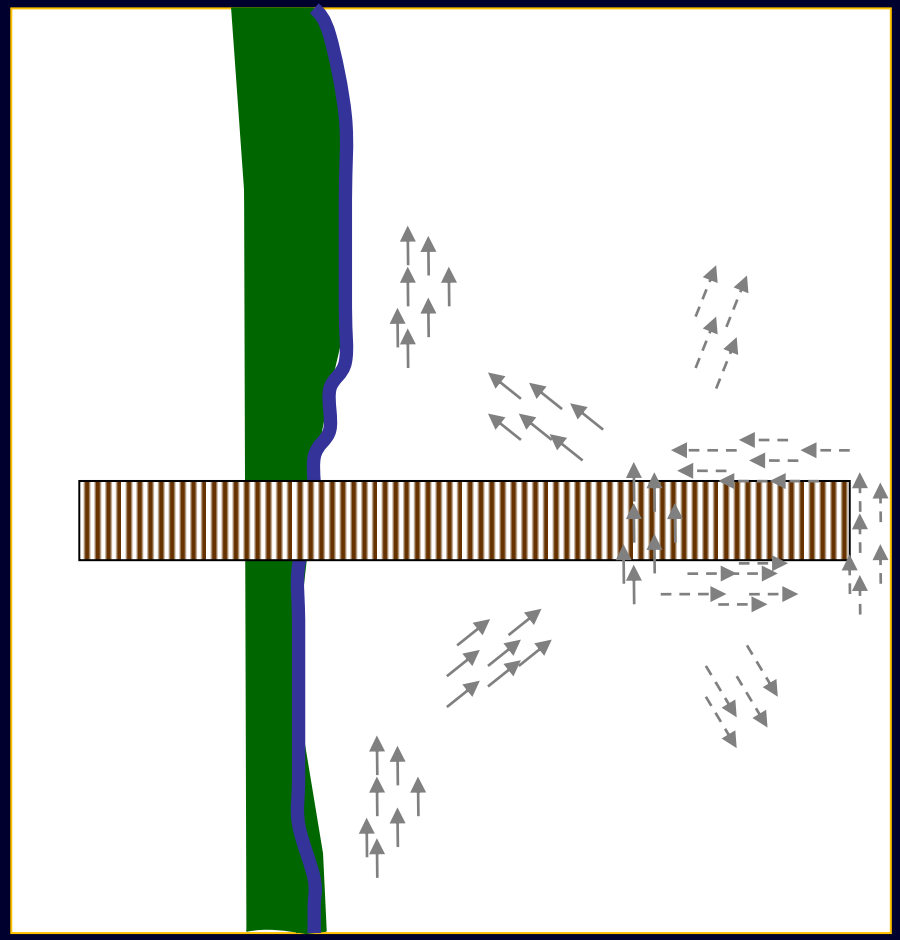
- More dispersed & in shallower water when not near structures
- Migration corridor is deeper & concentrated at structure edges
- More vulnerable to structure-oriented and deep-littoral predators?
- Light level beneath structure seems important (structure width, height)
- Structures in close proximity to one another keep migratory corridor offshore

Visual dock observations

- 11 docks in Lake WA
- 40 observations (1 day @ 1 dock)



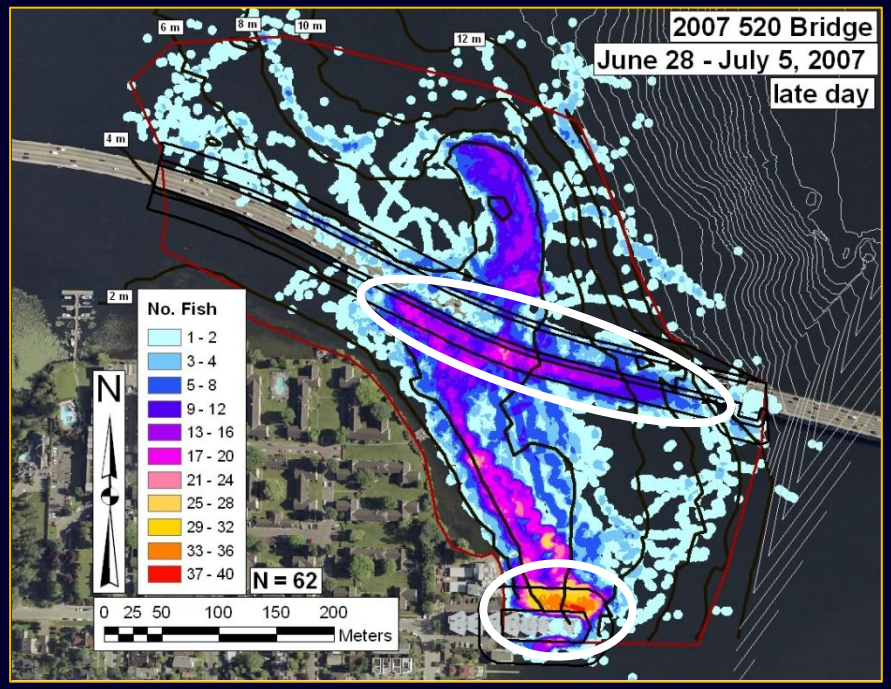
Actively migrating smolts in Lake WA move in schools close to shore (1-5 m depth) during the day

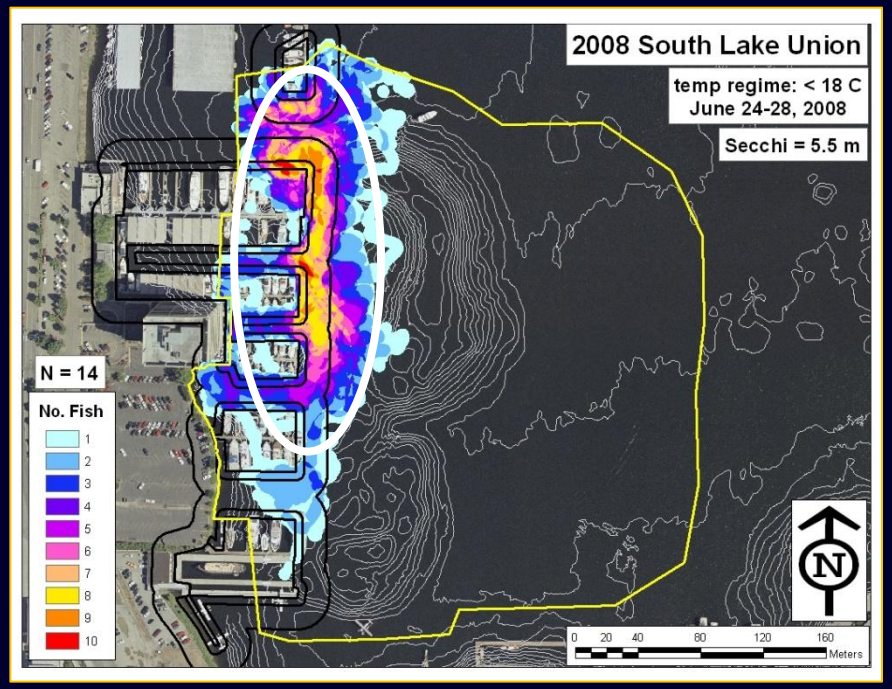


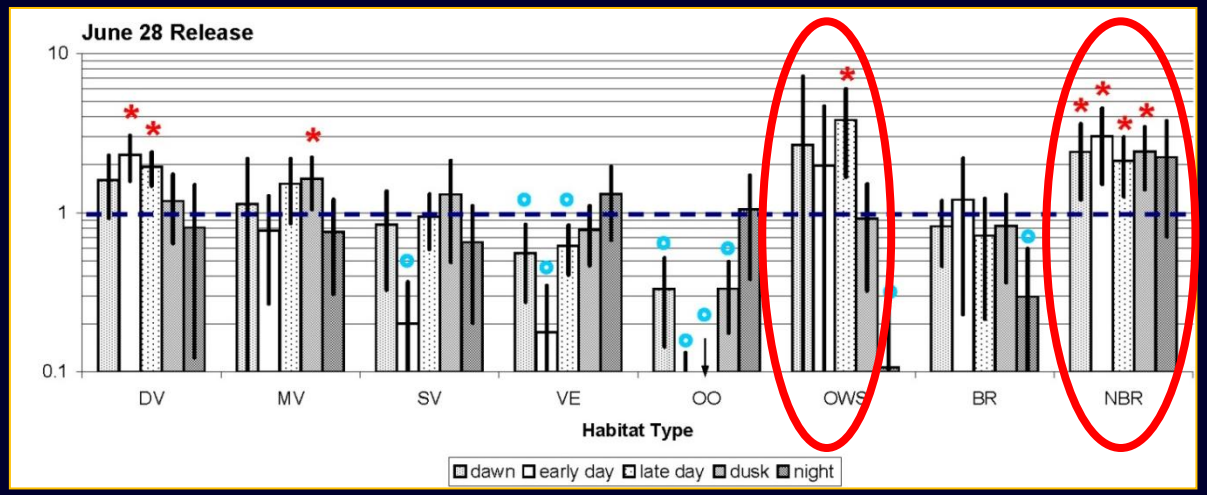
Commonly observed behaviors :

1. Move to deeper water upon encounter
2. Swim completely around the perimeter of the structure; or move underneath structure in deep water
3. Return to shallower water once beyond the structure

Holding Chinook are (sometimes) attracted to structure edges



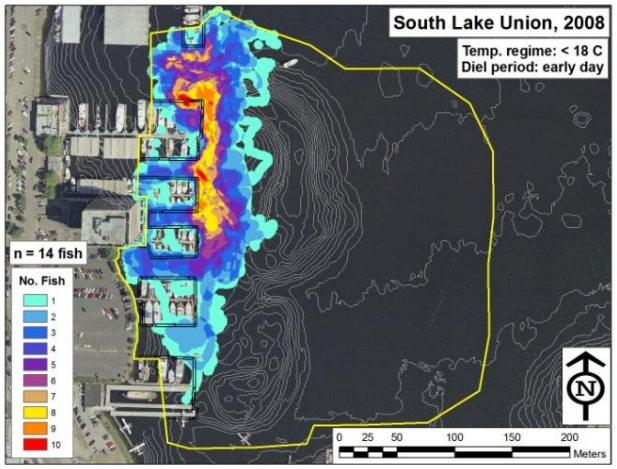


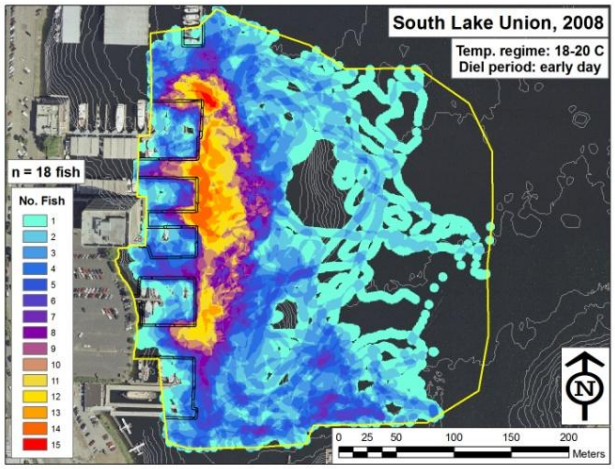


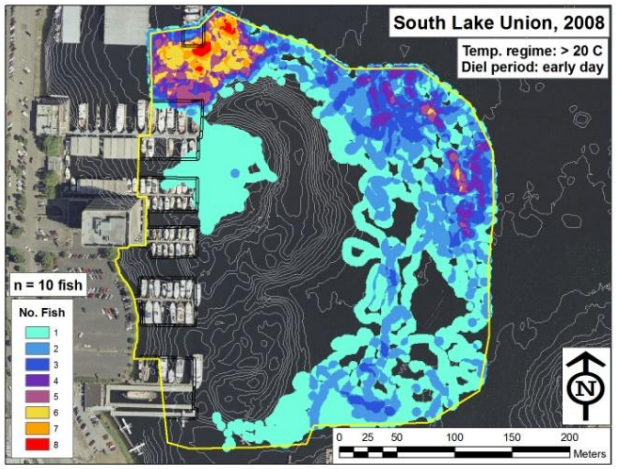
- Most activity generally w/in 20 m of structure edge.
- Water depth at used edges: 2-10 m, and deeper.
- Not all structures were used.
- Not all structures that were used, were used all the time.
- Appeal of cover properties? (darkness &/or in-water structure)

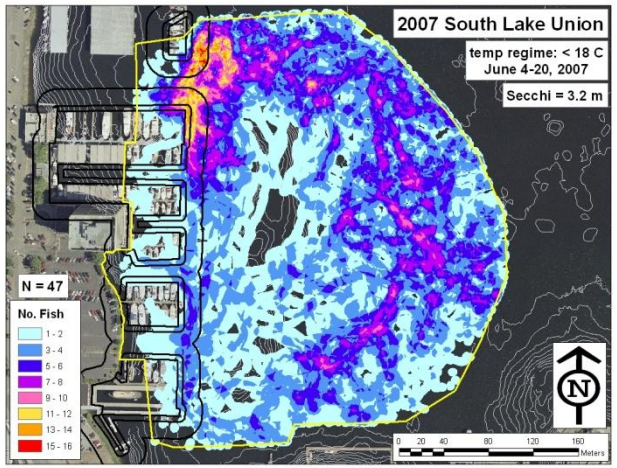
Use of structure edges varies within and between years

2008: shift from shallower structure edges (6 m depth), to deeper structure edges (10 m) with ***increasing temperature, fish size***



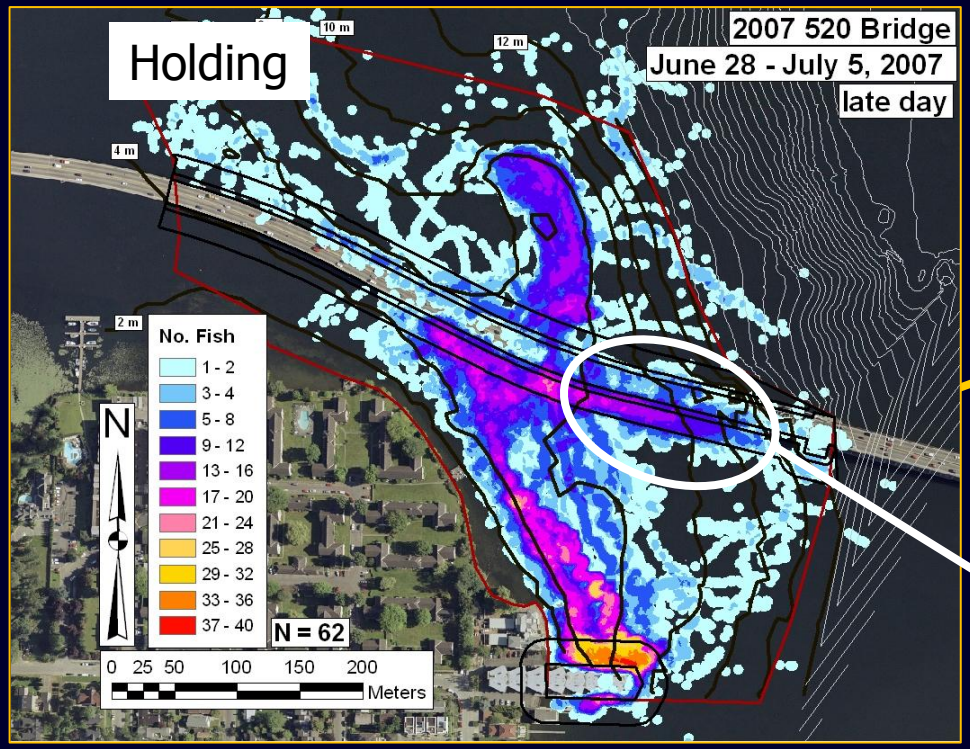


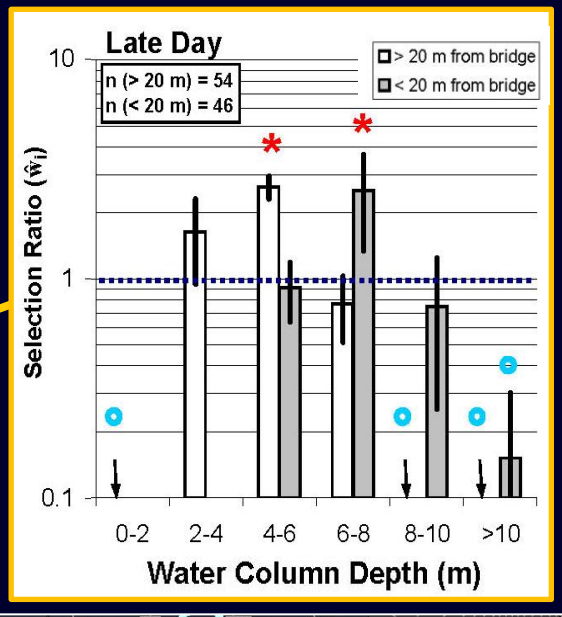


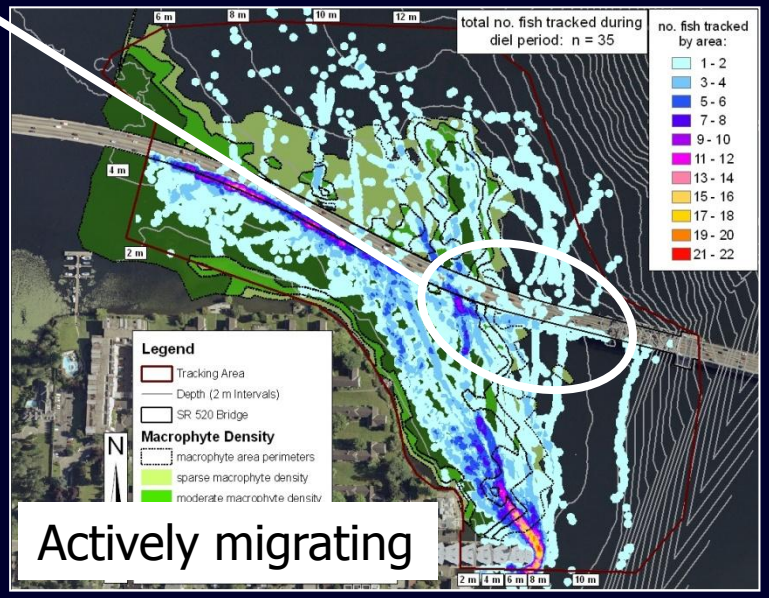


- **2007**: no early-season use of shallower structure edges
- some affinity for deeper structure edges
- no shift w/ temperature or fish size
- 2007: ***fish were bigger, water was more turbid*** than in 2008

Holding Chinook in Lake WA use deeper water when near structures

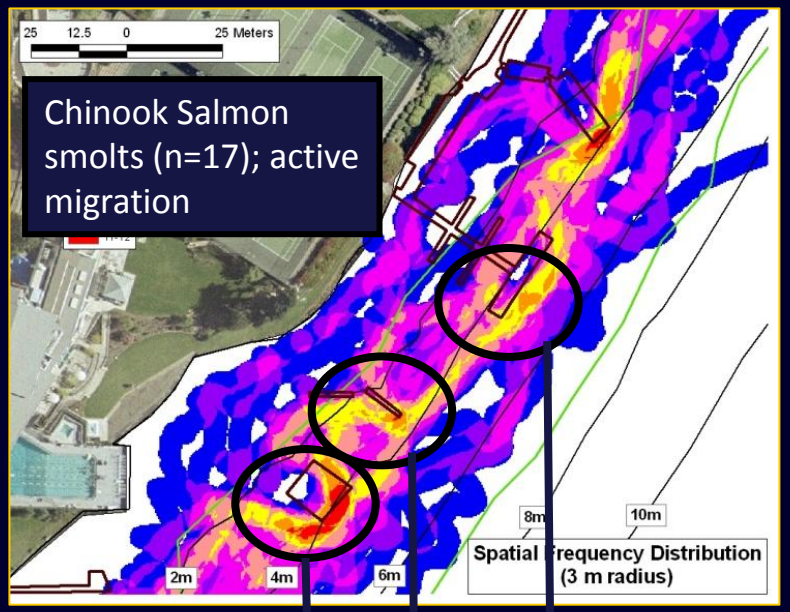


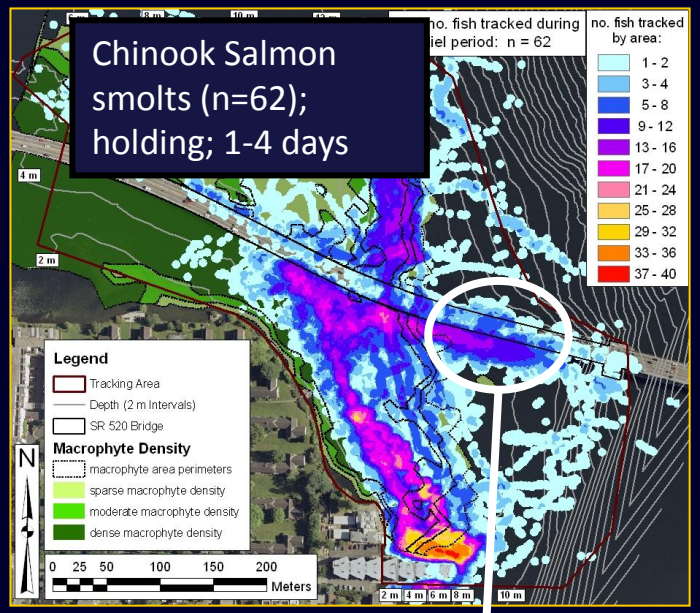




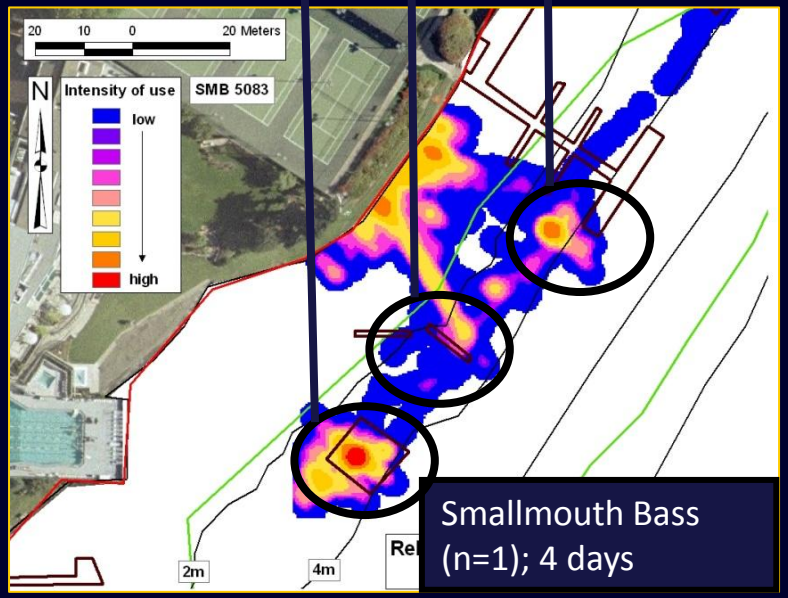
- Select for structure edges (20 m) more than any other habitat type (SR 520 bridge & condo)
- Repeated and prolonged use (1 hr or more)
- Better access to prey, and deeper, cooler water
- Good or bad? (growth, predation, delay)

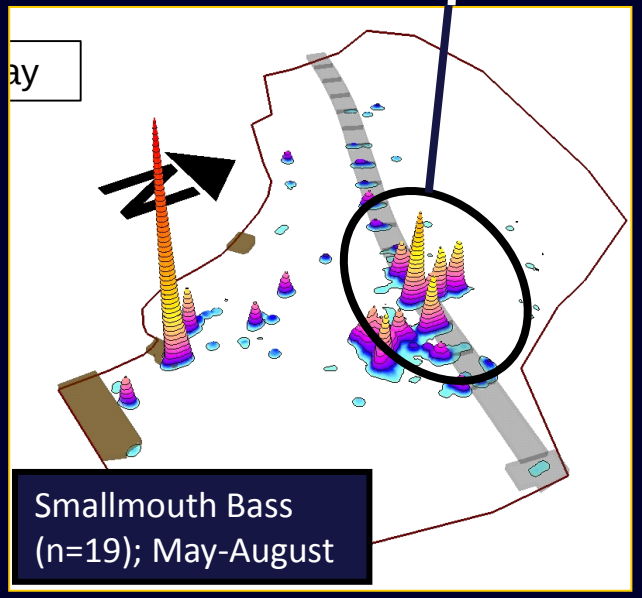
Overlap with structure-oriented predators – Lake WA





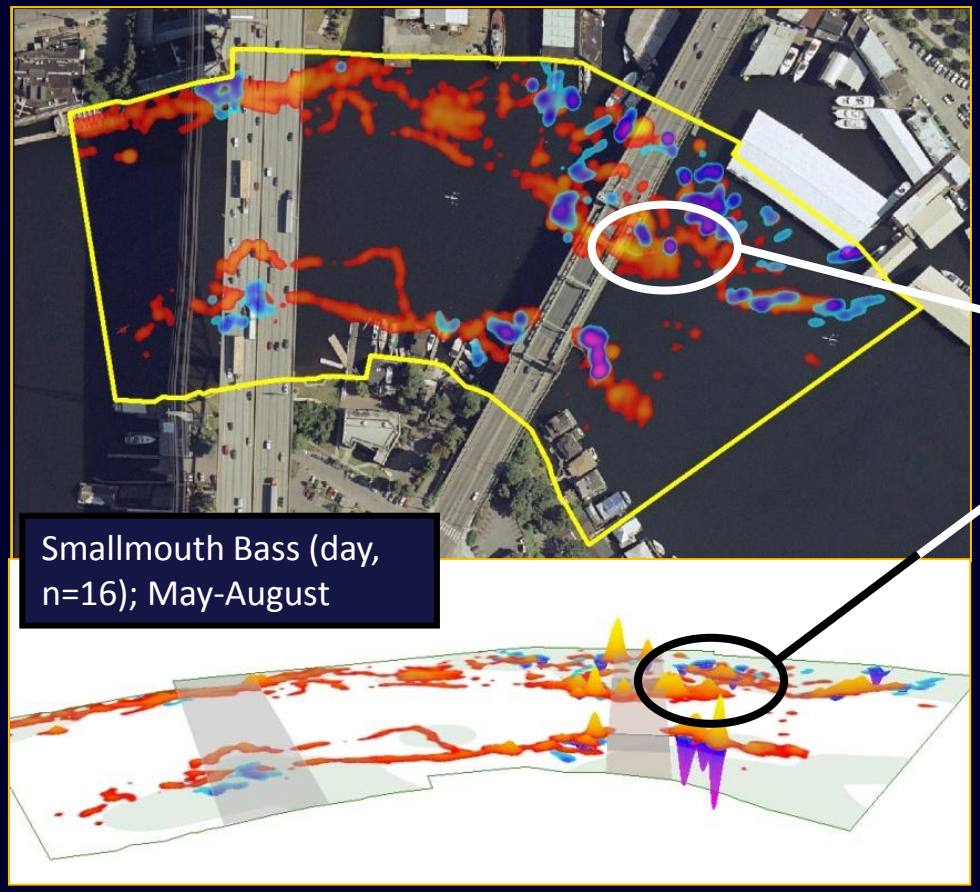
Chinook Salmon



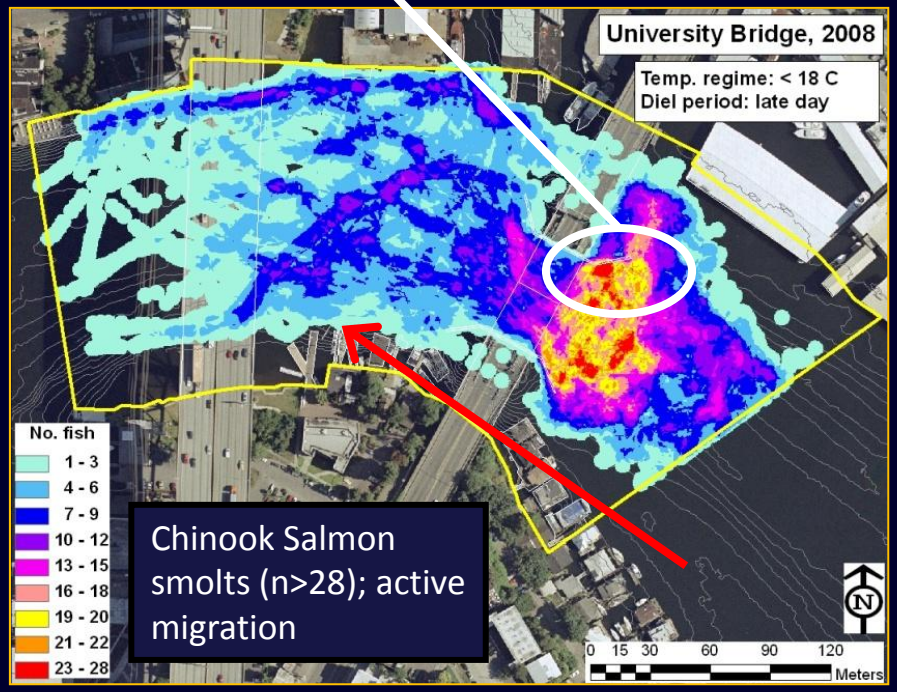


Smallmouth Bass

Overlap with structure-oriented predators – Ship Canal

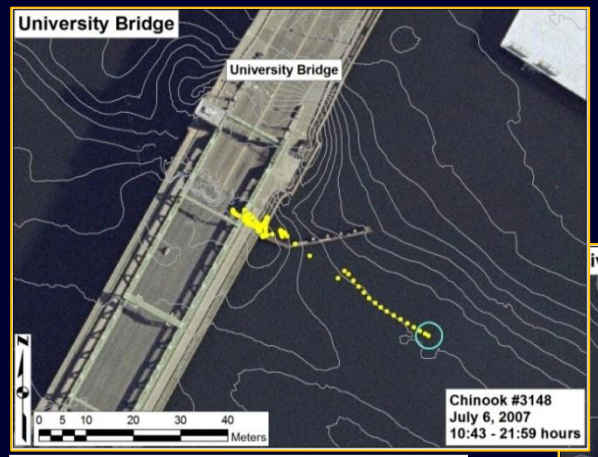


Many Chinook smolts mill in front of Univ. Bridge before passing underneath…

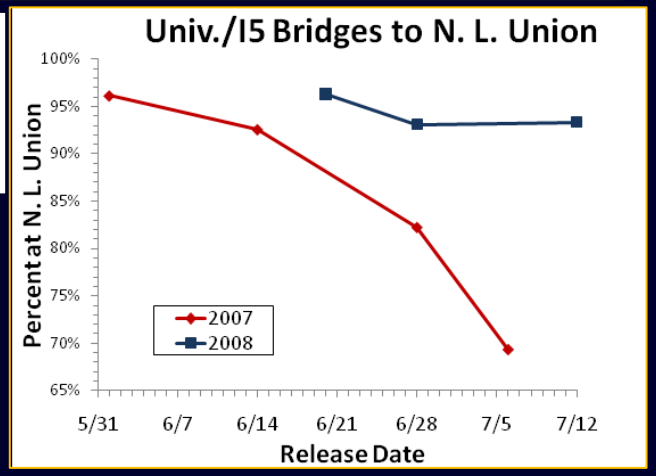


…this puts them in contact with piling-and-wing wall structures (8-10 m depth), which are also popular with Smallmouth Bass. (note lack of milling in front of I5 bridge)

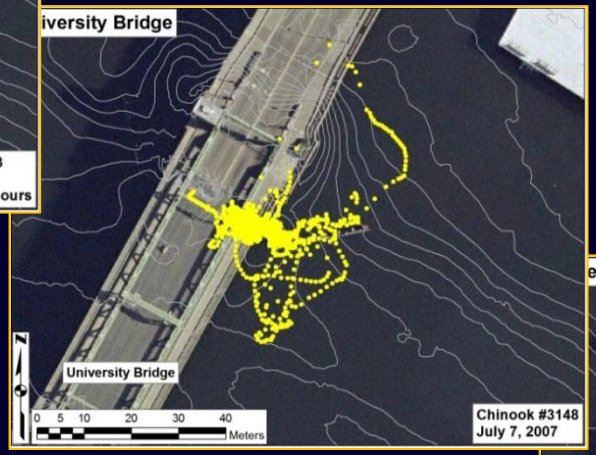
Predation in LWSC

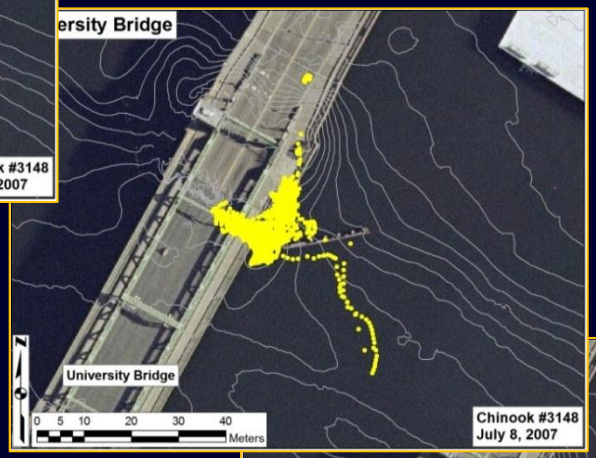


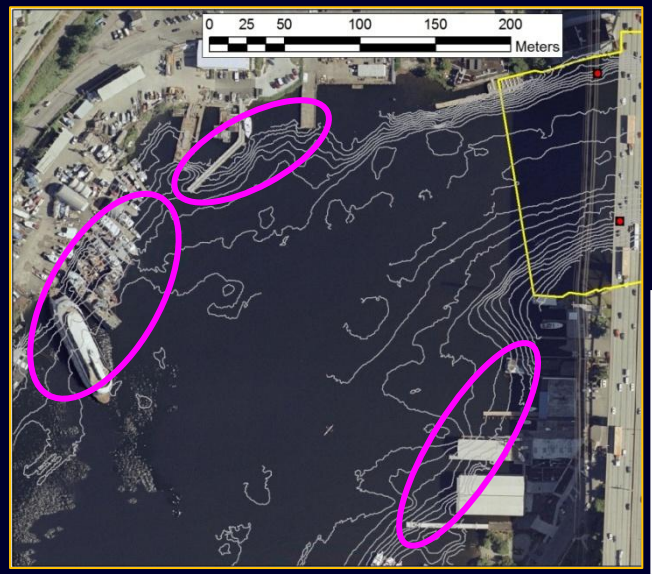
Decline in detections from I5 Bridge to N. L. Union (2007 only) [700 m]



Predation at deepwater structure captured!

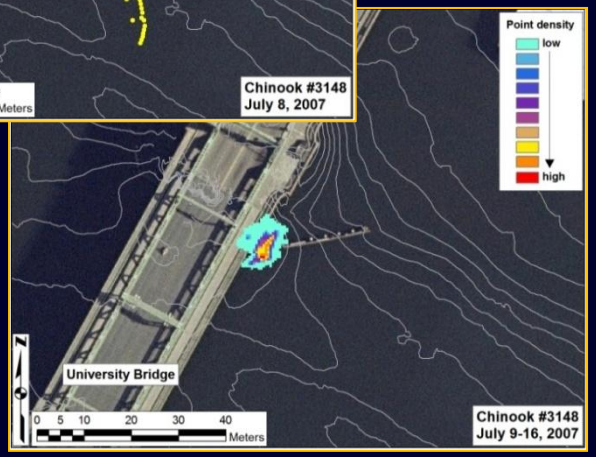




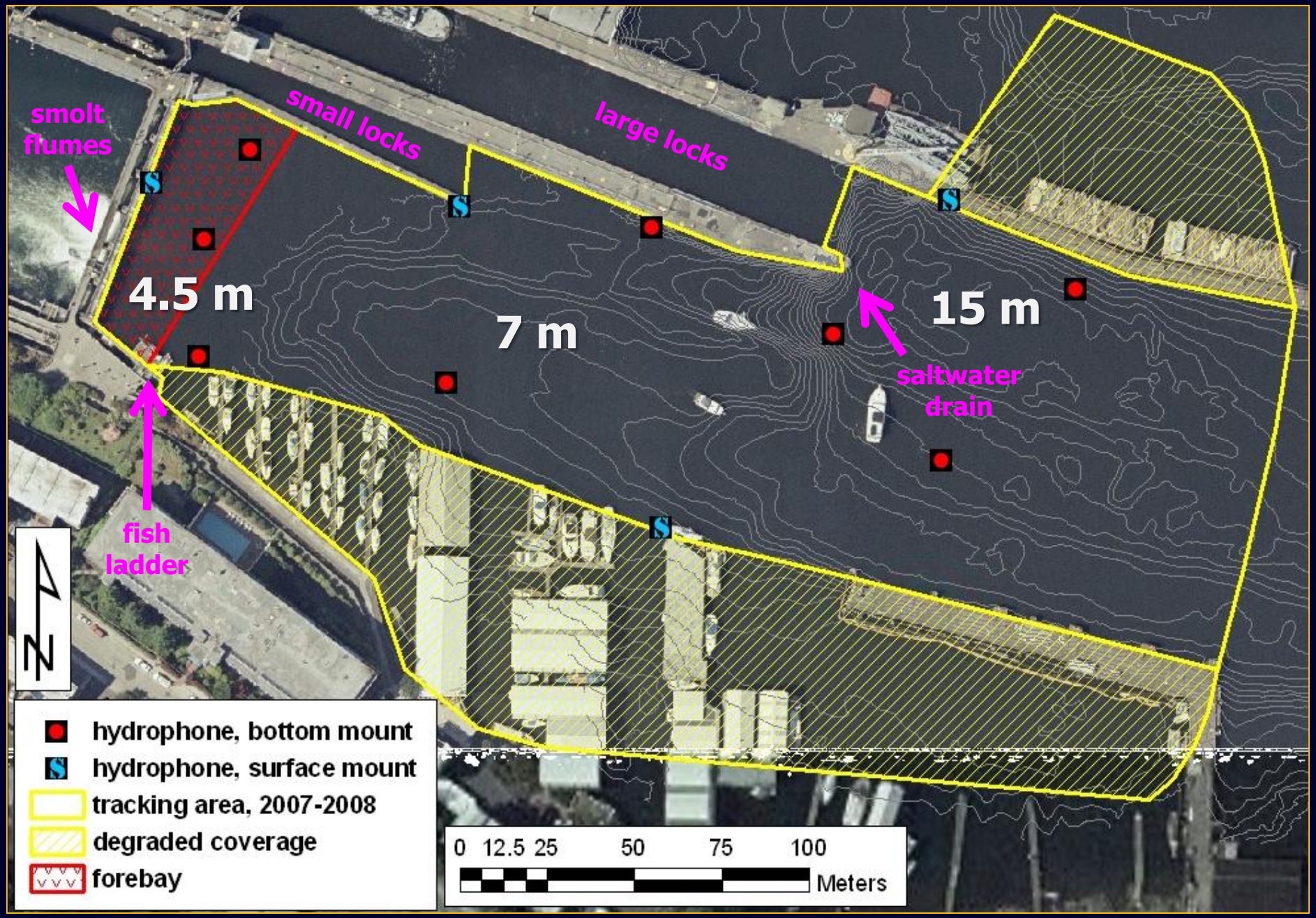


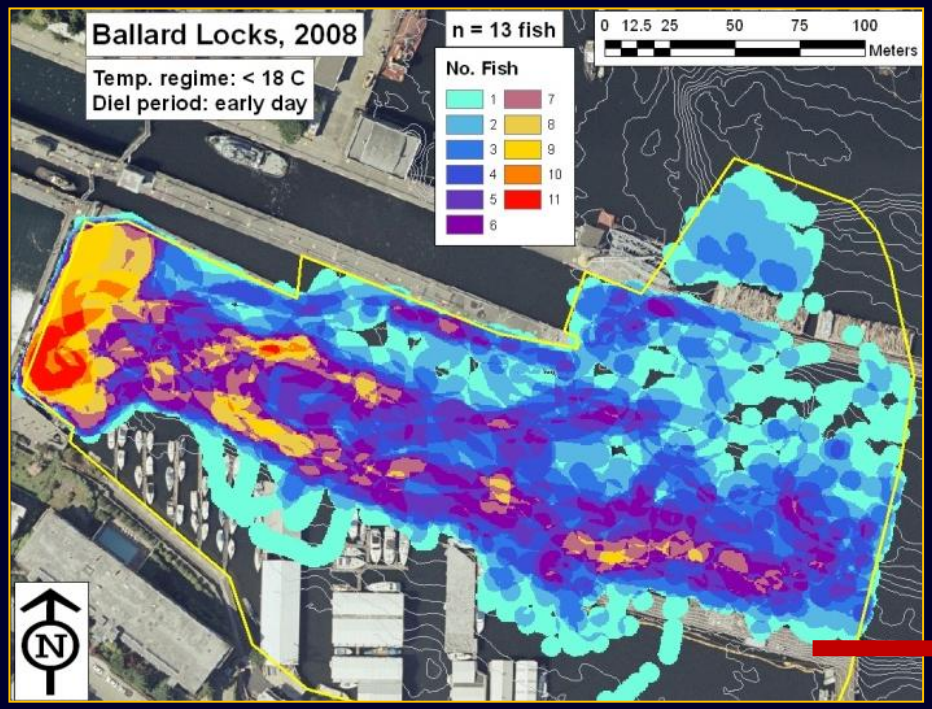
Loss of numerous tagged Chinook just west of I5 bridge

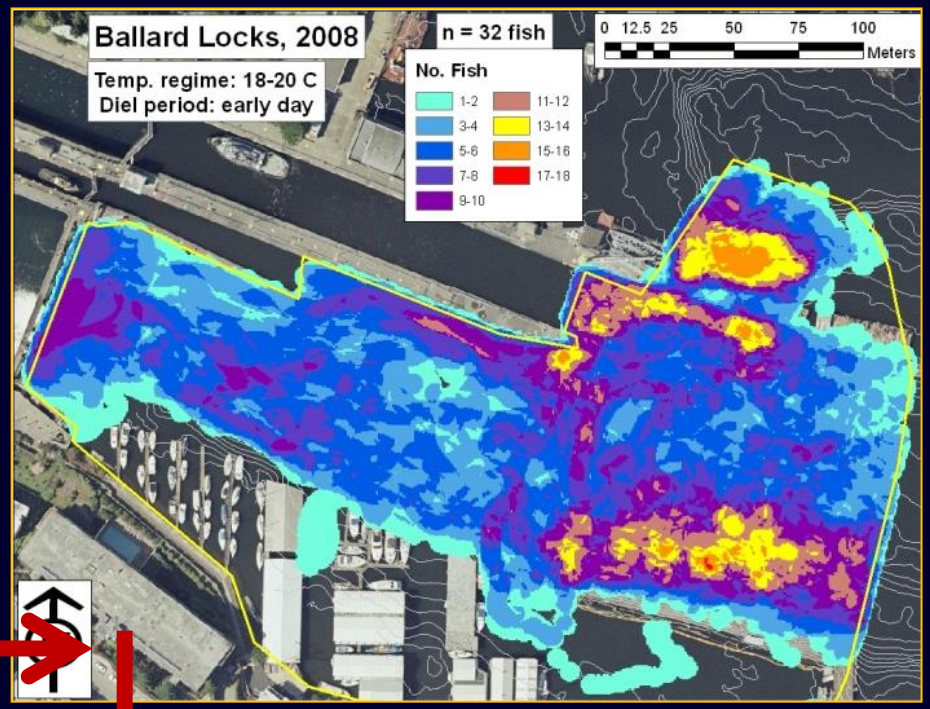
- Late in 2007 (> 20°C)
- Tags detected for long time with no movement

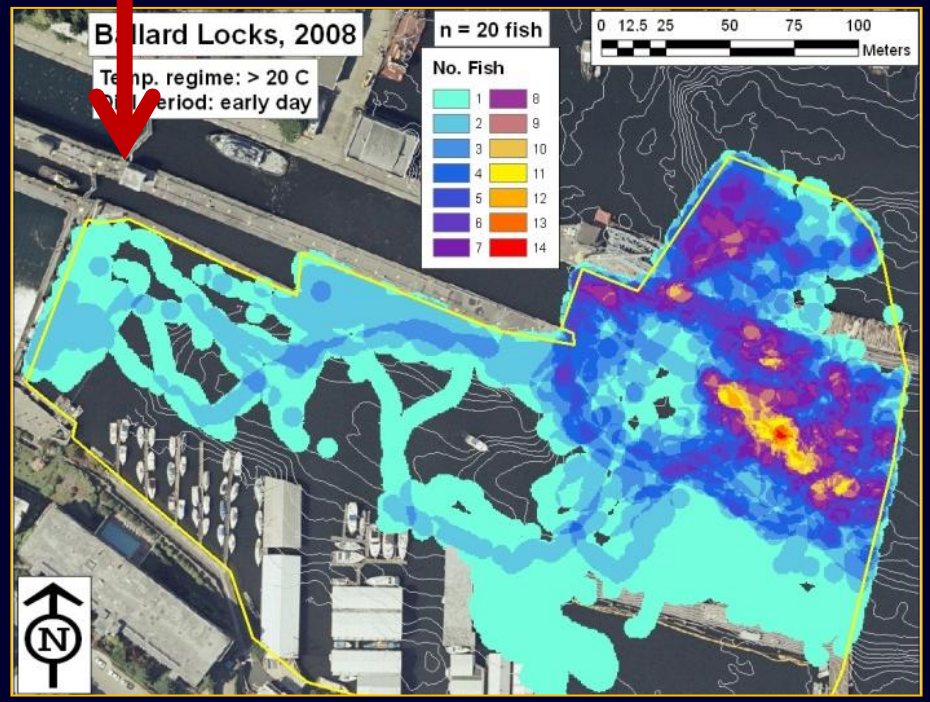


Ballard Locks



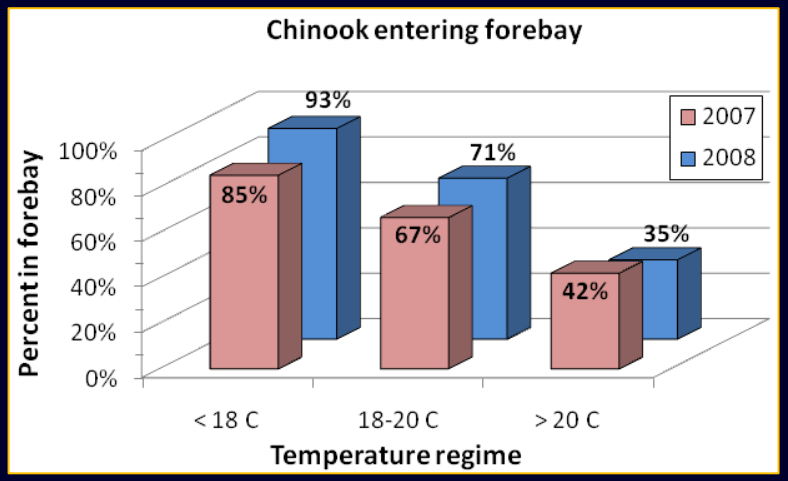


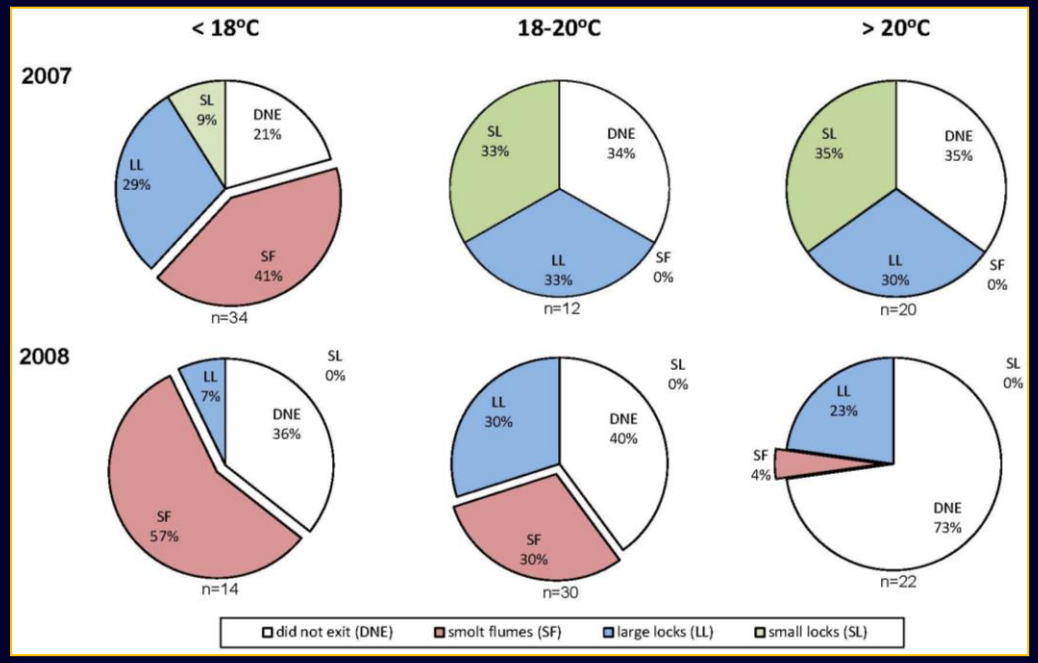


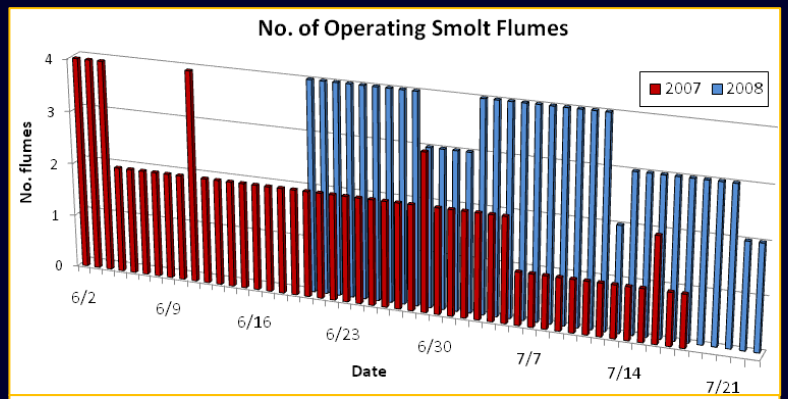


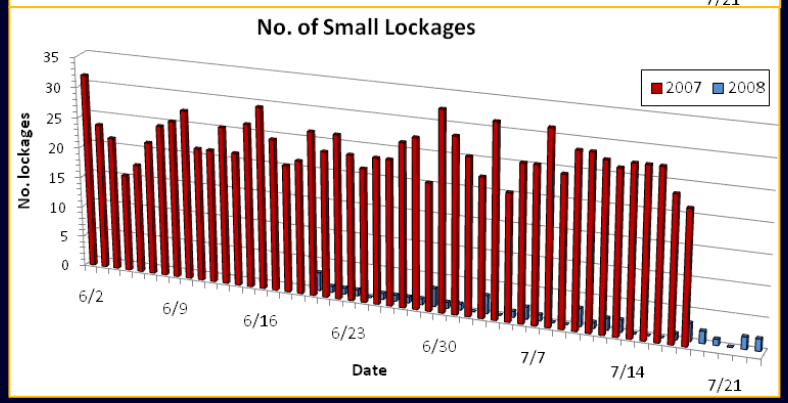
- Lower temperature: extensive activity in forebay area near fish passage flumes
- Increasing temperature: reduced activity in shallower water (i.e., forebay)
- Effects on passage…

Exit Pathways

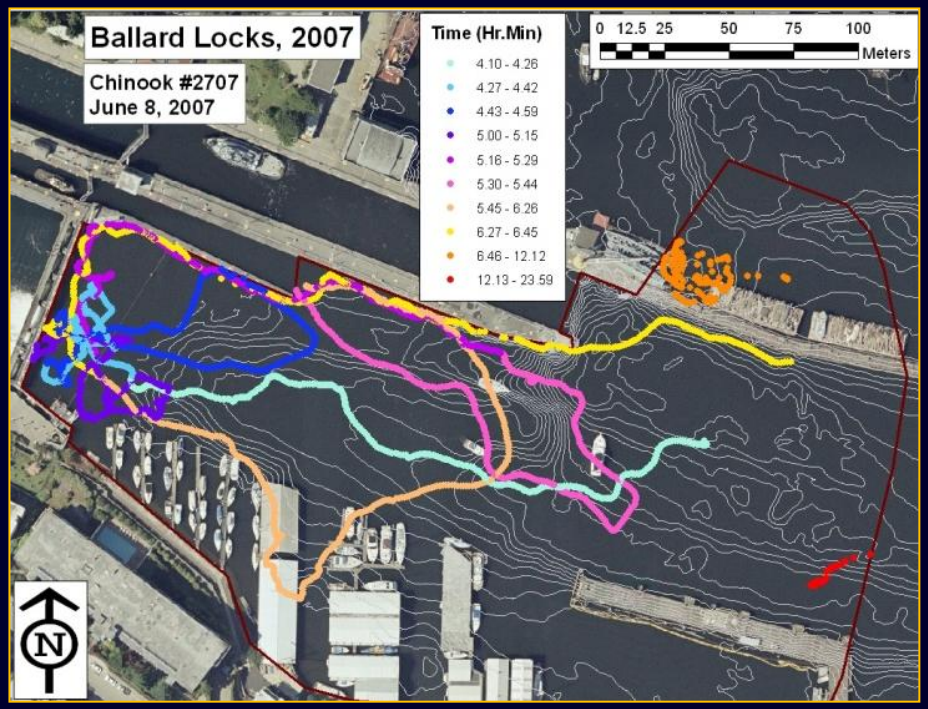


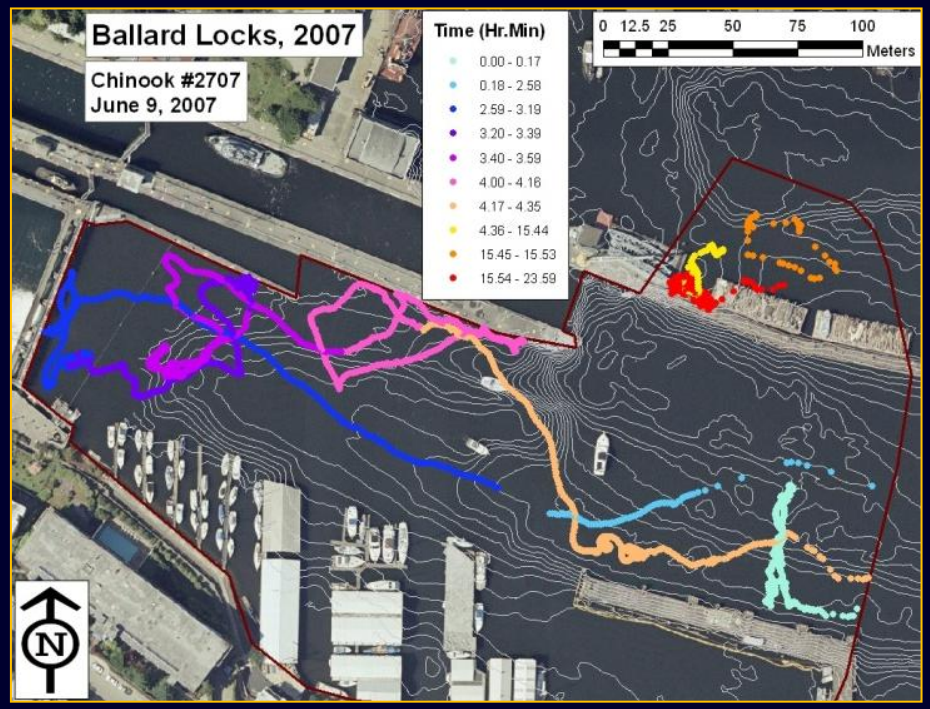






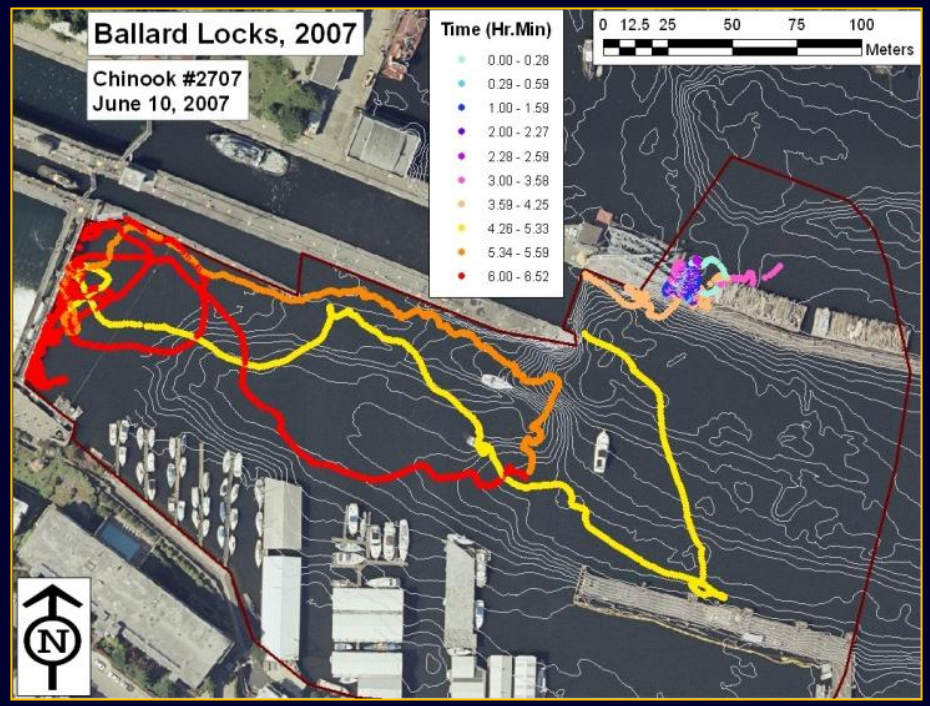
- Decline in forebay entrance w/ increasing temp.
- Decline in smolt flume use w/ increasing temp.
- Influence of locks & flume operations on residence time & flume use?
- In general, the locks inhibited smolt migration, and the degree of inhibition increased w/ increasing temperature.
- Alternative deeper-water exit pathway may be necessary.





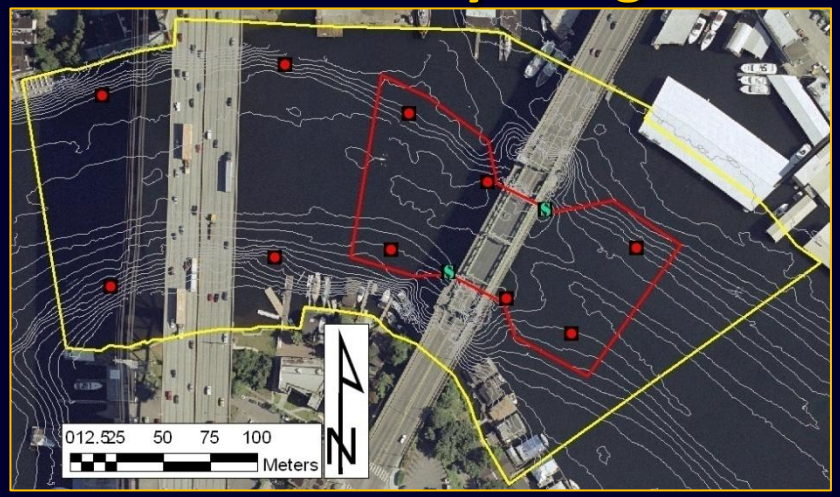
Chinook #2708:

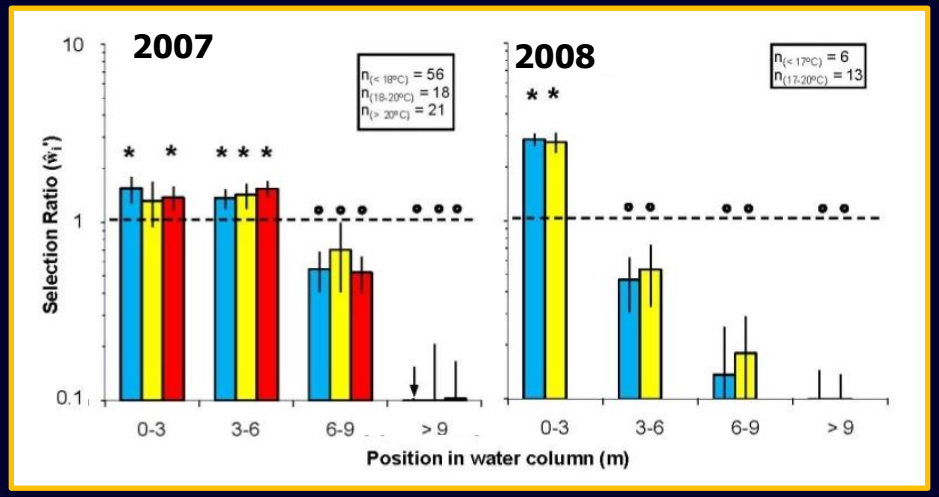
- Several forebay entrances
- Milling along pier walls
- Milling throughout site
- Holding in north shipyard area at night
- Present for 3 days prior to exit
- Exits via smolt flumes at 06:42 hours



Position in water column

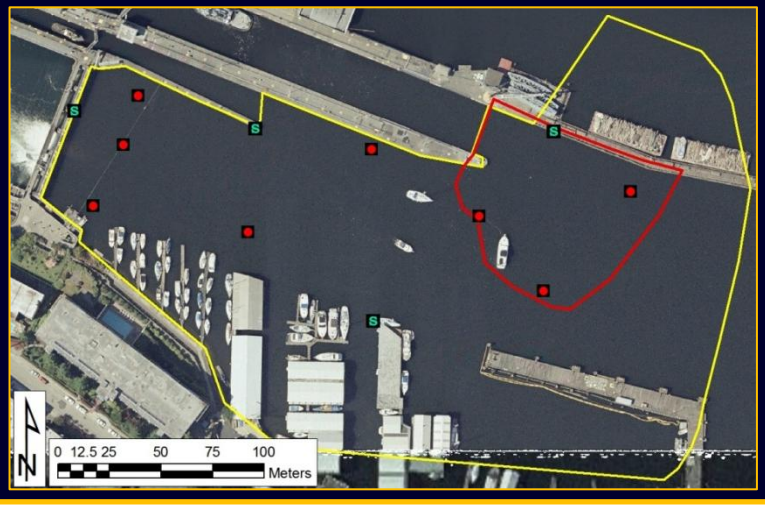
University Bridge

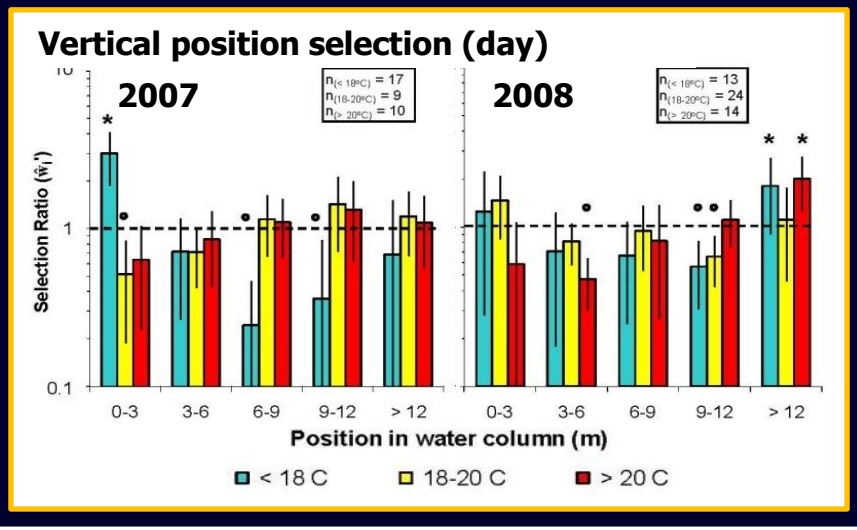




- Distribution mostly in upper 6 m
- Similarity within year
- Variability between years (due to water clarity?)
- No data for > 20°C in 2008 – schooled fish

Ballard Locks

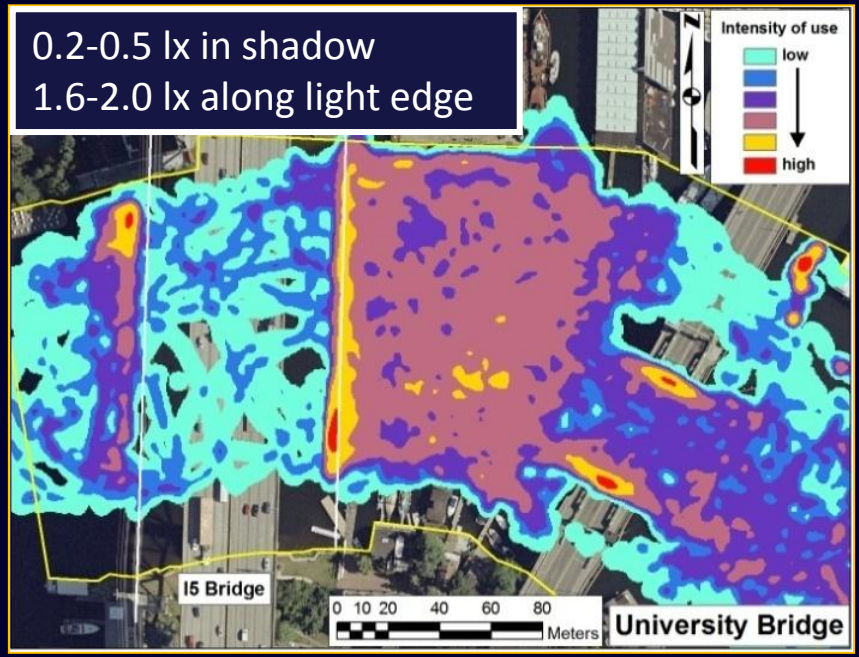


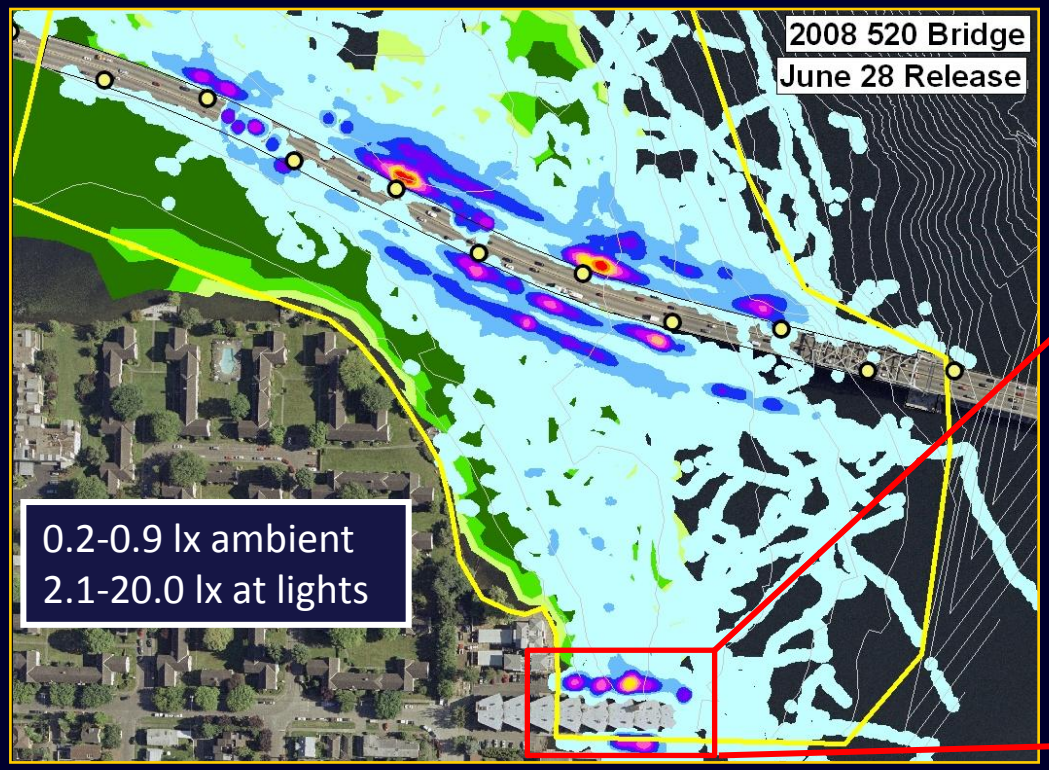


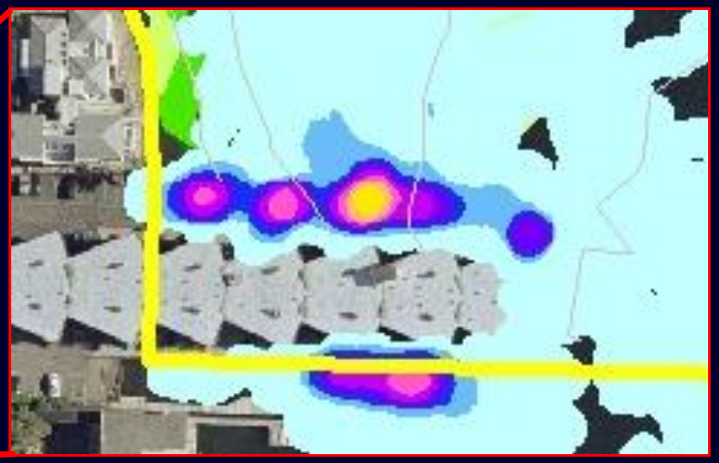
- Distributed throughout water column (except early '07)
- Difference w/ U. Br. due to salinity? (4-6 m; 0.5-5 ppt)
- Similarity within year; variability between years

Holding (not actively migrating) Chinook Salmon smolts are attracted to artificial light at night

- Neither Smallmouth Bass nor Northern Pikeminnow showed an affinity for artificial light
- Other predators? (Cutthroat Trout)
- How do these behaviors affect predation rate?







Summary

- Chinook use all parts of Lake WA & LWSC (except areas < 1-2 m deep, and where macrophytes are within 0.5-1 m of water surface)
- Chinook spend more time in some areas (Union Bay, Lake Union, Salmon Bay, Ballard Locks) than others (Montlake Cut, Portage Bay, Fremont Cut)
- At warmer temperatures:
  - Declining entrance into LWSC (no thermal barrier)
  - Increased predation
  - Increased desmoltification/residualism
  - Increased residence time at Ballard Locks
  - Declining use of smolt flumes
  - Declining passage through Locks into Puget Sound (?)
- The entirety of Lake Union (including south L. Union) is used for extended holding/rearing.
- Juvenile Chinook are attracted to artificial lighting.

Summary (cont.)

- Overwater structures can delay migration, alter behavior & habitat use, attract predators, & may expose fish to greater risk of predation.
- Overwater structures may act as a barrier to actively migrating Chinook (light), & as an attractant to holding Chinook (light, in-water structure).
- Overwater structures in Lake WA substantially alter the migratory corridor by constricting it, forcing it along structure edges, and pushing it into deeper water.
- Deepwater structure edges attract holding Chinook in Lake WA & LWSC.
- Smallmouth bass and Chinook salmon habitat overlap at structure edges.
- *Repeated study important to capture inter-annual variability*.
- Further study:
  - —Reasons for declining entrance into LWSC
  - —Reasons for holding in Lake Union
  - —Relative importance of predation, residualism, and declining locks passage
  - —Consequences of structure-induced behaviors (predation, survival, fitness)
  - —Consequences of attraction to artificial light
  - —Effectiveness of mitigation strategies (structure designs; passage at locks)
  - —Smaller fish

Questions