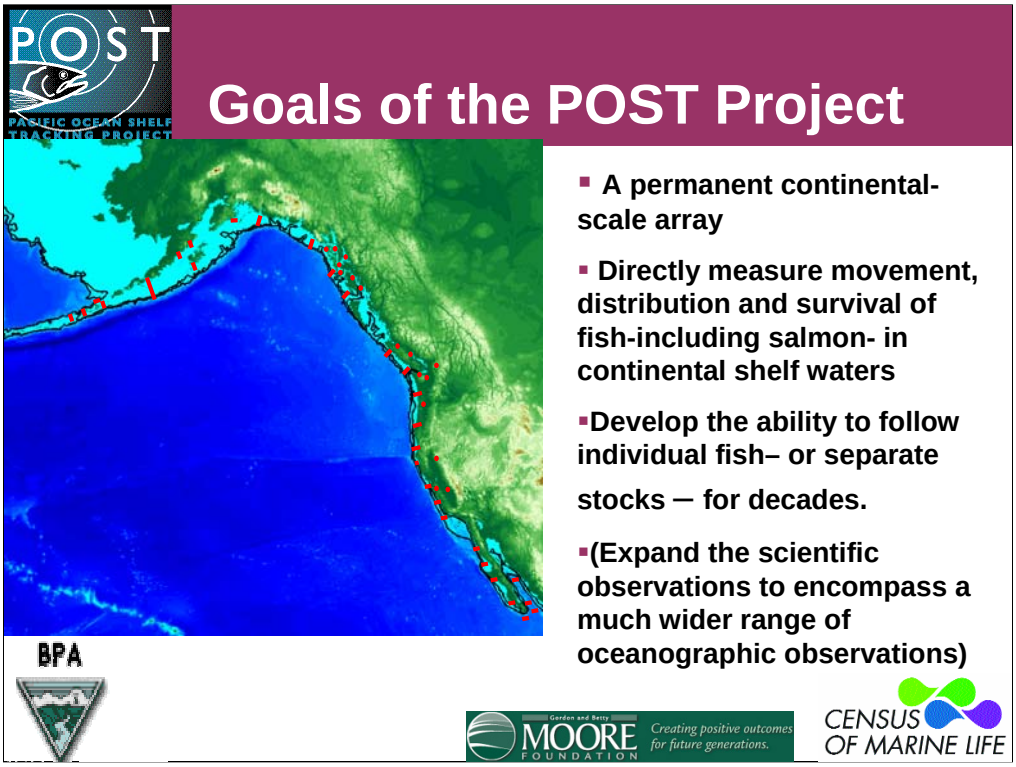
Applications of a Large-Scale Marine & Freshwater Telemetry Array: How POST (Pacific Ocean Shelf Tracking) is Measuring Marine & In-River Salmon Survival

-What POST has done & Where POST is going

David Welch



•The 2 year demonstration phase evaluates the scientific value and feasibility of building a permanent large-scale ocean telemetry system for studying the marine phase in the life history of salmon and other marine animals- “POST”.

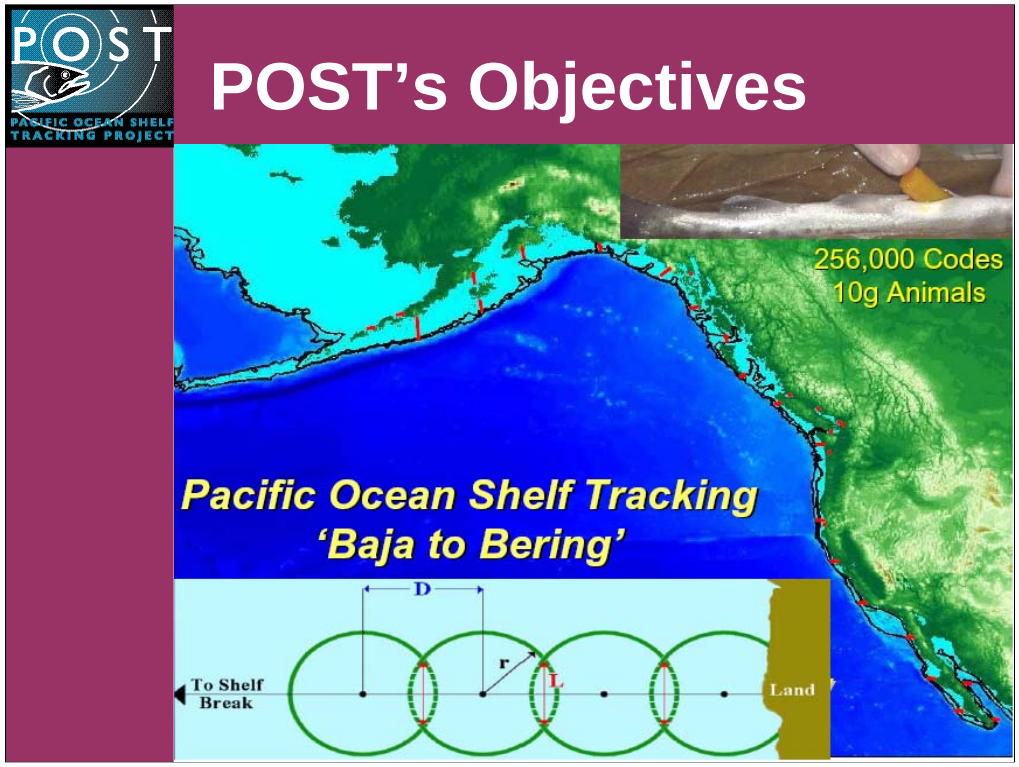
•By deploying a series of acoustic receivers in strategic listening lines on the ocean floor, the project tracks the movements of individual fish implanted with coded acoustic tags.

•Such a system can be used to address key issues in fisheries management, including: 1) the timing and rate of migration; 2) the residence locations of different fish species; and 3) differences in stock and species behavior– and directly measure survival.

•The system allows biologists to estimate marine survival by monitoring the migration of fish over successive acoustic curtains, thus providing information on the critical times and geographic locations where marine survival is affected.

•The system would be a powerful long-term monitoring and observation tool for conservation and protection programs world-wide.

POST's Objectives

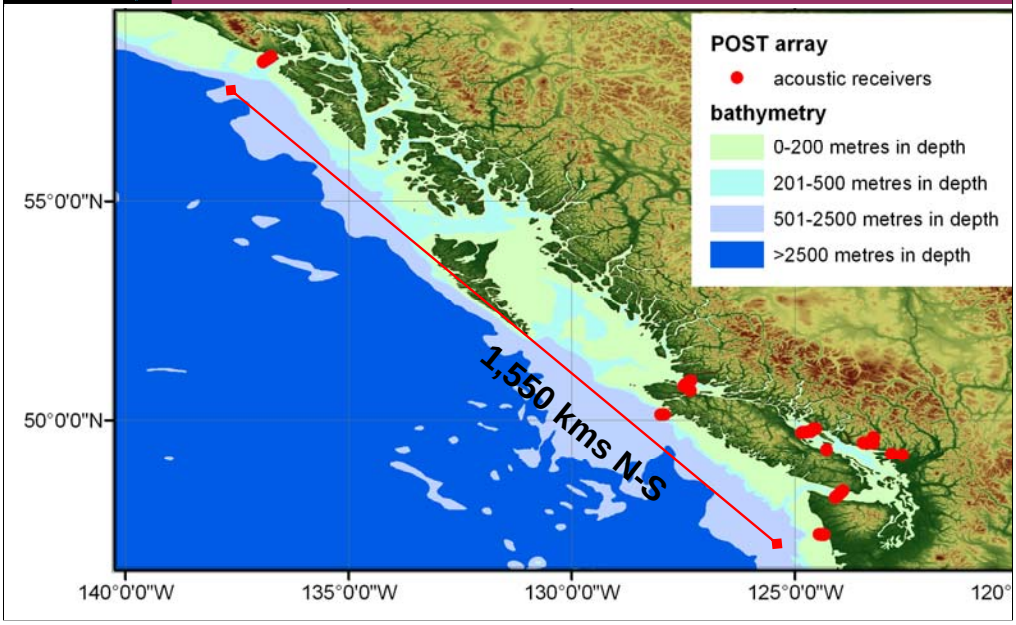


•The Census of Marine Life is a decade-long program to promote and fund research assessing and explaining the diversity, distribution and abundance of species throughout the world's oceans.

•POST is one of 13 major field programs within the Census of Marine Life.

•The Census promotes a new era of marine research around the world, with a strong international commitment and unique regional efforts.

2004 & 2005 POST Tagging



•The array currently spans a 1,550 km region, stretching from Cape Elisabeth (20 miles north of Grays Harbor) to north of the Alaska Panhandle

Three Components to POST

1. Deploy a near-perfect array of “acoustic curtains” on the seabed

2. Surgically implant thousands of fish with individually identifiable acoustic tags

3. Deliver the data from the array to:

    a. Prove the concept

    b. Establish the technical platform

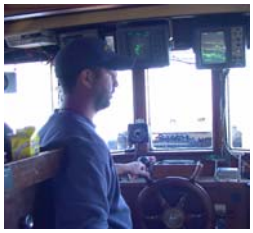
    c. Generate the scientific support & demand

    d. Motivate the widespread understanding of our ability to do so– and the need to do it!

POST Team at Work







•The project has involved dozens of people, ranging from commercial fishermen for deploying the ocean array, to commercial divers (for restricted work in the Fraser River), to graduate students.

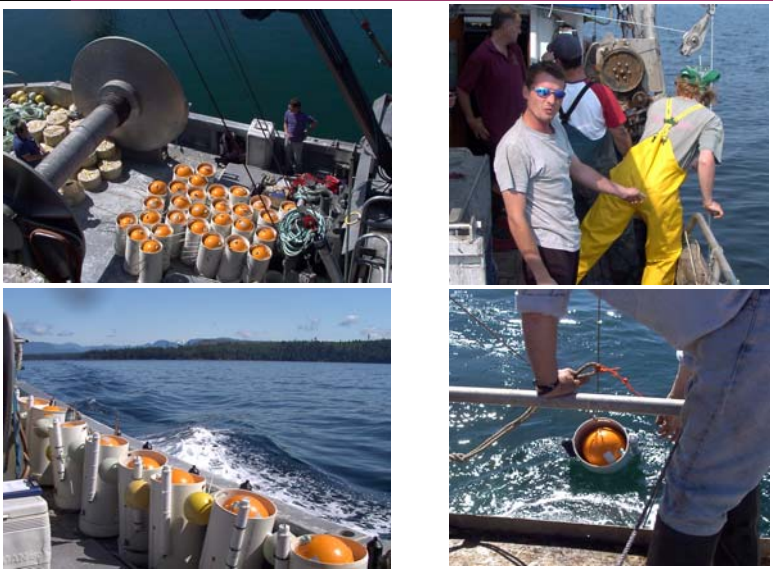
POST Team at Work






The purpose of all of the work (and infrastructure!) is to put out a small black fish tracking sensor in precise locations and get it back

Deployment of Listening Lines



Deployment of manufactured pop-up moorings with receivers & acoustic releases

•Fish-tracking sensors (in black) and acoustic releases (in white) are mounted on either side of moorings which pop-up to the surface when the release is triggered by acoustic signals from the boat.

•By recovering these sensors after months on the seabed, we can upload the stored data and get a complete record of the passage of each surviving salmon smolt.

•The date & time of passage for each uniquely identified fish allows us to build up a complete description of the fate of each stock (survival) and rate of movements

POST's 2004-05 Field Seasons

- **Deployed 120 km of acoustic listening lines (135 seabed nodes)**
- **Ran array for 5 months (April-Sept. 2004 & 2005)**
- **Both freshwater & marine lines**
- **Measured population-specific residence time & speed of movement**
- **Measured fish *survival* directly (never before done on this scale-- and the real reason for all the work)**

•Lines were deployed and recovered twice in 2004, once in 2005.

•Geographic range from Columbia River to SE Alaska.

•River systems studied include: Squamish, Thompson (Upper Fraser), Cultus Lake, Englishman, Keogh, Nimpkish, Qualicum and Sakinaw Lake in BC, and the Columbia River.

•Study covered hatchery and wild comparisons and species and stocks of concern.

• Stocks studies include: chinook, coho, Doly Varden, sockeye and steelhead.

Progress in 2004 & 2005- Results

2004	*2005*
8 River Systems	**16 River Systems**
14 salmon stocks tagged	**19 salmon stocks tagged**
1,051 smolts tagged	>2,700 smolts tagged **(2.6X)**
91% detection rate in ocean (10 out of every 11 fish detected per 20km ocean line)	95.5% detection rate in ocean (19 out of every 20 fish detected per line)
✓ Established movements	✓ Established movements
✓ *Measured survival*	✓ *Measured survival*
	✓ *Completed Wireless R&D for permanent system*

•In the 2005 field season, technical refinements to the ocean array increased detection rates on the 20+ km acoustic lines from 91% to 95.5%

•This small improvement corresponds to almost a doubling in detection efficiency; we have gone from detecting 10 out of 11 smolts crossing the lines in 2004 to detecting 19 out of every 20 smolts in 2005.

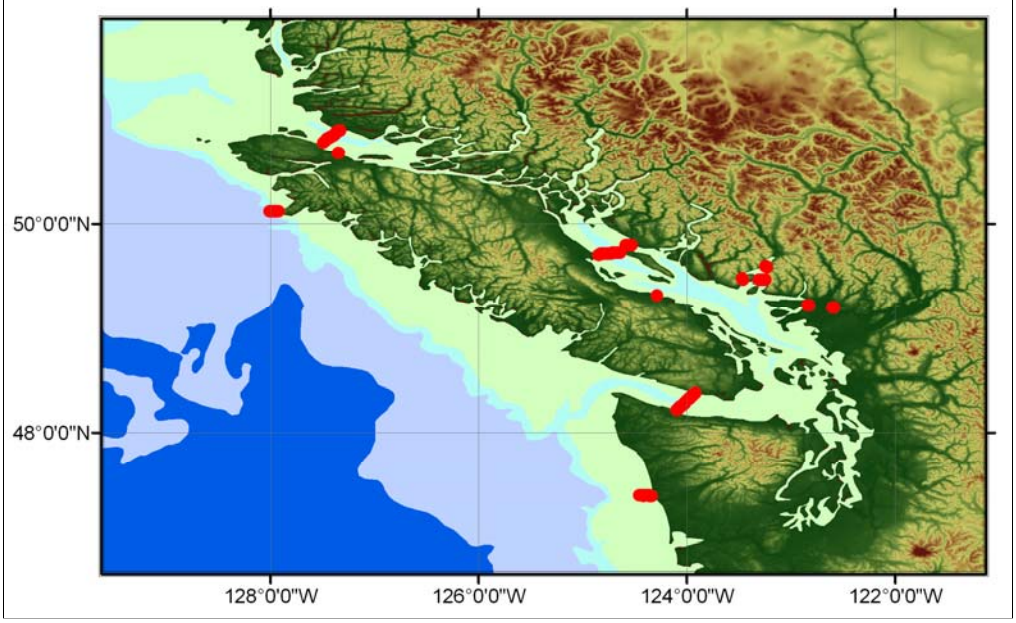
• In fact , our detection rates were even higher. The detection rate was reduced to 95.5% by some smolts that were missed on the N Strait of Georgia line, but were subsequently detected on the Queen Charlotte Strait line. These smolts had migrated past during an ~2 wk period when two of the receivers in the northern Strait of Georgia were out of the water in May, after being dragged up and brought back to land by a commercial fisherman.

•The array technology can therefore capture precise measurements of movement and survival in a way that was never done or possible before.

•The survival information, detailed below, means that we can precisely demonstrate what aspects of the life history are most important– and therefore establish the regions of the ocean where we need to study the conservation issues

•The survival results from two different years also means that we can now begin to calculate the tag sample sizes necessary to study individual populations– something we couldn't really do prior to reaching this stage.

2005 POST Tagging

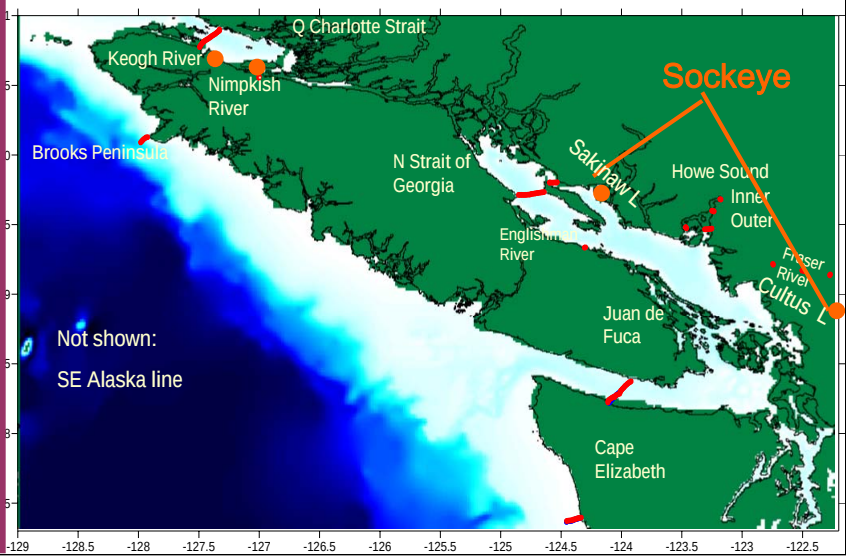


•We have developed a prototype “next generation” bottom node that can host oceanographic sensors as well as the fish tracking sensors.

•We have also deployed and tested a satellite-linked version of the fish tracking sensor. Although the communications protocol needs to be changed from the current satellite provider, we have established technically that these units can be deployed as part of a permanent array and used for real-time fisheries management, using a cell phone (or satellite cell phone) link.

•This approach will, in essence, allow each fish to “dial out” and report the departure of individual salmon smolts from river mouths– or the arrival of returning adults. This is critical information for improved salmon management.

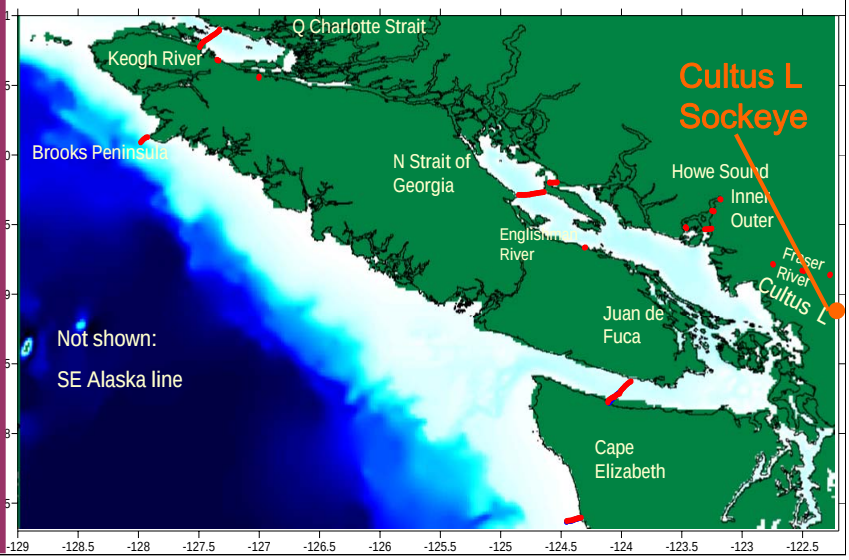
POST Listening Lines (BC & Washington)



•These are the major listening lines deployed in 2004.

•The location of the two stocks of endangered Canadian sockeye salmon are shown for reference

Movements of One Stock–
Cultus L Sockeye (2004)



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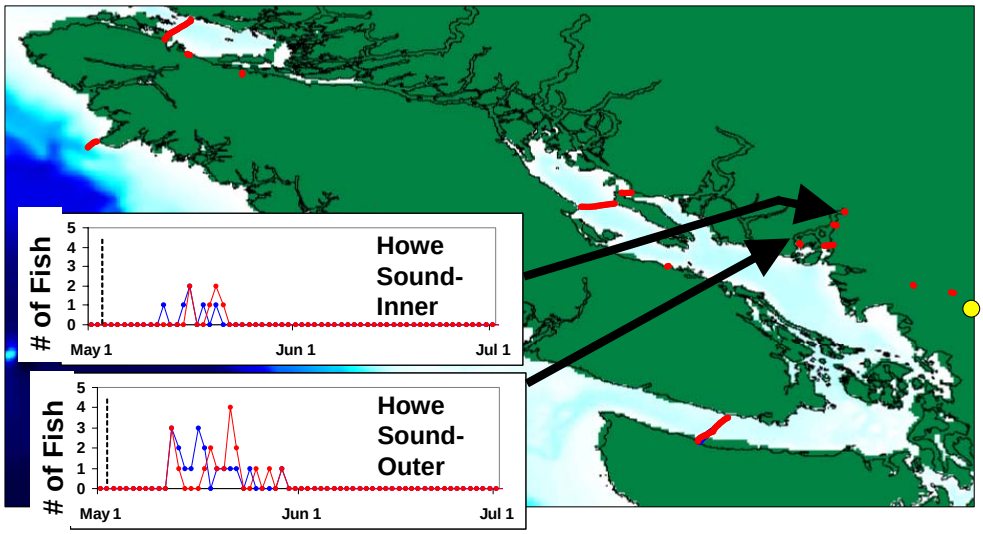
2004 Cultus Lake Sockeye (1)

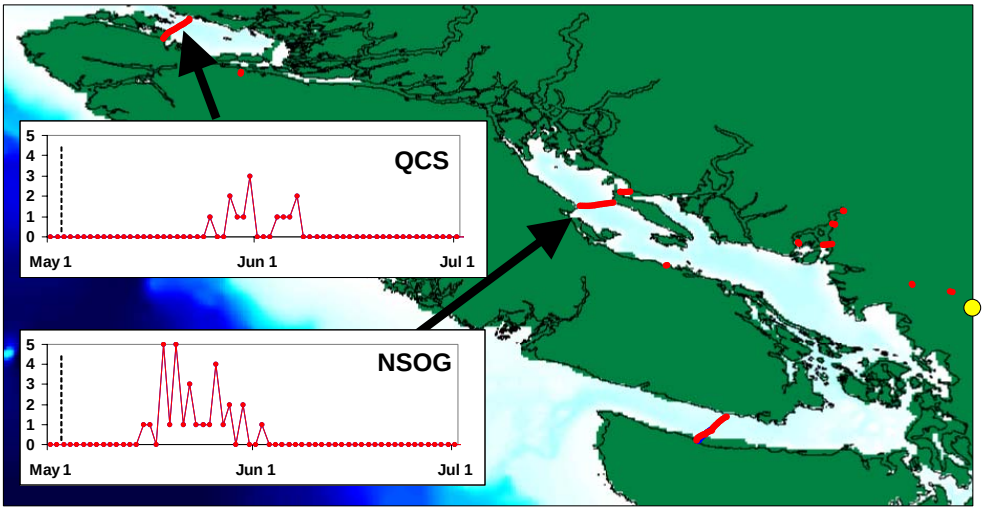


The graphs show the number of detections of Cultus Lake sockeye (yellow dot) detected on any of the fish tracking sensors deployed on a given detection line

The blue & red lines show the first and last detection of each fish on each line.

The shift between the two lines shows the amount of time the fish spent on their detour into the fjord system.

2004 Cultus Lake Sockeye (2)



The blue & red lines exactly overlap on these ocean lines, so the individual animals spent less than a day traversing a given listening line (in fact, we can directly measure the amount of time each fish spent in the vicinity of each line).

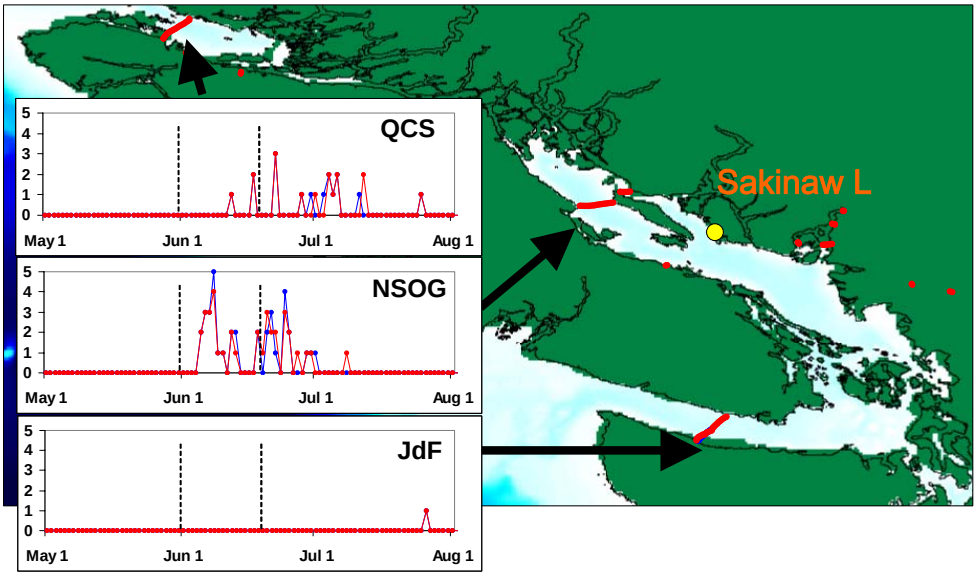
Note the decline in the total number of fish going over the Queen Charlotte Strait (QCS) line relative to the Northern Strait of Georgia line (NSOG). This difference is the mortality of smolts not reaching the next detection line. This allows us to measure mortality in different parts of the coastal ocean, and determine where migrating smolts have poor success

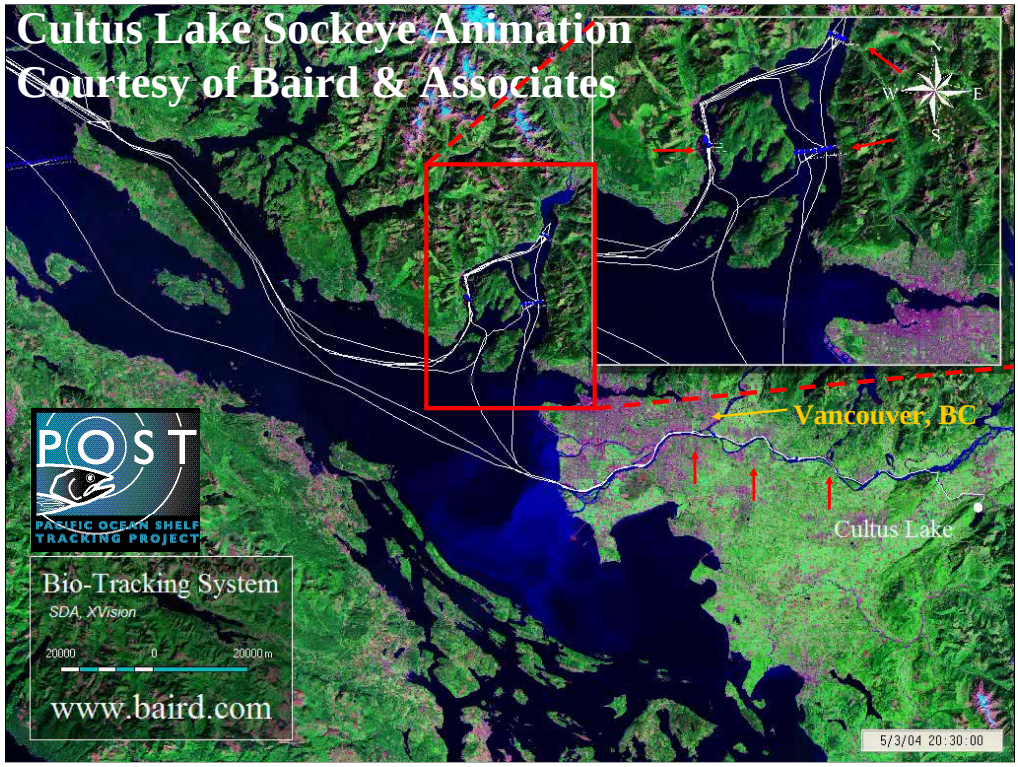
It also allows us to compare the performance of different salmon stocks

I am showing this not because of the NWPP Council's specific interest in this fish stock, but to make the point that for the first time it is now possible to directly measure the movement– and survival– of salmon smolts in the ocean

A later animation will show this year's results (movement & survival) for Snake R spring chinook smolts.

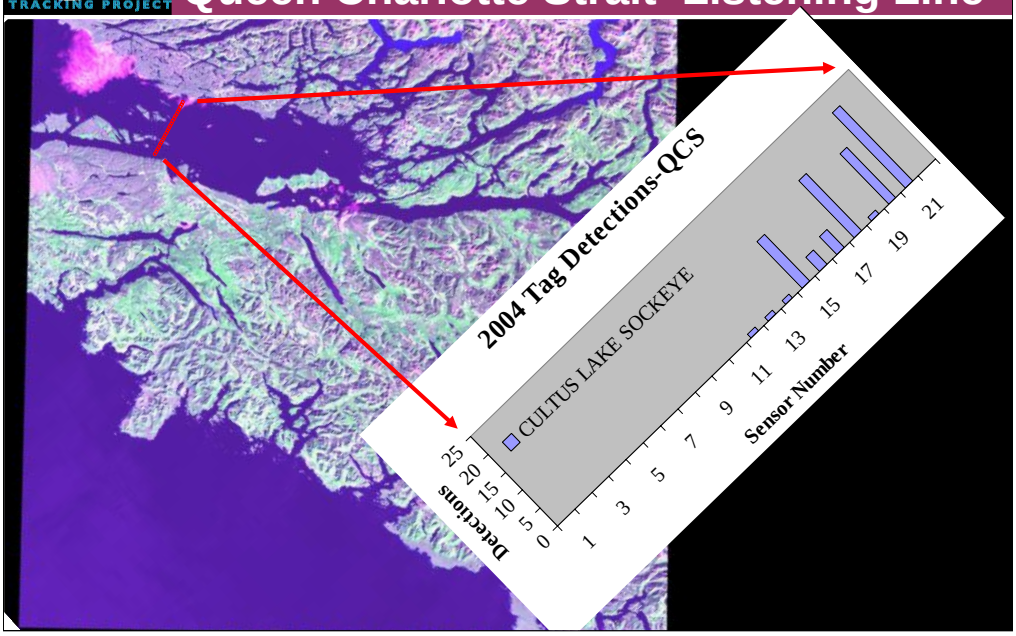
2004 Sakinaw Lake Sockeye (1)





Here is the animation of the 2004 Cultus Lake movements for southern BC.

2. Differences in Migration Routes- Queen Charlotte Strait Listening Line

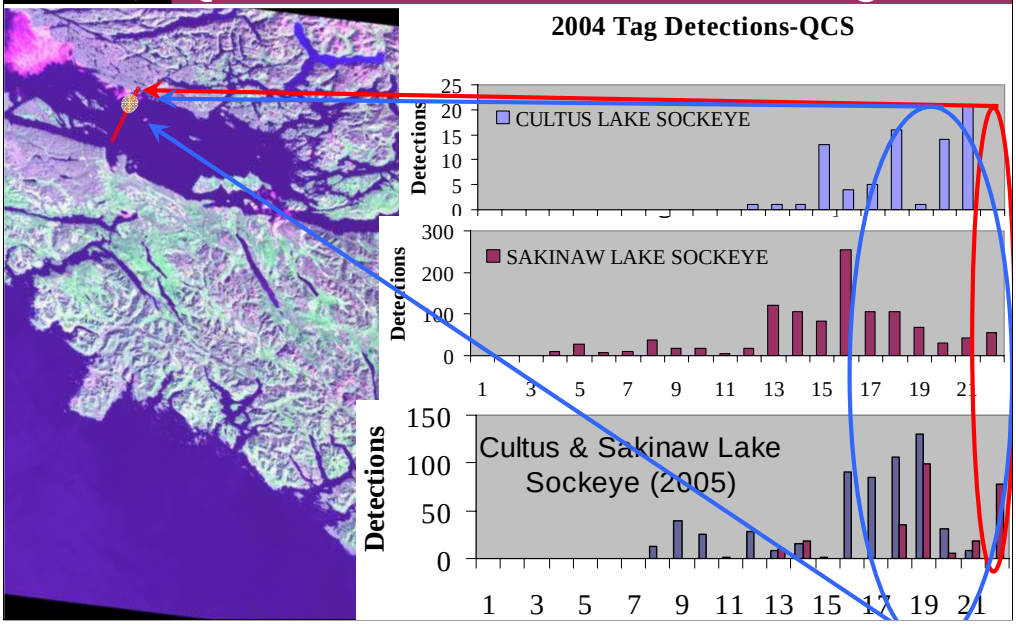


After leaving the area we animated for the 2004 Cultus smolts, here is the parts of Queen Charlotte Strait that this stock migrated over.

The animals only used a small fraction of the width of the Strait (20 kms), suggesting that they actually have very fine scale migration pathways

This suggests how different (yet apparently similar) salmon stocks can have very different movement pathways in the ocean– and thus different survivals if they encounter different ocean conditions on those migration routes

2. Differences in Migration Routes- Queen Charlotte Strait Listening Line



The 2005 results show that the results from 2004 are repeated (i.e. the pathway seems stable)

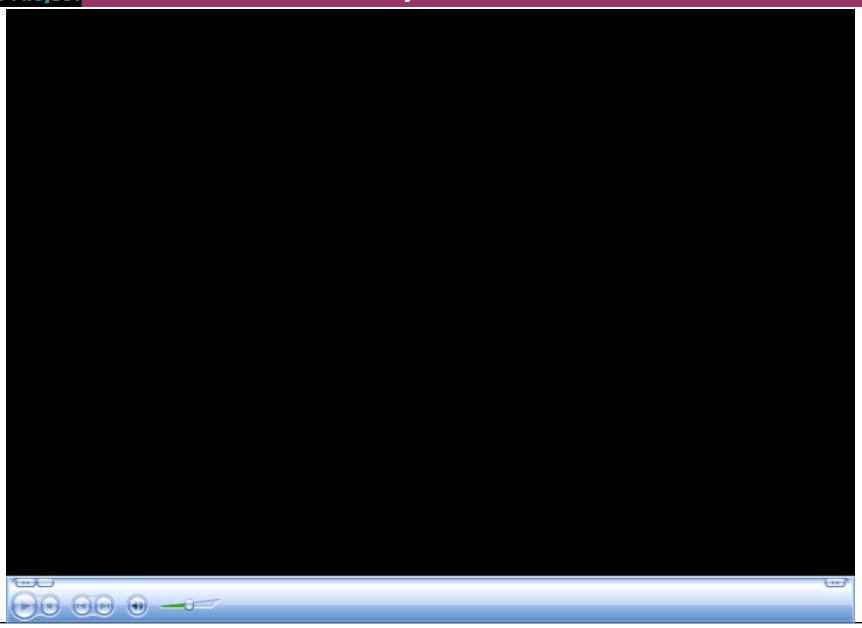
Note that the Cultus Lake sockeye migrated using only part of the width of Queen Charlotte Strait (QCS). This demonstrates how individual salmon populations may have far more precise marine migration pathways than previously thought

•There are other, more subtle, behavioural differences evident. In 2004, 19 Sakinaw sockeye migrated over the QCS line, while 13 Cultus Lake sockeye migrated over it. Yet the detections of Sakinaw sockeye were almost 10X greater than the Cultus Lake fish, despite there being only 1.5X as many fish present.

•We believe that this may reflect greater “milling”, so that the Sakinaw sockeye migrate less rapidly than the Cultus fish, because they swim in a more circuitous route that leaves them over remaining top of the listening line for longer period of time. The same thing appears to be true in 2005 (Cultus Lake sockeye: N=46; Sakinaw Lake sockeye: N=3 fish)

•Note that the Cultus sockeye were ***not*** detected on the receiver closest to shore in either year, suggesting that they remain at least a half kilometer offshore from the beach in each year!

Cultus Lake Sockeye Movements, 2005

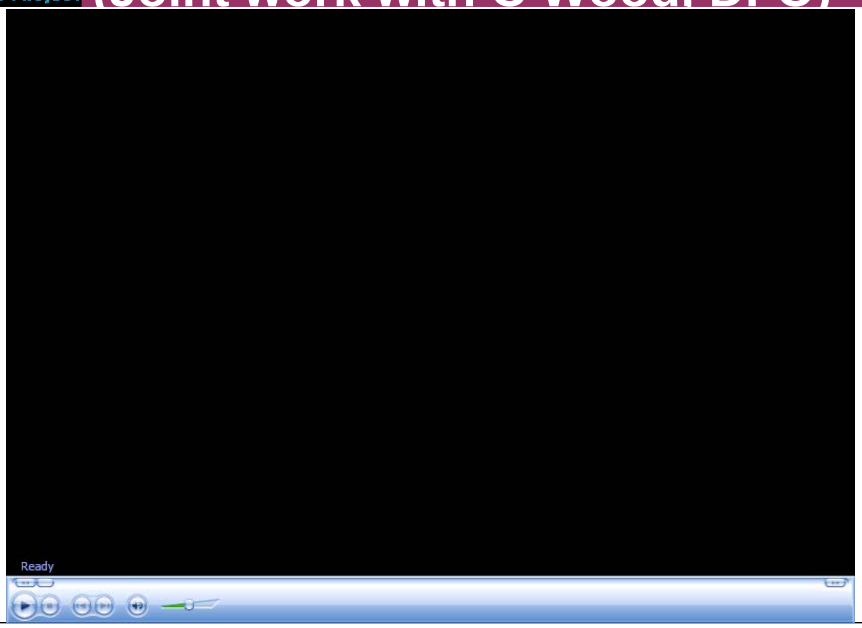


… & here is the animation of the 2005 Cultus Lake results for the full array in BC.

Note that in 2005 all the smolts still went north, but this year took the western route around Texada island, where they went over the northern Strait of Georgia Line– in 2004 they mostly passed east of Texada Island.

Sakinaw L Sockeye, 2005

(Joint work with C Wood, DFO)



•The 2005 Sakinaw sockeye smolt movements are completely different from the Cultus movements in 2004 & 2005– and also the 2004 Sakinaw movements (We have not yet animated the 2004 Sakinaw migration)

•Note that only 3 Sakinaw sockeye migrate north to the Queen Charlotte Strait line– the majority of the smolts went south and out Juan de Fuca

•Last year (2004), one Sakinaw sockeye smolt migrated ***into*** and up the Fraser River– a completely unexpected result. We assumed this might have been a seal that had eaten the smolt and still had the tag in its stomach

•This year ***two*** Sakinaw smolts apparently did the same thing! This is a bizarre behaviour which we see for no other stock of fish. We have no good explanation for it as yet, but suspect that the tags might have been carried up in the stomach of seals. Curiously, despite the thousands of tags applied, the only occurences have involved Sakinaw Lake sockeye

•There is also evidence from the detailed detection rates over the array that the Sakinaw smolts migrate much more slowly– i.e. greater milling– on their way out of the Strait of Georgia than the Cultus Lake sockeye.

•This points to stock-specific differences in marine behaviour– even between different populations of the same species-- that may explain why some stocks collapse and others do well.

Snake River Spring Chinook, 2005 (Dworshak/Kooskia Hatchery)

✓198 Snake R chinook surgically implanted at Kooskia Hatchery, May 2005
No compatible array at Mouth of Columbia River this year
2003 & 2004 survival averaged 50% to Bonneville, 50% to River mouth (25% survival overall; Carl Schreck, OSU)
Partial listening line at Cape Elisabeth/Greys Harbor

•We just recovered the Brooks Peninsula listening line shortly before the date of preparing this report.

•A total of 15 (of 198) tagged Snake River spring chinook smolts were detected at Brooks Peninsula (NW tip of Vancouver Island). Because of a technical fault with the acoustic releases, only 50% (5 of 10) sensors were recovered.

•A minimum estimate of survival is thus 7.5% (15/198); a more reasonable estimate taking into account the unrecovered equipment would double that to 15% survival to the northern end of Vancouver island from barge release below Bonneville.

•As Prof Carl Schreck's fine work has shown about half the smolts would have survived to the mouth of the Columbia from Bonneville dam in previous years (the project was unfortunately cancelled this year), a rough guess is that survival from the mouth of the Columbia to northern Vancouver Island might have been as high as 30%-- quite impressive if correct!

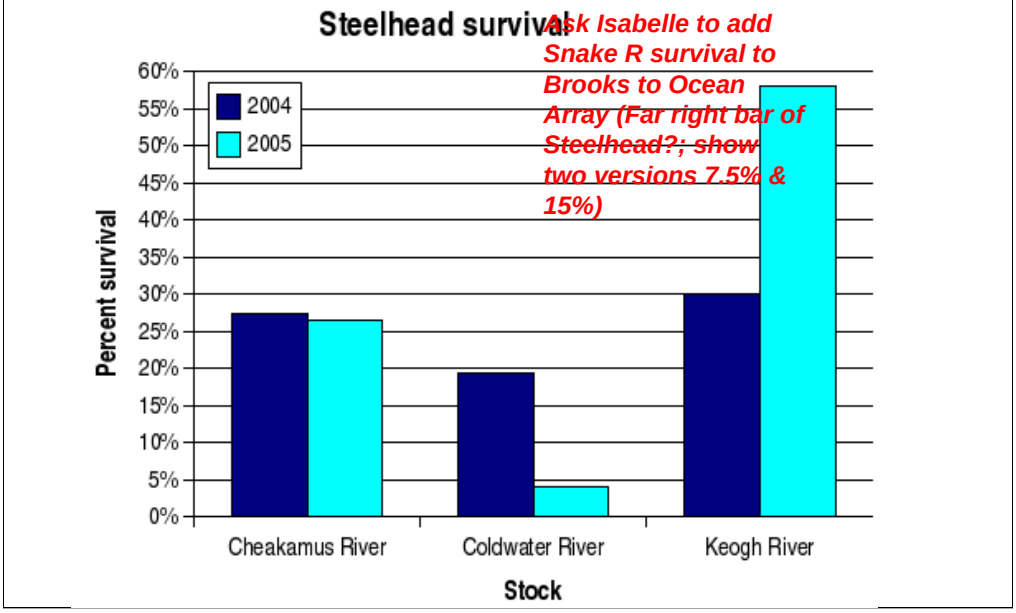
•As typically only 0.5% of outmigrating Snake River smolts survive to return as adults, this suggests that ocean survival past Vancouver Island could be as low as 1 in 60 fish. (These smolts will only return as adults in 2007 & 2008).

•In comparison, 1 in 4 chinook smolts typically survives from the Snake River to the mouth of the Columbia.

•The outmigrant smolts were migrating at 30 kms/day up the coast, so they do not appear to have remained either in the Columbia river, estuary or plume for any significant period of time.

•These preliminary results need to be verified and strengthened by improving the recovery of data from the ocean lines (and comparing the results with other Columbia R stocks).

Steelhead Survival (Queen Charlotte Strait/Juan de Fuca Exits)

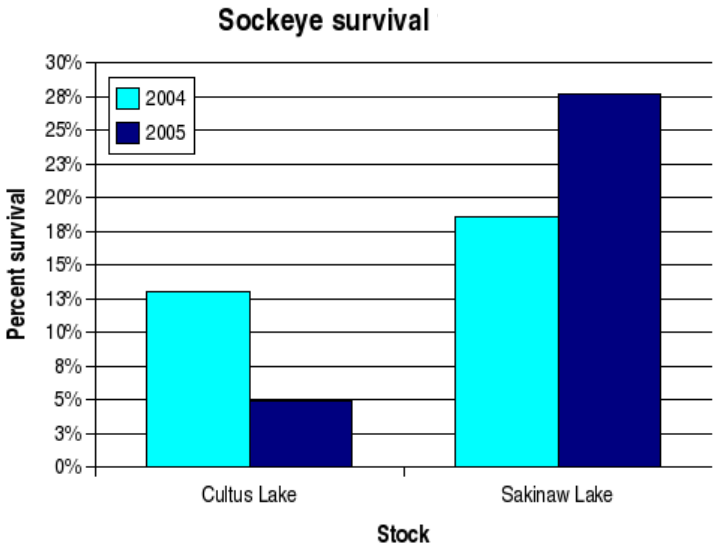


•In looking at the BC situation, where we have more data, we found large differences between years in survival for some stocks, and also appear to be seeing a pattern emerge in that some stocks of steelhead possibly have intrinsically lower survival than others within the region of the array.

•These results are based on calculating combined survival to either the Juan de Fuca or Queen Charlotte Strait line.

•For scientific accuracy, we still need to compare these survivals relative to distance (time) travelled, since the time required to get to a given line is not the same for different stocks

Sockeye Survival (Queen Charlotte Strait/Juan de Fuca Exits)



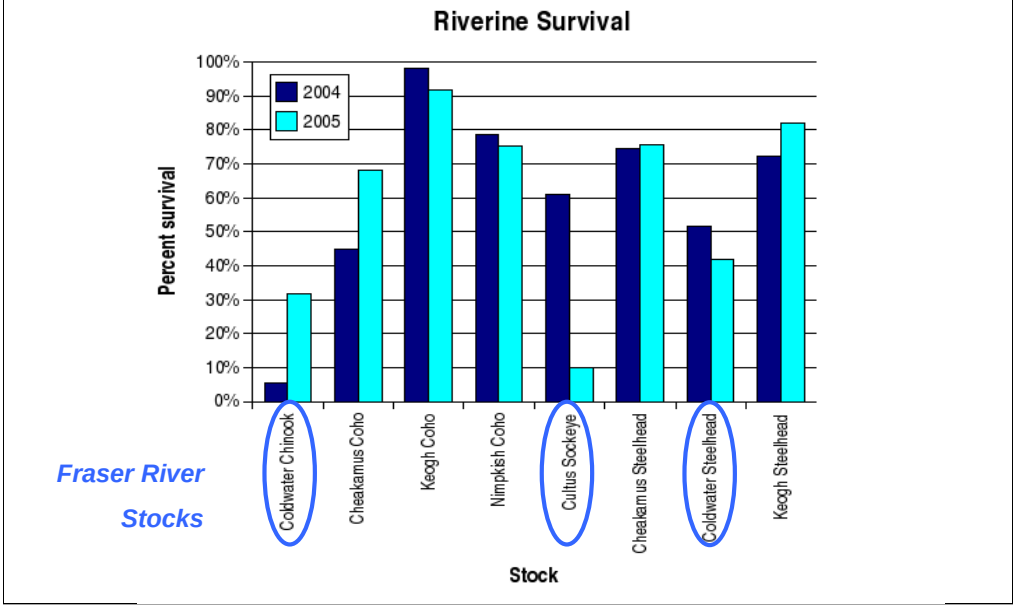
•Both of these sockeye stocks are now listed as endangered in BC.

•The improved survival from release to exit from the array of Sakinaw Lake sockeye in 2005 vs 2004 is in striking contrast to what was observed to happen to the Cultus Lake sockeye

•It is not clear why Sakinaw Lake sockeye survival increased in 2005; two things changed: We tagged wild-caught sockeye in 2005 instead of hatchery-reared fish in 2004, and in 2005 these tagged Sakinaw smolts had a radically different behaviour to the 2004 Sakinaw smolts (see the animation below). It is suspected that these wild smolts may have been kokannee.

•Although overall Cultus Lake sockeye survival dropped precipitously in 2005, the graphs on the next page shows that we can demonstrate that the problem was because of sharply reduced *in-river* survival in 2005– ocean survival changed little for this .

BC Salmon Survival to River Exit (Freshwater Survival)



•The POST results provided some surprises. There are some large-scale variation in survival between stocks in 2005.

•The largest surprise came from the endangered Cultus Lake sockeye stock. Fraser river survival was only ***one-sixth*** that of the 2004 survival measurement. This result suggests a possible reason for the decline in the status of this stock, and pinpoints an area that should be investigated further– the lower Fraser River.

•The Coldwater is a tributary of the Thompson River- and is the analogue to the relationship between the Snake & Columbia Rivers.

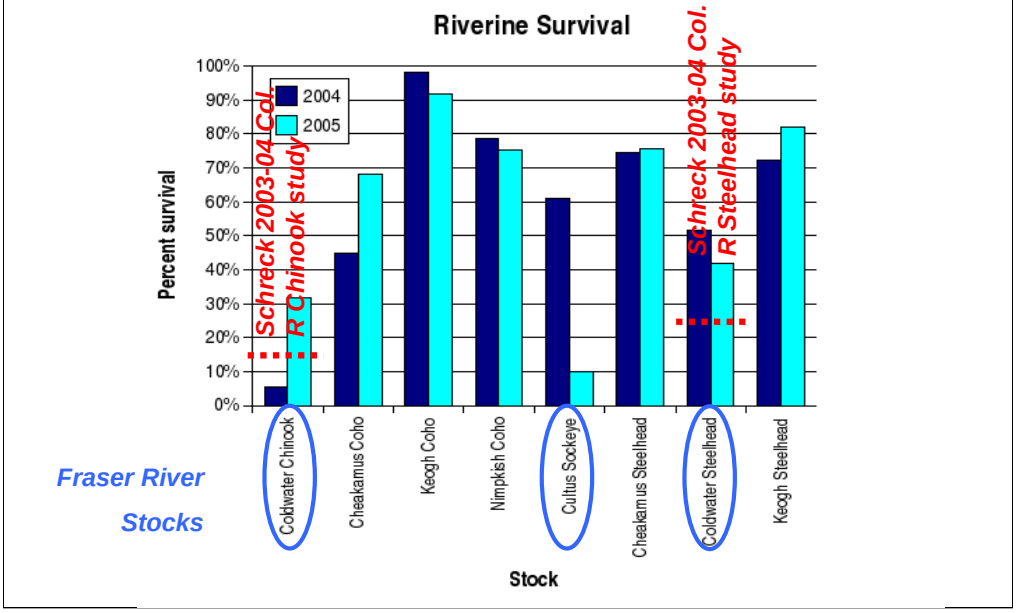
•Some stocks, such as the Nimpkish coho, again had excellent survival despite migrating 60 kms down a river & lake system, but again failed to shoiw up on the ocean array. We know that they have very poor survival till adult return the following year (ca. 1-2%), so this again means that we can pinpoint where the survival problem is expressed– in the ocean in this case.

•The region that the Nimpkish coho disappear into– the Broughton Archipelago-- is an area with a high density of fish farms. It is not clear if there is any causal relationship.

•The poorest technical performance, in terms of detection rates, came from the Fraser River units. This is apparently because of high sediment loads in the upstream water attentuating the signal.

•We will be working on improving the Fraser R detection rates for 2006

BC Salmon Survival to River Exit (Comparison with Columbia R)



•The comparison with the "typical" Columbia R results is based on data from Dr Carl Schreck's (OSU) work (2005; Draft), plus data from the BiOP &/or other published work. Schreck reports 30% survival from Bonneville dam to the mouth of the Columbia for ROR Chinook, and Snake River survival to Bonneville Dam is typically 50%, giving 0.5x0.3=15% survival through the Columbia, and is overlaid for comparative purposes against the Coldwater Chinook results– The Coldwater is a tributary of the Thompson River, and is geographically analogous to the Snake R/Columbia R situation.

•A similar calculation can be made for Snake River vs Coldwater (Thompson R) steelhead. Schreck (2005; Draft) reports an average survival from Bonneville to the ocean of 64%; we have assumed an in-river survival from the Snake River to Bonneville dam of 40%, yielding survival to the Columbia river mouth of 0.64x0.4=0.25.

•The key point is that survival down the heavily dammed Columbia River can now be compared to that of the Fraser River, which of course lacks dams.

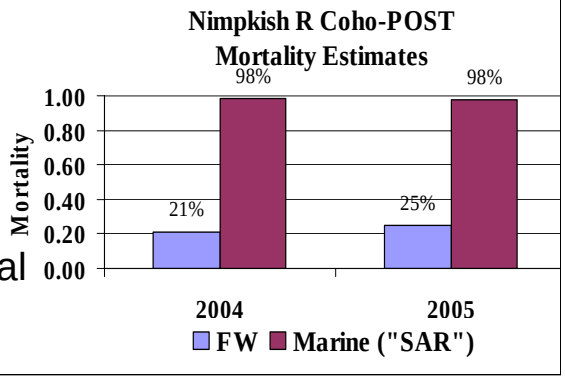
•Note that there are substantial differences in survival between years for a given stock in the Fraser River. Snake R chinook survival seems comparable to that of the Thompson R chinook migrating down the Fraser system, while Thompson R steelhead survival seems lower. It is not yet possible to put these estimates into a broader context.

•It would not have been possible to have made these survival estimates to the ocean (or in the ocean) before the development of the small acoustic tags from Vemco that have been used in the POST research.

•We are not yet drawing strong conclusions from these preliminary results. The main point here is that it is now technically possible to make these measurements, and they have relevance to the issue of salmon restoration.

A Personal Perspective on Freshwater & Ocean Studies on Salmon

Columbia R in-river survival "seem" reasonable (to me)
Adult returns from the ocean are unreasonable
(~0.5% vs the 4% minimum needed)
These differences are evident in BC as well
We need to understand ocean survival so we can understand what freshwater changes are important- and can be manipulated successfully to improve salmon survival
POST can inform that process



•The Nimpkish coho results provide another example of the relative importance of ocean versus freshwater survival issues for a BC salmon stock with severe conservation concerns.

•Only 1-2% of smolts now survive to return as adults.

•Survival of 100 released smolts to the river mouth was 79% in 2004 & 75% in 2005. These smolts traversed 60 kms in their swim downstream to the ocean (including a 25 km long lake).

•This means that 1 in 5 smolts died in the river in 2004, and 1 in 4 smolts died in-river in 2005

•If adult survival is typical of the last decade, then 49 out of 50 smolts reaching the ocean will not survive to return. This is consistent with the dramatic decline in ocean survival of southern BC coho stocks in the last 20 years– to 1/10th of previous levels. The reason for the decline in ocean survival is unclear– but important.

Detections by POST of Other People's Fish:

Overall Summary (Excluding Alaskan Line)

- **Columbia R Reconditioned Steelhead Kelts (Doug Hatch, CBFWA)**
- **Possibly California salmon (Still checking)**
- **>100 Green Sturgeon in 2005 (~48 in 2004)**
  - **All three Spawning Populations (Rogue, Klamath, & Sacramento)**
  - **Ca. 24 green Sturgeon heard on *both* Cape Elisabeth & Brooks Peninsula in 2005 (8 in 2004)**
  - **Fastest Sturgeon travelled 480 kms in 4 days**
- **Other species likely detected on array**

•. In addition to all the data collected on survival & movements of "POST" salmon in 2005 (tags programmed to transmit on Channel D), a large number of tagged salmon released by other projects were recorded.

•Although the results are not complete as yet, it now appears that we have tracked:

- •Probably over 50% of all the acoustically tagged green sturgeon that have been released in the US.
- •We have now detected and tracked green sturgeon from all three of the known spawning populations on the West Coast
- •We know that we have tracked reconditioned adult steelhead (kelts) out of the Columbia River
- •We **may** have tracked California Department of Fish & Game salmon up the coast- but we are still trying to verify the tag owner and the species tagged

•The results speak to the power of a large-scale tracking array– which provides the motivation for developing a highly cost-effective and efficiently run utility.

Where POST is Going:

Current Testing Phase: Rivers

Satellite-Linked Acoustic Sensors

Above water antennae allows tagged smolts to email their departure times (and survival!)

Ability to measure survival out of large rivers

Two beta-test units are currently deployed in the mouth of the Fraser River

Antennae and surface floats for marine component of array is unrealistic

•These satellite-linked units passed their testing phase this summer, but we will be switching the telecommunications layer to a combination of conventional cell phones (where services exist) and satellite cell phone (Iridium).

•This link-layer will allow full two-way communications and the automation of equipment service checks and data downloads.

•It should then be possible for the units to “dial out” each time a tagged fish passes by, turning at least the river components into a real time system for fisheries management (and also satisfying the interest of the scientists and public for data “right now”).

Where POST is Going: Longer-Term Plans

✓**In the Near Term:**
Modem-Equipped Tracking Sensors
- Provide 5-7 Yr Projected Lifespan
- Ability to provide year-round fish
  - Survival data
  - Migration pathways
  - Timing of migrations
  - Accurate return forecasts?

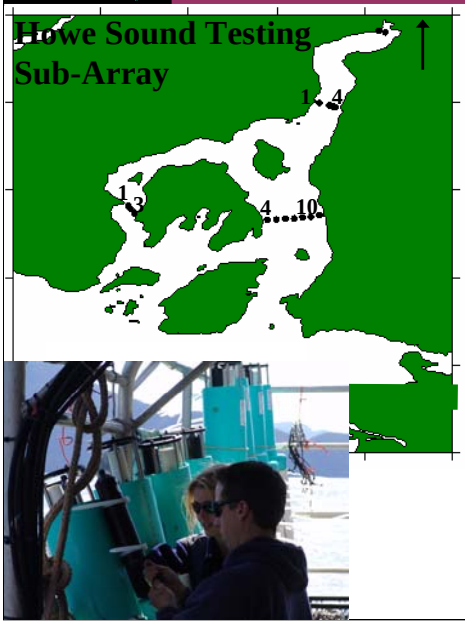
✓**In the Long-Term:**
Modem-Equipped <u>Ocean Observing Systems</u> Provide:
- Fish Tracking Sensor
- T, S, Currents
- Fish, plankton abundance…
- ***… And how they determine Columbia salmon survival???***

•The next generation of receivers can host oceanographic sensors.

•They will be deployed with acoustic modems.

•Fishing vessels going along on the water surface with hydrophones can talk to the modems and access the data stored in the receivers.

Where POST is Going: Final Testing of Modem-Equipped (Wireless) Ocean Array



•This slide shows the location that the final testing of the modem equipped sub-array was completed in.

•Based on these results, we will be changing the deployment strategy in time for 2006.

•The difficulty in physically recovering equipment to the surface of the ocean before downloading the data was the chief cause of failure in 2005. By moving to long-lived units with a remote upload function, we believe that we will substantially improve data recovery, improving the scientific results.

POST's Findings: Management Implications for Pacific Salmon

I. **The ocean migration behaviour of different salmon *species* is not the same**

II. **There are differences in migration pathways (speed, route, distribution) of *different populations of the same species***

III. **There is high & variable in-river mortality of Fraser River salmon stocks– the reason(s) are unclear, but the Fraser is a very different river from the Columbia.**

Where POST is Going: Summary

A permanent tracking system for salmon and other marine animals is now feasible

- ***For salmon smolts, 4 month~2 year tags are feasible***
- ***For animals >2 kgs, tags can have 10 year lifespans***
- ***For animals >5 kgs, tags can have 20+ year lifespans***
- ***A complete census of fish (salmon & sturgeon) moving in & out of large rivers is now feasible***
- ***A wide range of other ocean sensors can be supported off this observation system.***

•The POST array will have utility beyond salmon

Where POST is Going:

Key Points to Keep in Mind

- **In combination, this will lead to an unparalleled ocean observing system telling us how the fish react to the changing ocean environment, where they move to, and where– and perhaps– how they die**

- ***POST will allow direct study of salmon in the ocean, with the response of free-ranging fish studied directly, replacing conjecture with observation***

Where is POST Going?