

DATALOGGER DEVELOPMENT

Planning

One of the original goals of the CROOS project was to investigate technologies that could facilitate incorporation of genetic, fishery, and oceanographic information collected into near “real time” management of future fisheries. To advance this objective, we tested the use of an electronic “datalogger” to record fishery information onboard the vessel and rapidly transmit the data to scientists and managers on shore.

Digital information from these records could also be used by potential seafood consumers. They could find, by looking up an online record of selected project information, the origin of a given fish, who caught it, and even information about its storage and handling history.

Various devices have been tested in other fisheries, including the Albacore tuna fishery. These devices are capable of electronically recording high resolution spatial-temporal information about the catch location of each fish, the fishing track of the vessel, depth of capture, oceanographic observations, mark or tagging information, fish storage information, and fisherman comments. The information can then be transmitted to either a storage device on the vessel (generally a laptop computer) or, with suitable onboard telecommunication equipment, to receiving stations on shore. The information can be used in electronic fishermen logbooks, as part of tracking and traceability systems, or to build “expert systems” for individual fishermen or fishery managers.

These devices must be rugged enough to function on the deck of the fishing vessel under sometimes extreme weather conditions, must tolerate exposure to salt water, and be capable of operating with wet or gloved hands. They must also be simple enough to be operated by users with limited technical expertise, and must be able to be downloaded, adjusted, and/or reset without the use of highly skilled technicians. To be incorporated into full-scale data collection regimes, they must be inexpensive enough so that many of them can be deployed over the full geographic range of the fishery being tested.

The devices chosen for this project were a functional combination of a DAP CE8640 handheld computer (the data entry device), a wheelhouse mounted laptop computer to store the data, a connected GPS unit, and the necessary auxiliary equipment needed to power and connect these devices.

A full description of these devices and the protocols for their operation is provided in Appendix 3.



Results and Observations

Up to four datalogger systems were installed on selected vessels at any given time during the course of the 2006 CROOS project. Software settings and protocols for their use were adjusted during the project as experience dictated. Some of these adjustments were complicated by the requirement that the majority of the software configuration for the datalogger devices had to be performed by factory technicians.

Once the equipment was installed and configured for each vessel, and fishermen became acquainted with its operation, the systems generally worked well over a wide range of environmental conditions. Operation of the equipment was reported to be compatible with the other requirements for project data collection, and was not particularly disruptive of the normal fishing routine. Most fishermen testing these units thought that the equipment was easier to use than “manual” sampling protocols (e.g. paper logs, writing on envelopes, etc.).

There were some difficulties in selecting vessels for datalogger use. Salmon fishing boats are generally smaller vessels with very limited space for additional equipment. They are generally set up for optimum efficiency in fishing operations, with limited options for placement of temporary electronics. They are uniquely different in their electrical and electronic configuration, and technical assistance was required for each installation. There was also some difficulty in finding fishermen who felt comfortable with learning a new technology for such a short project.

Due to the inexperience of some fishermen in hardware configuration protocols, there were several cases of equipment failure. The need to integrate the datalogger’s software with the wheelhouse computer and the GPS signal inputs created some problems when the equipment was first turned on or was restarted. Sometimes this happened as a result of electrical supply interruptions, either as a result of temporary power interruptions, or, for example, due to normal shutdown of vessel electronics between fishing periods.

Although these problems could generally be solved at sea, in some instances, the equipment could not be successfully restarted, and the fishermen were required to manually log the data and use the handheld GPS devices.

Due to the demands of downloading the data (which was stored in Microsoft Access database format) and resetting the equipment for the next fishing trip, technical assistance was generally required after each fishing trip to transfer data to the laboratory. Although the equipment had the capability of downloading data directly from the vessel to the lab, the need for satellite communications equipment or cell phone modem software on each vessel and the appropriate training for their use prevented us from utilizing that option.

Because of these issues and the relatively high cost of the systems (approximately \$5,700 per unit), it was generally concluded that a more rugged but less complex and costly system would be desirable for future projects that require this type of virtual “real time” information from large

numbers of relatively small vessels. Research into identifying and developing such equipment will continue.

In general, the use of datalogging devices proved to be successful and deserves further testing and development. Additional refinement of equipment, software, and protocols will be needed for applying this technology to applications in large projects requiring numerous fishing vessels. But the potential for improvement in data collection was demonstrated and the long term benefits for cost effective and comprehensive “real time” data collection may be substantial.

SCALE ANALYSIS

Introduction

The Scale Project of the Oregon Department of Fish and Wildlife interprets circuli patterns on scales to determine age composition, hatchery or wild origin, life history, and growth information for salmonid and warmwater fish species. Data provided by this project are used for trend analyses, stock size forecasts, status assessment, identification of hatchery strays, and growth analyses. We analyze about 15,000 scale samples annually. By number, we analyze scales from more Chinook salmon than any other species. For the CROOS Project, we determined the total age of Chinook salmon that were sampled from the ocean troll fishery and had high probability of assignment to a genetic group. Our data will help with status assessment and, if continued in the future, may be used for stock abundance projections.

Methods

The scales that we analyzed were collected by commercial fishers at sea. We provided each collector with sampling instructions, including a diagram showing location of the key scale area (Nicholas and Van Dyke 1982), so that all scales were sampled by the same methods.

After scales were removed from the fish, they were placed in an envelope that was labeled with the bar code assigned to that fish. Sampling data were recorded on the envelope. After the genetic analysis was completed for each fish, we were given the scale samples from those fish that were assigned to a genetic group with greater than or equal to 0.90 probability of group membership. From each sample we mounted one to four of the best scales on gummed cards and made plastic impressions using a hydraulic heat press.

Fish age was determined by counting winter annuli. We identified annuli as bands of closely spaced or broken circuli (Figure 11). If the winter has been harsh, an annulus may also appear to have scarring which is caused by resorption of the scale. For salmon such as Chinook salmon that spawn in the fall, total age equals the count of annuli plus one to account for the winter spent in the gravel as an egg or sac fry. Catch year minus total age provides the brood year. An exception to this last equation is the late fall Chinook population that spawns in California's Central Valley. They are spawned January to March so are of a different brood year than the fish that are spawned in August through December. Since the scale pattern of the late fall Chinook looks the same as that of other Chinook, we aged them in the same manner. This means that catch year minus our assigned age does not provide their brood year although the assigned age still reflects an accurate total age had they escaped to spawn.

Two people read the collection and resolved disagreements during a joint, third reading. The first reading by both people was made without knowledge of field data, such as length, so that the reading was based only on information provided by the scale pattern and was not biased by conflicting field data. Field data were taken into consideration for the third reading.

We randomly mounted 31 "known age" samples from coded wire tagged fish within the collection that served as a test to our accuracy. The "known age" samples were aged in the same

manner as the general collection except that if we disagreed on any of the 31, the tag code and know age was withheld from the field data that was available during our third, joint reading.

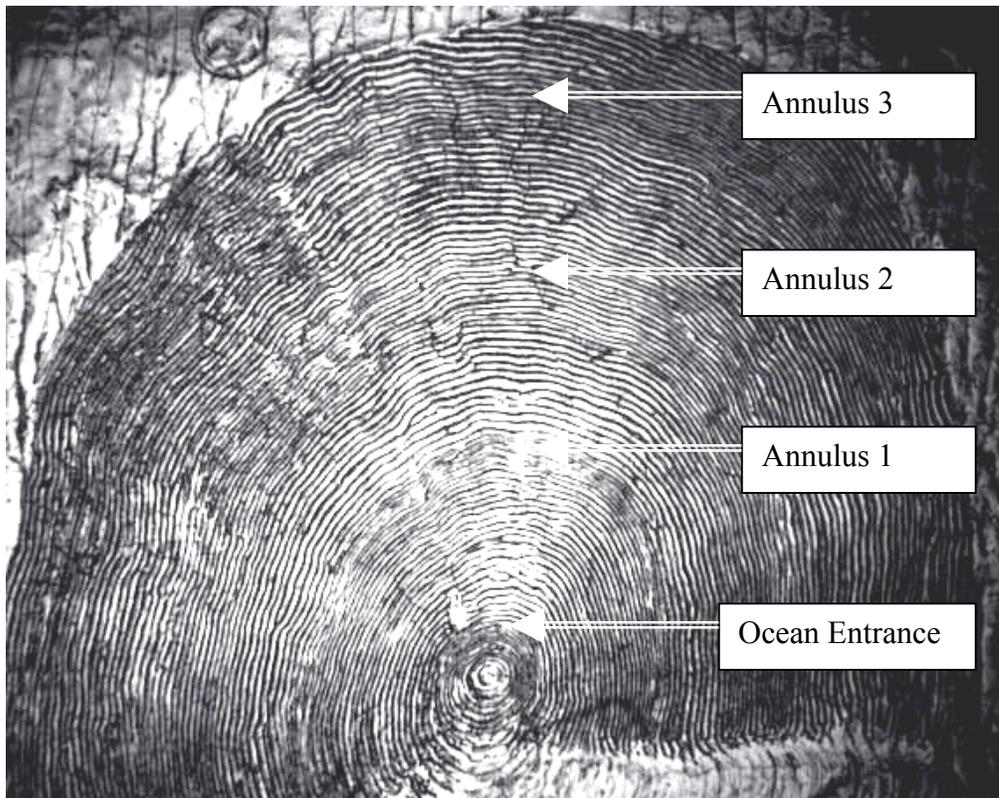


Figure 11. Scale of an age-4 Chinook salmon caught in the ocean off Oregon in 2006.

Results and Discussion

We mounted 2,094 scales samples and were able to determine the age of 2,045 fish. We were unable to read 49 scales because they had been regenerated after the original scale had been lost. Regenerated scales have no circuli or annuli in the regenerated portion. We included 31 samples from CWT fish in our analysis. Three samples were of late fall stock from Coleman National Fish Hatchery. These fish were spawned in January or February of 2003 so were calculated to be age-3 in the summer of 2006. We aged all three fish as age-4 since they carry the same scale pattern of Chinook salmon that were spawned from August to December in 2002. As stated in our methods section, this is an error that we cannot correct and these fish would have been age-4 upon return to their hatchery. The other 28 samples from CWT fish were correctly aged. A list of the CWT fish included in the scale collection is found in rows 1-31 of Table 5 in the Genetic Science section of this report.

The age composition for the entire collection was 0.1% age-2, 57.0% age-3, 38.5% age-4, 3.9% age-5, and 0.5% age-6. The age composition by month is given in Table 6. We saw a big change in the percentage of age-3 and age-4 fish between August and September with age-3 fish increasing and age-4 fish decreasing. The fishery was closed between August 4 and September 16. Had samples been available later in August and earlier in September, the age composition shift might have been less dramatic but the trend would probably still exist.

Table 6. Age composition Chinook salmon stocks caught in the ocean in the summer of 2006.

Month	Percentage of sample					Number of scales aged
	Age 2	Age 3	Age 4	Age 5	Age 6	
June	0.0	30.5	59.4	9.9	0.0	131
July	0.0	36.0	59.7	3.7	0.6	705
August	0.0	43.8	51.7	4.0	0.5	201
September	0.2	77.8	18.4	3.2	0.5	657
October	0.0	77.9	18.0	3.5	0.6	316

To further explore the shift in age composition between June through August samples and September and October samples we looked at the individual assignments to stock groups determined from the genetic analysis (Genetic Science section, this report). Genetic stock compositions for age-3, age-4, and age-5 Chinook salmon are given in Tables 7-9. The one age-2 fish in the sample was of Central Valley stock, while 8 of the 10 age-6 fish were from North or mid-Oregon coast stocks.

In catch of age-3 and age-4 fish, California's Central Valley (fall and spring runs combined) was the major genetic stock for the entire season. Some age-3 fish of Central Valley stock probably left the fishery area to spawn since we saw a small decrease in their contribution in the September fishery. Fisher (1994) estimated that the 3-year-old age class was predominant among Central Valley runs, being 77 and 57% for fall and late-fall runs, respectively. We theorize that Central Valley age-3 fish were still a major part of the fishery in September and October because smaller fish that would have matured at age-4 became large enough to enter the fishery. Information on the state of gonad maturation of smaller Chinook salmon (<75 cm) caught in September and October could determine if this is true.

On a monthly basis, the stock composition of age-4 fish showed a big decrease in Central Valley stock beginning in September. This coincides with the general decrease in age-4 fish in the catch for September and October and was probably the result of Central Valley stocks leaving the fishery area to return to California to spawn. In September, Rogue, Klamath and mid-Oregon coast stocks became more important contributors to the fishery and in October, Rogue stock fish made up almost a third of the catch of 4 year olds.

The stock composition of age-5 fish in our sample was more varied than other ages with major contributions of upper Columbia River summer/fall stocks in June, mid-Oregon coast stocks in September, and North Oregon coast stocks in October. Central Valley stocks were still major contributors in July and August. Age-5 fish are a major component of the spawning populations of North and mid-Oregon coastal fall Chinook salmon stocks (Nicholas and Hankin 1988, Borgerson and Bowden 2001) while they are a small component to Central Valley spawning populations (Myers et al 1998).

Table 7. Monthly estimates of genetic stock composition of age-3 Chinook salmon caught in the ocean troll fishery off Oregon in 2006. Greatest stock contributions each month are highlighted.

Genetic Stocks	Month, 2006					Season	N
	June	July	August	September	October		
Central Valley fa/sp	66.67%	77.87%	83.72%	76.51%	73.98%	76.45%	873
Klamath River	2.38%	1.98%	3.49%	9.90%	7.72%	6.92%	79
Rogue	2.38%	2.37%	1.16%	4.85%	8.94%	4.82%	55
S Puget Sound	7.14%	8.70%	3.49%	0.39%	0.41%	2.71%	31
California Coast	0.00%	0.40%	0.00%	3.88%	3.25%	2.54%	29
Mid Oregon Coast	2.38%	1.98%	1.16%	2.91%	2.03%	2.36%	27
L Fraser	7.14%	2.37%	2.33%	0.00%	1.63%	1.31%	15
Mid Columbia tule	11.90%	2.37%	3.49%	0.19%	0.00%	1.31%	15
N Cal. S Ore. Coast	0.00%	0.00%	0.00%	1.17%	0.81%	0.70%	8
L Columbia fall	0.00%	0.79%	0.00%	0.00%	0.41%	0.26%	3
L Columbia spring	0.00%	0.40%	0.00%	0.00%	0.41%	0.18%	2
N Oregon Coast	0.00%	0.00%	0.00%	0.19%	0.41%	0.18%	2
Deschutes River fall	0.00%	0.00%	1.16%	0.00%	0.00%	0.09%	1
SSE Alaska	0.00%	0.40%	0.00%	0.00%	0.00%	0.09%	1
U Columbia R su/fa	0.00%	0.40%	0.00%	0.00%	0.00%	0.09%	1
Monthly sample size	42	253	86	515	246	1142	1142

BC = British Columbia, CA = California, Col. = Columbia, E = East, L = Lower, N = North, OR = Oregon, R = River, S = South, U = Upper, W = West, fa/sp = fall/spring, su/fa = summer/fall

Table 8. Monthly estimates of genetic stock composition of age-4 Chinook salmon caught in the ocean troll fishery off Oregon in 2006. Greatest stock contributions each month are highlighted.

Genetic Stocks	Month, 2006					Season	N
	June	July	August	September	October		
Central Valley fa/sp	77.78%	77.27%	74.26%	32.23%	19.30%	65.68%	778
Klamath River	4.94%	5.98%	6.93%	14.05%	10.53%	7.58%	59
Rogue	3.70%	0.72%	0.99%	18.18%	31.58%	6.04%	47
Mid Oregon Coast	3.70%	2.63%	1.98%	14.05%	14.04%	5.27%	41
N Cal./S Ore. Coast	0.00%	0.96%	2.97%	9.09%	8.77%	2.96%	23
S Puget Sound	4.94%	3.59%	0.99%	0.00%	0.00%	2.57%	20
L Columbia fall	1.23%	2.39%	2.97%	1.65%	0.00%	2.06%	16
California Coast	1.23%	0.72%	4.95%	4.13%	1.75%	1.93%	15
N Oregon Coast	0.00%	0.00%	0.00%	4.13%	10.53%	1.41%	11
Mid Columbia tule	0.00%	1.20%	1.98%	0.00%	0.00%	0.90%	7
L Fraser	0.00%	1.44%	0.00%	0.00%	0.00%	0.77%	6
U Columbia R su-fa	0.00%	0.96%	0.99%	0.00%	0.00%	0.64%	5
L Columbia spring	2.47%	0.24%	0.00%	0.83%	0.00%	0.51%	4
L Thompson	0.00%	0.72%	0.00%	0.00%	0.00%	0.39%	3
Deschutes River fall	0.00%	0.24%	0.99%	0.00%	0.00%	0.26%	2
Mid Fraser	0.00%	0.24%	0.00%	0.00%	1.75%	0.26%	2
Snake R fall	0.00%	0.48%	0.00%	0.00%	0.00%	0.26%	2
U Fraser R	0.00%	0.24%	0.00%	0.83%	0.00%	0.26%	2
N Gulf Coast Alsek	0.00%	0.00%	0.00%	0.83%	0.00%	0.13%	1
Willamette R	0.00%	0.00%	0.00%	0.00%	1.75%	0.13%	1
Monthly sample size	81	418	101	121	57	778	778

Table 9. Monthly estimates of genetic stock composition of age-5 Chinook salmon caught in the ocean troll fishery off Oregon in 2006. Greatest stock contributions each month are highlighted.

Genetic stocks	Month, 2006					Season	Number of samples
	June	July	August	September	October		
Central Valley fa/sp	21.43%	30.78%	75.00%	4.76%	0.00%	18.75%	15
Mid Oregon Coast	14.29%	11.54%	12.50%	38.10%	9.09%	18.75%	15
N Oregon Coast	0.00%	0.00%	0.00%	14.29%	81.82%	15.00%	12
U Columbia R su-fa	35.71%	15.38%	0.00%	0.00%	0.00%	11.25%	9
N Cal. /S Ore. Coast	7.14%	3.85%	0.00%	14.29%	0.00%	6.25%	5
California Coast	0.00%	3.85%	0.00%	14.29%	0.00%	5.00%	4
L Columbia fall	0.00%	11.54%	0.00%	4.76%	0.00%	5.00%	4
Rogue	0.00%	3.85%	0.00%	4.76%	9.09%	3.75%	3
L Columbia spring	7.14%	0.00%	0.00%	4.76%	0.00%	2.50%	2
Mid Columbia tule	0.00%	3.85%	12.50%	0.00%	0.00%	2.50%	2
Snake R fall	14.29%	0.00%	0.00%	0.00%	0.00%	2.50%	2
Klamath River	0.00%	3.85%	0.00%	0.00%	0.00%	1.25%	1
L Fraser	0.00%	3.85%	0.00%	0.00%	0.00%	1.25%	1
L Thompson	0.00%	3.85%	0.00%	0.00%	0.00%	1.25%	1
S Puget Sound	0.00%	3.85%	0.00%	0.00%	0.00%	1.25%	1
Monthly sample size	14	26	8	21	11	80	80

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OTOLITH STRUCTURAL AND CHEMICAL ANALYSES OF CROOS CHINOOK SALMON

Background and Objectives

A portion of the CROOS funds contributed to an on-going effort to determine the feasibility of providing relevant information on the ocean ecology of Chinook salmon using otolith structural and chemical analyses. Here, we present the objectives and status of those efforts.

Otoliths are crystalline structures, comprised primarily of calcium carbonate, located in the inner ear of bony fishes, which function as balance organs. Otoliths grow by continuous deposition of calcium carbonate, which generates growth increments much like the annual rings on a tree. Therefore, an otolith provides a permanent chronological record. If fish reside in water masses with different chemical compositions and/or temperatures, those properties are reflected in the otolith composition. Certain elements, such as strontium and barium, and isotopes, which are forms of the same element that have different atomic masses, can tell different things about the life of a fish. Studies that examine a suite of elemental ratios, i.e., Ba/Ca, Sr/Ca, Mg/Ca, within otoliths can provide information on whether fish collected from different areas mixed together during past periods. This combination of elements within the otolith is often referred to as the otolith elemental signature. By examining the Sr/Ca ratio across the otolith growth axis, information on when an anadromous fish, such as Pacific salmon, entered the ocean can be determined. By measuring the oxygen isotope ratio in otoliths, we can learn about the temperature of the water the salmon lived in. The oxygen isotope analysis relies on the relatively well-established assumption that the oxygen isotopic ratios present in fish otoliths are in equilibrium with, or close to, seawater. The proportion of a heavier isotope, ^{18}O , incorporated into otoliths increases as water temperature decreases so that, all other things being equal, otolith carbonate precipitated at colder temperatures will be enriched with ^{18}O compared to otolith carbonate precipitated at warmer temperatures. All of these chemical analyses can be combined with microstructural analyses, i.e., counting of daily or annual increments within the otoliths, to provide information about discrete periods in the life of a fish.

Because otoliths grow continuously, spatially-explicit sampling methods can provide information from distinct periods in the life history. Laser Ablation-Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) and micromilling techniques combined with Isotope Ratio Mass Spectrometry (IR-MS) allows for the determination of elemental and isotopic otolith composition at discrete regions on the otolith. Therefore, otolith chemical and structural analyses can be combined to provide novel information on individual life histories.

The otoliths of a subset of Chinook salmon collected during the CROOS project are being examined to determine:

- 1) If, and when, Chinook salmon from different stocks resided in waters with similar chemical characteristics. This will provide information on whether we can use otolith chemistry to learn more about stock-specific ocean migration and mixing in Chinook salmon.

- 2) The temperature history of individual Chinook salmon. Although we have information on the temperature of the water where fish were captured, we do not have information on the temperature history of individual fish. We will take a subset of individuals from 2 or 3 stocks and mill portions of the otolith for oxygen isotopic analysis. This will provide information about the past temperature history of individual fish.
- 3) If the ratio of $^{87}\text{Sr}/^{86}\text{Sr}$ in otoliths can be used to distinguish fall vs. spring Chinook. It is important to be able to determine the run time of a fish for ecological, conservation, and management reasons. Currently, genetic information cannot always readily separate fall vs. spring Chinook.

Methods

The otoliths were collected from a subset ($n = 420$) of the CROOS Chinook. This was accomplished through the cooperation of several CROOS fisherman and local fish buyers. Heads were frozen whole after fish were filleted for sale and frozen heads were then delivered to HMSC. All otolith pairs were extracted and a tissue sample from within the head region was placed in ethanol for genetic analysis. This second sample was collected in case there were problems with the field-collected fin clip, i.e., lost sample, DNA extraction problems, etc. This action proved very valuable as many of the secondary tissue samples were needed to verify the genetic identification of the fish used for otolith analysis. Genetic identification of the fish was finalized in early November 2006 and 280 fish were selected for otolith analysis based on stock composition. Otoliths were weighed, measured, cleaned, embedded in resin, sectioned, and polished. The form of calcium carbonate in otoliths is typically aragonite. Due to unknown reasons, aberrant otoliths comprised of vaterite, another structural form of calcium carbonate, occur frequently in fish from certain hatcheries. Vateritic otoliths do not form visible daily or annual check marks and incorporate elements differently than aragonite and are, therefore, useless for structural and chemical comparisons. A disproportionately high occurrence of vateritic otoliths was observed in Central Valley Chinook, i.e., 30%, which reduced the number of otoliths for analysis to 198 (Table 10).

Polished otolith sections were mounted onto glass slides, cleaned, and transported to OSU's WM Keck Collaboratory for Plasma Spectrometry, Corvallis, Oregon, for elemental analysis. Elemental data (^{25}Mg , ^{43}Ca , ^{55}Mn , ^{86}Sr , ^{88}Sr , ^{138}Ba , and ^{208}Pb) were collected along the otolith growth axis (Fig. 12). Time-resolved software allows elemental data from discrete periods in the life of the fish to be measured and compared. For example, Sr/Ca ratios are typically much higher in more saline ocean waters than freshwater rivers. Therefore, the period when a fish entered waters with elevated salinity can be identified by examining the strontium concentration across the otolith growth axis (Fig. 13). When combined with microstructural analysis, the elemental composition of the otolith during discrete periods of an individual's life can be determined.

Objective 1: Determine if, and when, Chinook salmon from different stocks resided in waters with similar chemical characteristics. This will provide information on whether we can use otolith chemistry to learn more about stock-specific ocean migration and mixing in Chinook salmon.

Elemental data were collected from 200 fish in early February 2007. Microstructural and statistical analyses are on-going. One potential concern was adequate identification of annuli, i.e., visible winter check marks on otoliths, to allow accurate identification of comparable years of ocean residence. Preliminary analyses indicate that visual identification of annuli is feasible in most all otoliths (Fig. 12). Age estimates generated through otolith microstructure will be directly compared with those generated by scale analysis, which was recently completed. Elemental concentrations within discrete years of ocean residence, i.e., 2006 vs. 2005 vs. 2004, will be compared among fish from different stocks.

Table 10. The stock, river of origin, and number of fish used in otolith structural and chemical analyses. The fa/sp and sp/fa fish from the Central Valley (*in italics*) will be further analyzed for $^{87}\text{Sr}/^{86}\text{Sr}$ to provide a determination of run-timing (See **Objective 3**).

Stock	River	n
Central_Valley_fa	Battle_Cr	32
Central_Valley_fa	Feather_H_fa	27
Central_Valley_fa	Butte_Cr_f	20
Central_Valley_fa	Stanislaus_R	10
South Puget Sound	Soos_Cr	18
Mid_Columbia_Tule	Spring_Cr_H	11
Rogue River	Applegate R	7
Rogue River	Cole Rivers H	4
Klamath River	Klamath	5
Klamath River	Trinity	8
<i>Central_Valley_fa/sp</i>	<i>Feather_H_fa</i>	<i>11</i>
<i>Central_Valley_sp/fa</i>	<i>Feather_H_sp</i>	<i>6</i>
<i>Central_Valley_fa/sp</i>	<i>Stanislaus_R</i>	<i>2</i>
<i>Central_Valley_fa/sp</i>	<i>Butte_Cr_f</i>	<i>3</i>
<i>Central_Valley_fa/sp</i>	<i>Battle_Cr</i>	<i>6</i>
Other stocks		30

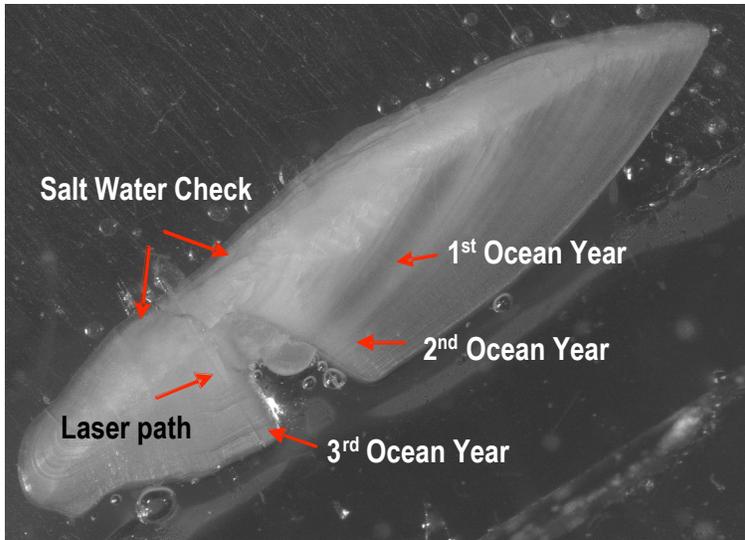


Fig. 1. Otolith from a 27 cm Mid-Columbia Tule Chinook collected on June 11, 2006. Laser path, time of entrance into higher salinity water, and three ocean years are identified. Time of entrance into salt water confirmed with Sr/Ca data.

(Figure 12)

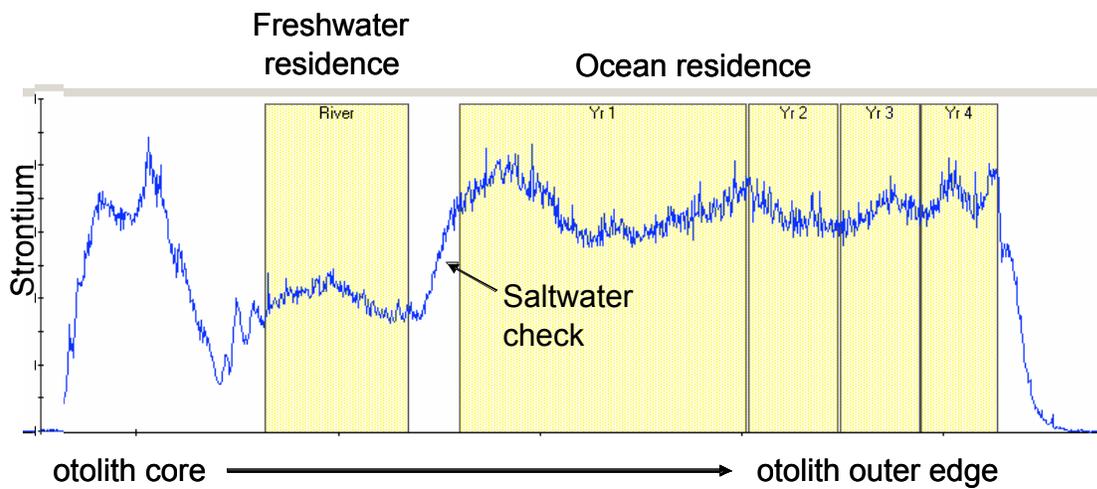


Fig. 13. Relative strontium concentrations across the laser path of fish pictured in Fig. 1. The period of freshwater residence, the salt water entry check, and years of ocean residence are identified.

Objective 2: Re-create temperature history of individual Chinook salmon.

Otolith carbonate for fish selected from 2 stocks will be sampled with a high precision micromill. The oxygen isotopic composition, i.e., $^{18}\text{O}/^{16}\text{O}$, from 8 to 10 time periods within each ocean year from 4 fish will be determined. The oxygen isotope analysis rely on the relatively well-established assumption that the oxygen isotopic ratios present in fish otoliths are in equilibrium with, or close to, seawater. The proportion of a heavier isotope, ^{18}O , incorporated into otoliths increases as water temperature decreases so that, all other things being equal, otolith carbonate precipitated at colder temperatures will be enriched with ^{18}O compared to otolith carbonate precipitated at warmer temperatures. This analysis will provide detailed information on temperature histories of individual fish and assess its feasibility for examining stock-specific variation in temperature preferences.

Objective 3: Determine if the ratio of $^{87}\text{Sr}/^{86}\text{Sr}$ can be used to distinguish fall vs. spring Chinook.

The genetic basis for differentiating between spring and fall Chinook is not fully established. In some regions, i.e., California's Central Valley, the inability to distinguish between spring and fall Chinook creates uncertainty and can pose management problems. We have been developing a method to distinguish maternal run-timing by examining strontium isotopic ratios in otoliths. The element strontium is well-mixed in the modern ocean and the ratio of two isotopes, i.e., $^{87}\text{Sr}/^{86}\text{Sr}$, is considered invariant ($=0.7092$). The $^{87}\text{Sr}/^{86}\text{Sr}$ ratio within a watershed, however, is dependent on local geology and weathering processes. The basaltic coastal watersheds in Oregon typically have lower $^{87}\text{Sr}/^{86}\text{Sr}$ ratios than seawater. For example, the Feather River in California has an average $^{87}\text{Sr}/^{86}\text{Sr}$ ratio $= 0.706150 \pm 0.00003$.

The composition of a salmon's otolith core is influenced by its mother's body composition. Thus the otolith cores of offspring of spring Chinook, which have resided in freshwater for months prior to spawning, should have lower $^{87}\text{Sr}/^{86}\text{Sr}$ ratios than the otolith cores of fall-run offspring. This premise has been supported with juvenile spring and fall Chinook collected from hatcheries on the Rogue, Umpqua, and Trask Rivers. In all three watersheds, juveniles were correctly identified as spring or fall, based on the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio in the core of their otolith, $>90\%$ of the time.

The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in the otoliths of a subset of the Central Valley Chinook that have been classified as spring or fall run but with low assignment probabilities, i.e., $<60\%$, will be measured at the OSU WM Keck Collaboratory in late March or early April.

Additional Information: Determination of the size-at-ocean entrance for Chinook collected in the Oregon fishery.

The importance of early ocean survival is increasingly recognized as a key determinant of cohort size. The individual size and time a juvenile Chinook enters the ocean can be a determinant of overall survival. The majority of coastal Chinook in California and Oregon migrate to the ocean in their first year of life, i.e., as subyearlings. A small percentage of individuals from some basins, i.e., Rogue and Umpqua, display a yearling life history. Currently, estimates of size at

ocean entrance are available for about 20% of Oregon’s coastal Chinook. The hypothesis that there is a size or time for optimal survival has been postulated. If supported, there are implications for both hatchery management, i.e., release strategies, as well as habitat restoration and management implications.

Size-at-ocean entrance will be determined for all Chinook used in Objective 1. Preliminary estimates of individual size-at-ocean entrance, using linear regressions from Titus et al. 2004, were determined based on otolith microstructure and Sr/Ca transects along the otolith growth axis (Table 11). Based on discussions with hatchery operators, back-calculated estimates are reasonable given the size and timing of fish release with the exception of the Feather River Hatchery. This is somewhat surprising as the linear relationships used for back-calculation were generated based on Central Valley hatchery Chinook. The bulk of the Feather River hatchery production fish are released in May through June at sizes >100 mm. There are some experimental releases of smaller, coded wire tagged (CWT) fish from February to May. These preliminary data indicate that the fish released earlier may comprise a disproportionate percentage of the catch. We emphasize the preliminary nature of these results and additional analyses are on-going.

Table 11. Estimated size-at-estuary/ocean entrance based on back-calculated length determined with otolith microstructure and Sr/Ca transects. Mean, standard deviation (SD), range, and percentage classified as sub-yearling and yearling are included.

Basin	River	Mean	SD (mm)	Range	% Subyearling	% Yearling
Central Valley	Feather River Hatchery	77.63	23.1	37-99	100	
Klamath	Klamath River	77.59	24.1	45-96	100	
Mid Columbia	Spring Ck Hatchery	78.23	7.4	66-89	100	
Rogue River	Applegate River	91.48	42.7	39-151	80	20
So. Puget Sound	Soos Ck Hatchery	112.83	51.9	73-198	67	33

OCEANOGRAPHIC DATA COLLECTION

Summer 2006 CROOS-Glider Collaboration

Project CROOS partners recognized that it would be critical to collect oceanographic data in conjunction with fisheries and genetic stock information. The early strategy was to employ a subset of industry vessels and collect an array of oceanographic data using both simple and sophisticated oceanographic equipment. However, it became quickly apparent that this would require the vessels to stop their fishing operations to employ oceanographic instruments (e.g., CTD's). Although project vessels collected sea surface temperature, and some collected temperature at depth of fishing (via portable temperature recorders attached to the cannon ball), it was not practical for vessels to collect other types of oceanographic information (visibility, salinity, chlorophyll, etc.). Scientists from the College of Oceanic and Atmospheric Sciences, at no cost to the project, volunteered to help us test the feasibility of collecting oceanographic information near or below the CROOS project vessels using autonomous underwater robotic gliders. The following section describes the results of this pilot effort.

Beginning in April 2006, the OSU Glider Lab has more-or-less continuously maintained an autonomous glider, sampling a cross-shelf transect along the Newport Hydroline (44 39.1 N) off central Oregon to study wind-driven flow-topography interactions and the impacts on processes such as the formation of hypoxia in coastal waters. The Newport Hydroline is a 45 mile-long, cross-shelf array of hydrographic stations, mainly temperature and salinity observations, running from the 20 m isobath to the deep ocean, and has one of the best historical records in the northwest US. In September 2006, we coordinated the operation of two autonomous gliders with concurrent CROOS sampling from commercial fishing boats in Oregon's coastal ocean.

Autonomous underwater vehicle (AUV) gliders are robots capable of travel through and making observations in the ocean. The gliders do not have a propeller; instead they "fly" through the water by changing their buoyancy, using their wings to convert vertical motion into forward motion. At the surface the glider takes water in through the ballast pump. This makes the glider heavy relative to the surrounding water. The glider sinks, and some of this vertical motion is converted to forward motion by the wings. At the bottom, the glider expels the water in the ballast pump, becomes lighter than the surrounding water, and rises, reversing the process. In this fashion, the glider goes up and down, flying a saw-tooth pattern through the coastal ocean. This mode of propulsion is slow (1/2 – 1 knot), but the trade off is an especially long endurance (3-4 weeks). The glider comes to the surface at pre-programmed, six-hour intervals, and determines its location by GPS and communicates back to our lab via Iridium satellite phone, downloading data and uploading new instructions. The benefits of autonomous sampling are well known - the cost relative to comparable ship-time is miniscule, and sampling is not constrained by weather; the other benefits come by maintaining a continuous presence in the ocean - just by being there your chances of observing intermittent, unpredictable (possibly important) processes are increased.

In September 2006, we conducted a coordinated sampling plan with two gliders and the commercial fishing observations. One glider (Bob) continuously sampled the Newport Hydroline, a cross-shelf section off Newport, Oregon (Figure 14). The second glider (Jane) conducted a sampling pattern over sites selected to match the efforts of the commercial fishing observations. Jane started inshore, transited to the first site near Stonewall Bank, spent six days sampling there, then transited to the second site further south, spent four days sampling there, then transited back up to the offshore end of the Newport Hydroline, and finally sampled a transect onshore, where Jane was recovered.

Physical conditions in the coastal ocean during September 2006, as revealed by the glider observations, are the result of one of the strongest upwelling seasons in several years. The glider observations of temperature and salinity (Figure 15) were exceedingly cool and salty relative to historical averages.

This pilot project was a success and showed that autonomous underwater gliders could be used in conjunction with fisheries research conducted by commercial fishing vessels to record oceanographic data. Project CROOS partners believe this data will be important for both short and long term understanding of salmon migrations, feeding behavior, and other spatial/temporal characteristics of salmon stocks.

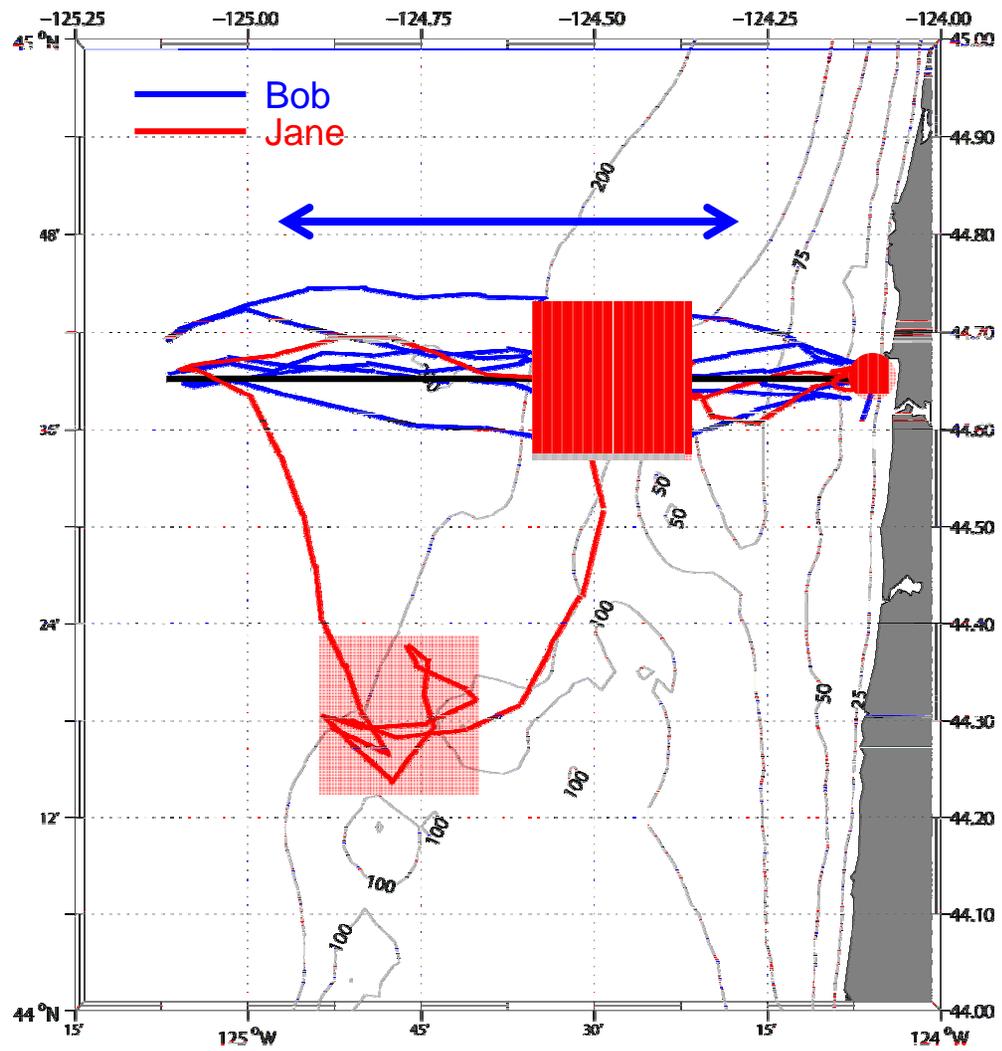


Figure 14: The path of autonomous gliders Bob and Jane during the September 2006 CROOS project. The red dot is the deployment site off Newport, the black line is the traditional Newport Hydroline, and the red squares are the sites designated for sampling by the CROOS scientists.

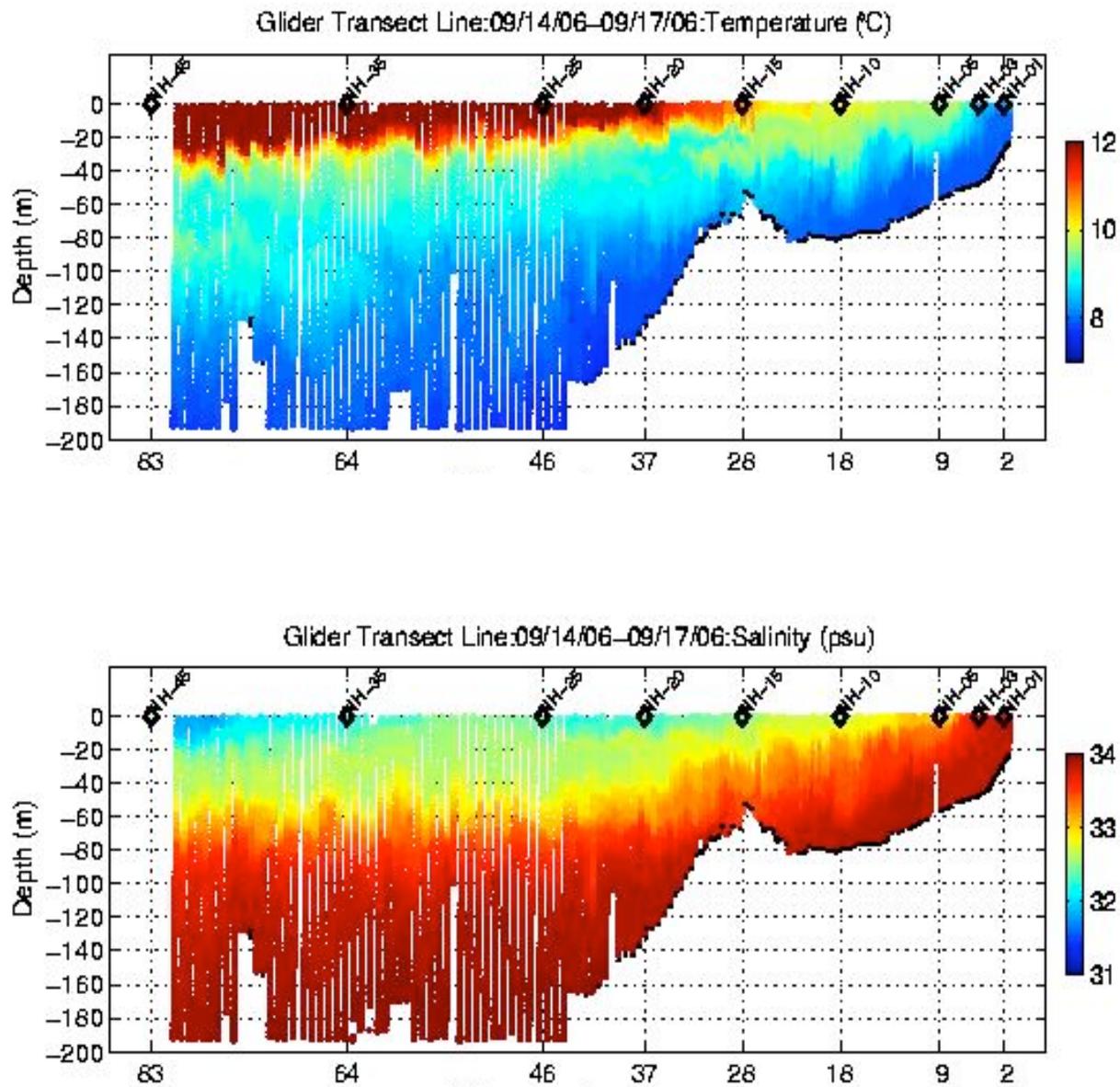


Figure 15: Glider observations of temperature and salinity from September 14-17, 2006 along the Newport Hydroline. Temperatures were exceeding cool and salinities were very high compared to historical averages, reflecting the intense upwelling in 2006.

WEBSITE DEVELOPMENT

Planning

In planning for the CROOS project, it was envisioned that a website would be developed that could be used to:

1. Describe the project and report general project information to educators and the public
2. Compile data gathered from the project for analysis by affiliated researchers
3. Report the results of the genetic analysis of the sampled fish, their distribution, and other significant oceanographic information in “real time” to management entities
4. Report results and significant oceanographic data to the contributing fishers
5. Disseminate information about origin and catch history of individual fish to support marketing strategies

It was understood that varying levels of access would need to be designed into the site in order that confidentiality concerns were addressed. For example, the level of access to the raw data which makes up the basis for the website would be more restricted for individual fishermen and the general public than it would be for researchers and managers attempting to analyze the data. Participating fishermen would be able to access a higher level of information about their own data than they would about the cumulative data from the entire project. Potential consumers would be able to enter an ID number (associated with a bar code) and find information about the catch history of individual fish; however they would not be able to access many types of cumulative project information.

To visualize how such a website could be incorporated into a future, GSI based management application, a schematic diagram of how one such website would work for a hypothetical, real-time fisheries management regime is shown on Figure 20.

ProjectCROOS.com Website Development

The CROOS team hired Beartooth Creative Group which developed the original – *ProjectCROOS.com* website. The website is currently hosed on a server on an off campus server and describes the purpose and history of the CROOS project.

The site explains:

The need for the project at this time, including a description of the current problem with weak stocks of Klamath River salmon.

1. A description of the funding for the project
2. Identification of the project collaborators
3. An explanation of the science behind the project
4. The contribution of the fishermen to the project
5. A brief economic picture of the losses to the salmon fishery in 2006 due to weak stock management constraints



Figure 16 ProjectCROOS.com Home

At this stage of development, the ProjectCROOS.com website does not allow access to any data or results from the analysis of the 2006 data. When technical and confidentiality issues are fully addressed, the site will offer varying levels of access to those pages.

A more detailed explanation of the website is presented in the Appendix 6, *Project CROOS Website and GIS Development Proposal*.

GIS based science website development

A separate website was developed to incorporate the interactive GIS facets of project information. This “beta” phase of the website was developed by Chris Romsos at OSU in the College of Oceanic and Atmospheric Sciences laboratory. This site, which is now restricted by user login and password, uses currently available interactive GIS web mapping software (ESRI’s ArcIMS and Arc GIS) to display the full range of data collected in the project and allow for manipulation and interpretation. When access protocols are determined and technical issues fully developed, these pages will be accessed through the ProjectCROOS.com website.

This website actually consists of three linked websites, each dealing with separate areas of project focus.

The science and fisher sites are “viewers” or more simply, just websites. No specific software, license, or download is required by the end user other than a connection to the internet and a modern web-browser. The sites are coded primarily in HTML though some javascript is used for web configuration, initialization, and to build a Table of Contents. Each viewer contains a main map window, a set of navigation and query tools, a layer index or table of contents, and a results pane. Users interact with the site by toggling among various data layers and performing layer queries. In this way users may easily explore information from the project and from the fishing grounds by actively looking for relationships and trends, or by querying (selecting) subsets of a data layer. Query results are presented in tabular format.

The science site allows access to all of the data compiled in the project database. It allows researchers to view layers of information in a mapping format for each week of the duration of the project. Catch location of each sampled fish, including latitude/longitude as well as depth of capture, time of capture, water temperature, capture vessel, the length of the fish, its age, and the presence of any applied markings (fin clips, etc.) can be correlated to the probability that it “assigns” to a specific river of origin. The entire vessel track of each participating vessel (during the time it has gear in the water) can be displayed. Other geographical, bathymetric, oceanographic, and meteorological data can also be layered on the display.

At present, to protect the confidentiality of the participating fishermen, all information linking a datapoint to a specific vessel or fisherman has been removed from access by all reviewers, except that each fisherman may fully access his own data on a separate page (actually a separate, linked site). The science site can only be accessed with a unique login and password.



Figure 17. This Science web mapping site loads after the user is authenticated. Navigation and query tools are located in the upper left corner, the white space at the bottom of the view is reserved for query output, and the table of contents is located on the right. The main map window is manipulated by selecting a tool and performing either a click or drag inside the window.

The fishermen site also requires a unique login for each fisherman. It only presents the specific catch data that pertains to the catch information of that particular fisherman. Non-confidential data, such as oceanographic and bathymetric information, is identical with that on the scientist site.

The consumer site is in an early stage of development and is written with different software and has a different look than the science and fishermen sites. It will allow a consumer to perform a website “lookup” to find catch and stock origination information about a specific fish by entering the unique code number attached to that fish.

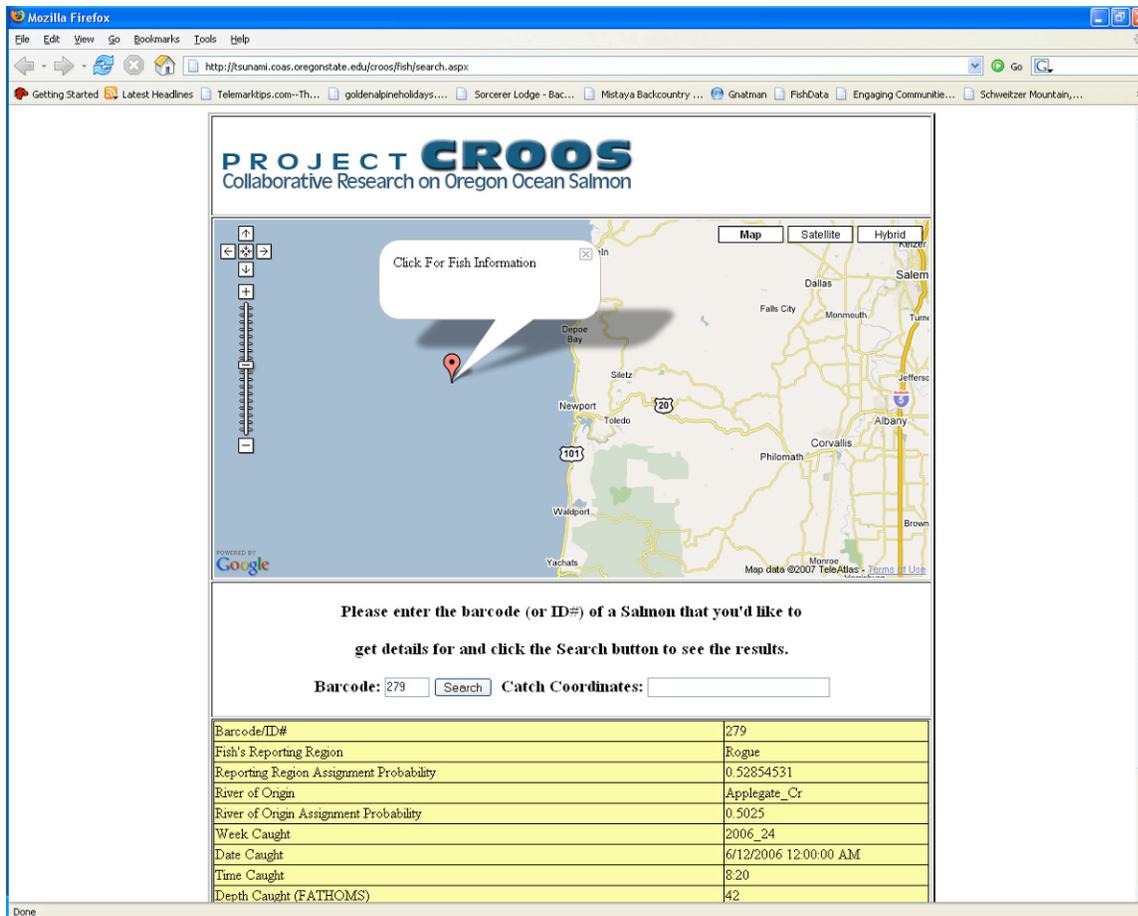


Figure 18. This is an example of the Project CROOS consumer webpage. The consumer enters a barcode from a fish that they purchased in the market and the website “looks up” that barcode in the database. Results are returned to the map and to a table.

Interactive Web Mapping Software

ESRI’s ArcIMS (Internet Mapping Server) software was chosen to illustrate the geographic information generated through this project. ArcIMS is a mapservice, a type of server that generates maps in the form of an image. The server processes requests from a client (in this case, the CROOS science websites) and generates new map images based upon each request. ArcIMS integrates well with other ESRI GIS software and allows relatively easy creation and management of geographic representations of the tabular data records that constitute the database. It is also an extensible product that can grow, supporting customizations on the client side that could include building more sophisticated analytical capacity into the system.

Database Protocols and Maintenance

All data collected and generated through the efforts of project CROOS is currently stored in a Microsoft Access database. Data types include: Vessel Navigation, Salmon Catch Records, Sample Records, Genetic Stock Assignment Results, and Ocean Temperature data. Data from

separate tables is indexed by a combination of Vessel (fisher's name) and Sample ID. An example of the nascent data model is shown in figure 19.

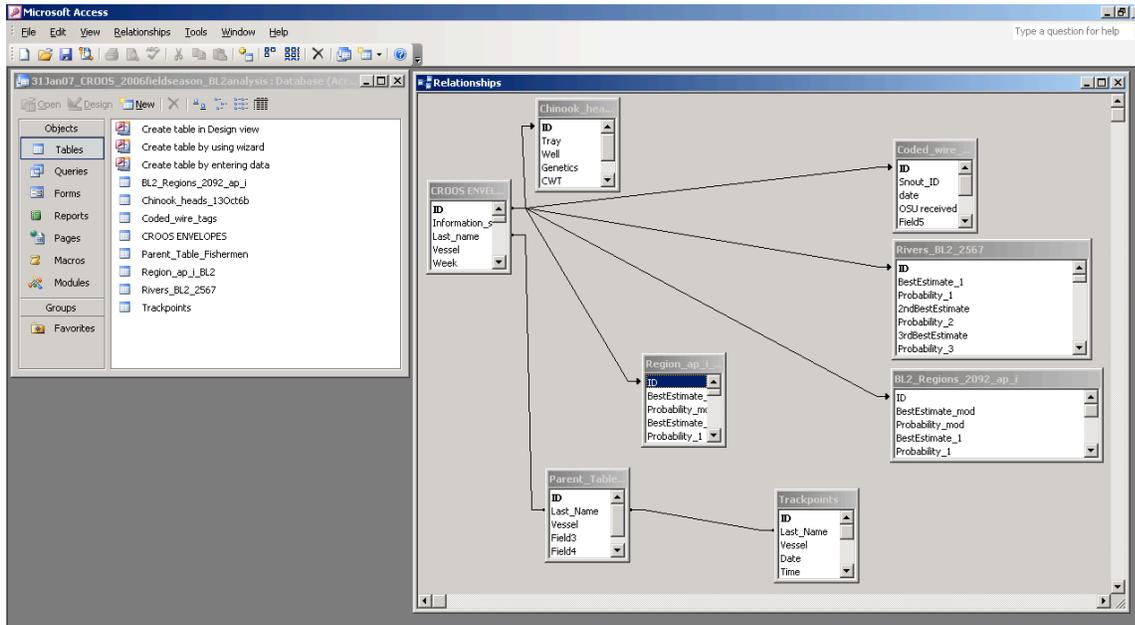


Figure 19. Diagram of the Project CROOS relational data model. Vessel navigation (trackpoints) is indexed using the last name of the fisher in a parent table; all other data is indexed by a unique sample ID.

Observations and Suggestions for Future

Accurate and rapid entry of data from the logs and electronic devices used in the sampling protocols and its correlation with the genetic information analyzed in the laboratory is vital to the success of not only the website, but the entire CROOS project. This is a complex and challenging task, particularly in a pilot stage project such as this.

As information from the participating fishermen arrives at the lab, it must be checked for obvious errors or omissions, and then entered into a format which will be compatible with that required by the website. This involves manual entry of the data from paper log sheets and digital entry of data from electronic dataloggers, temperature recording devices, and GPS units into a database where it can be correlated with the results of the genetic analysis for each fish. This process can involve several steps, and may require conversion of data from text, spreadsheet, and/or ACCESS database format to the eventual SQL database format required by the GIS software.

Utilization of the handheld GPS units to record vessel tracking and fish capture waypoints greatly simplified the database entry process, as manual transcription of each vessel's tracking logs was very time and effort intensive, but was not directly useful in transferring the information to the website.

Migrating newly entered data into an existing master ArcIMS database has proven to be challenging, and solving this shortcoming is critical to the website's success. A specialized web-programmer would need to write programming code to automatically update the database tables and maintain the integrity of the links. Accomplishing this was beyond the expertise of project participants, although the problem was temporarily circumvented by developing a master database table with the fields pertinent to immediate needs. This, however, is not a permanent solution as it does not deal with the necessity of maintaining the integrity of relationships wherein one datapoint links to other types of data (one-to-many relationships).

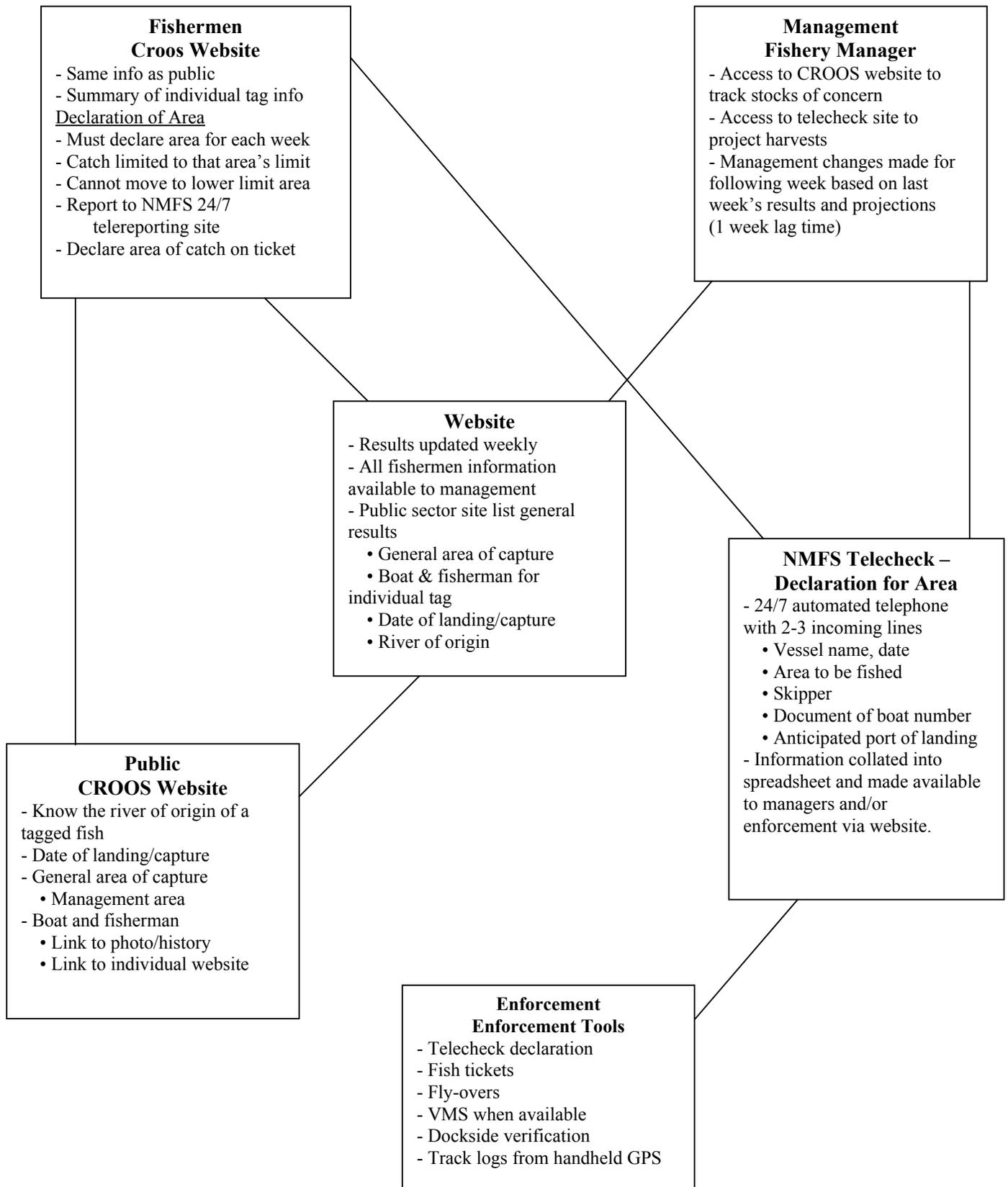
Optimization and standardization of these protocols will become even more important if results are to be uploaded to the website directly from different port liaisons in various ports and from several different laboratories. Such a capability would be desired in future projects, particularly if they involved other states and NMFS laboratories. A system to standardize the error checking and data filtering prior to uploading will have to be established, since some field errors will always be part of such a large research project.

In future projects, spatio-temporal patterns of distribution or oceanographic/meteorological linkages to fish movements could be assessed directly using ArcIMS or MatLab software.

Since some sort of a central project website of this type would likely be expected in future GSI-based projects, further development of the present website should be explored. Plans are under way to use several analytical techniques, such as focus group sessions and surveys, to help define the best website design and functionality for presenting the results of those projects to scientists, fishery managers, the fishery itself, the seafood market, and the general public.

Figure 20

Collaborative Research on Oregon Ocean Salmon
How Things Work



MANAGEMENT

The long-term goal of this project is to increase the information available to managers on the temporal and spatial distribution of specific West coast salmon stocks. If this work indicates that substantial variation in temporal and spatial distribution exists, week to week management measures may be employed that allow commercial fishermen access to relatively abundant stocks of salmon while protecting weak stocks. The first step in applying GSI technologies to fisheries management is to explore and map the distributions of stocks in Council-managed fisheries. An Exempted Fishing Permit has been developed that will allow us to begin mapping stock distributions in ocean fisheries in 2007 in times and areas outside of the open areas and seasons. In addition, this proposal will allow us to test the feasibility of new techniques that could allow rapid-turnaround quota management in limited areas and times in the future. However, the biggest gains will ultimately come from an improved understanding of stock-specific marine distributions and migration pathways in relation to submarine topography and oceanic conditions. In the long term this constitutes a step toward ecosystem-based management for salmon.

The CROOS project is designed specifically to help improve fishery management. The short-term problem addressed is the need to reduce fishery impacts on Klamath fall Chinook while maintaining some access to other, more abundant stocks. In the longer term, GSI data could provide a superior add-on or alternative to the coded wire tag (CWT) data that have been the basis for management since the 1970s.

The primary objective is to improve information on spatio-temporal distribution of West coast Chinook salmon for use in salmon management. To achieve this we collected time and location-specific genetic samples, along with scales, otoliths, stomachs, and oceanographic data. The data of short-term interest to management is stock identification and specific catch locations. We demonstrated that we can map the precise locations of catch by stock. Data are currently being analyzed for differences in distribution among stocks that might be useful for directed harvest on non-Klamath stocks. From the data we collected in 2006 we hope to develop analytical techniques. Fisheries were not extensive enough to expect to see major distributional differences. Future years of data collection with a greater spatial extent will be needed to achieve this objective. We are working with fishermen in California to coordinate sampling from the two states. Washington has also expressed interest in sampling fisheries North of Cape Falcon.

The longer-term purpose of these collections is to begin developing a database of stock distributions for comparison with the historical CWT database. Over time we expect to develop a database similar to the CWT contribution rate database but with fewer assumptions (e.g.; fewer hatchery indicator stocks representing natural production) and much higher resolution in space and time. Coast wide, about 5 percent of Chinook and coho salmon have CWTs. With 20% of the catch sampled there is substantial statistical sampling and expansion error in catch composition estimates. Rare or untagged stocks are difficult or impossible to detect. With GSI

data we can identify a high percentage of fish to stock of origin and map catch location precisely and in near real time. This enables us to identify stocks that are not CWT'd, and gives us a better likelihood of observing stocks that contribute at a rate of 1% or less to fisheries. This can be used to improve the base-year data used in fishery harvest models, thereby improving the preseason modeling of fishery impacts and perhaps allowing finer-scale shaping of fisheries.

In addition to the sampling component of Project CROOS we have expertise in the fishery management process. We plan to help develop the statistics and the modeling techniques that will be required to implement GSI data into fisheries management. As we develop these models we will also be looking to expand the scope of modeling to include links to economic models. In this way we will be able to project the impacts of fishery regulations on fishing communities along the coast and evaluate policies and incentives to help target healthy stocks while minimizing catch of weak stocks. This may result in fishing seasons that improve overall economic benefits while distributing economic impacts more equitably than is currently possible.

In addition to improving the stock contribution rate data we will be able to examine migration routes, evaluate “hot spots” and see how long they persist, relate fish distributions to ocean conditions, and generally expand the range of information available to fishery managers. Compilation of such a database will require several years. We anticipate providing preliminary results to fisheries managers after three years of sampling, with continuing improvement in the information in future years.

Work in 2007 will be designed to (1) extend the development of techniques and methodologies based on 2006 experience, (2) provide relief to fishermen via payment for participating in sampling programs, and (3) start to answer questions relative to distribution of Chinook stocks that may prove useful for management. It is too early to actively apply GSI technologies to fishery management on the West coast, although a simulation of a potential in-season weak stock quota management application may be conducted based on data collected during this study. Project CROOS is specifically designed to help meet the needs of management. Regional fisheries are managed by the National Marine Fisheries Service (NMFS) and the Pacific Fishery Management Council (PFMC).

NMFS has a Strategic Plan for Fisheries Research. In this plan Section I.A. treats “Biological research concerning the abundance and life history parameters of fish stocks.” From that section:

Understanding aspects of the life history of fish stocks will be of increasing importance in the management of the Nation's living marine resources. Describing migratory and distribution patterns, habitat use, age, growth, mortality, age structure, sex ratios, and reproductive biology will be essential information for scientists and managers to optimize sustainability and yield of these resources...

There is an increasing need to identify and characterize discrete stocks. This will allow scientists and managers to correctly structure stock assessments and design stock specific management measures for groundfish complexes, salmon species, coastal migratory and oceanic migratory species and reef fish. Stock identification involves many techniques, including mark-recapture, otolith shape analysis, parasite distributions, and biochemical genetic methods.

The improved understanding of ocean distributions that will result from conducting studies like this over a period of years will help us characterize discrete stocks and design stock-specific management measures. This is also directly related to Goal 1 of the Strategic Plan:

GOAL 1: Provide scientifically sound information and data to support fishery conservation and management. (Ongoing)

Objective 1.3: Determine and reduce the level of uncertainty associated with stock assessments through improved data collection and advanced analytical techniques. (FSP Strategy 1.2.1)

Objective 1.6: Collaborate with the Councils and other management authorities to develop fishery management regimes that will effectively control exploitation. (FSP Strategy 1.1.4)

The PFMC assesses its research and data needs every two years. The draft 2006-2008 Research and Data Needs for the Pacific Fishery Management Council (Council) identifies as its highest priority the development of GSI for fisheries management applications. The report states:

Advances in genetic stock identification, otolith marking, and other techniques may make it feasible to use a variety of stock identification technologies to assess fishery impacts and migration patterns: The increasing necessity for weak-stock management puts a premium on the ability to identify naturally reproducing stocks and stocks that contribute to fisheries at low rates. The CWT marking system is not suitable for these needs. The Council should encourage efforts to apply these techniques to management.

Substantial progress has been made on this item in the past 6 years. A coast wide microsatellite database for Chinook has been developed. A similar database for coho salmon is under development, but needs resources to coordinate efforts for the entire coast. GSI techniques have improved so that samples can potentially be analyzed within 24-48 hours of arrival at the laboratory. GSI is actively being used in Canada to manage coho salmon fisheries off the West coast of Vancouver Island. Studies are under way to evaluate the potential usefulness of real time GSI samples in Chinook management, particularly in relationship to Klamath fall Chinook. There are proposals to develop operational alternatives to time-area

management using these techniques, in combination with existing CWT marking, mass marking, otolith microchemistry, and other emerging stock identification techniques. These studies are now the highest priority for salmon management.

The report also identifies emerging issues related to this priority. From the report:

Emerging issues are related to the high priority recently assigned to the implementation of GSI technologies in weak-stock fishery management. Research tasks and products necessary for this to be successful are:

1. Identification of the error structure of GSI samples taken from operating fisheries.
2. Development and application of technologies to collect high-resolution at-sea genetic data and associated information (time, location, and depth of capture, ocean conditions, scales, etc.)
3. Identification of stock distribution patterns useful for fisheries management and appropriate management strategies to take advantage of these distribution patterns.
4. Development of pre-season and in-season management models to implement these management strategies and integrate them with PFMC management.

The studies proposed here will work toward resolving these issues. The second and third items will be addressed directly. Work on the first item will also be progressing during the course of this study. The fourth item, development of new management models, is a future project that depends on results of the proposed study and similar sustained efforts over the next few years.

SUMMARY: KEY FINDINGS AND RECOMMENDATIONS

CROOS was an ambitious undertaking given the relative short window of time for conducting the project (nine months) and the diverse set of objectives. CROOS project managers attempted to combine basic and applied interdisciplinary science, genetic and oceanographic research, industry and scientist collaboration, and data technology and website development -- while also providing financial assistance to a large portion of the fleet. This required a high degree of adaptive learning and a fundamental commitment to day-to-day communication and coordination. CROOS project accomplishments were due in large part to the cooperation and hard work of a large and diverse team including fishermen, scientists, managers, and educators from both the private and public sectors. Although readers of this report can make their own judgments regarding project success, the CROOS group is proud of its accomplishments and believes that the project builds a strong foundation for future work. Together with other salmon GSI work being conducted along the West Coast, these projects herald a new era for ocean salmon science, management, and marketing.

This project primarily focused on developing protocols, providing “proof” of concepts for science and management, and laying the groundwork for future GSI-based salmon research and management. Key to project success were fundamental core principles guiding this work:

- Authentic collaborative research between industry and scientists based on mutual learning and respect
- Integrated fishing and research activities benefiting fishermen, scientists, and resource managers
- Integrated research and project management using digital technologies
- Creating and managing “real time” data for diverse audiences and uses including fishery science, fishery business management, resource management, seafood marketing, and education.

Project Results and Findings

- Financial Assistance to the Fleet The project provided financial assistance to about 20% of the fleet that participated in the Oregon salmon troll fishery in 2006. More than seventy contracts were signed and 72 vessels participated in at least one opener (72 operators, 54 crew members) conducting 707 “sampling days”. Sampled fish totaled 4,270 and represented 17% of all salmon harvested by the commercial fleet off the Oregon coast south of Cape Falcon in 2006. A total of \$332,100 was distributed to operators and crew. A post-season fleet survey indicated that fishermen and crew were supportive of the project and satisfied with project management and financial remuneration.
- Protocols, Fleet Management, Project Coordination Project managers developed detailed protocols for biological sampling, data collection and management, fleet training, and project coordination. Fleet coordination required considerable staff time and will be a crucial component of any future work. These protocols will be invaluable for future GSI-based salmon research and management along the West Coast.

- Dataloggers Digital datalogging devices for fishing vessels proved to be successful. Most fishermen testing these units believed the equipment was easier to use than “manual” sampling protocols. The devices deserve further testing and development for cost-effective and comprehensive “real time” data collection.
- Genetic Stock Identification (GSI) From mid June to late October 2006, over 4,200 tissue samples were delivered to the genetics laboratory along with digital or paper logs with time/harvest location, troll tracks, fish length, harvest depth, water temperature, etc. The paper log data was then manually entered into the computer at the laboratory. Approximately 3,100 samples were processed and 2,567 fish were used to estimate stock mixture proportions and for individual assignment to baseline populations. Probability values of stock assignment for the 2,567 fish ranged from 28% - 100%. By the end of the season a total of 2,097 fish were assigned probabilities $\geq 90\%$ to a specific hatchery or reporting region (river basin or coastal region). Samples not processed in the laboratory (1,221) were stored in the OSU archive and can be genotyped at a later date.
- Analysis of Stock Mixture Proportions Analysis of stock mixture proportions indicate that the majority of fish were from California’s Central Valley (59.08%) The Rogue River was estimated to contribute the second greatest proportion (7.61%), followed by the Mid Oregon Coast (7.11%) and the Klamath basin (6.58%). The California Coast and Northern California Coast/Southern Oregon Coast regions contributed 2.17% and 1.89%, respectively. The Upper Columbia River summer/fall run was estimated to contribute 3.03% of the total. Twenty other stocks contributed less than 2% each.
- Stock Proportions Across Time Over time Central Valley fall and spring Chinook contributed the greatest percent (weekly average 61.01%; range 43.91% - 71.49%). The Klamath ranged from 3.82% to 11.32% with an average of 6.47%. The Rogue River spiked at 19.13% during October, up from 1.70% in the first week of August (average 7.26%). Stocks from the California Coast reporting region averaged 2.20% (range 0.67% - 5.38%), and the Northern California/Southern Oregon Coast contributed an estimated average of 2.25% (range 0.60% - 5.75%).
- 100% Assignment of Coded Wire Tag (CWT) Fish Thirty-one of the 2,097 fish that met the 90% probability criteria contained coded wire tags. All 31 CWT fish assigned to the correct hatchery of origin.
- Near “Real Time” Analysis During the “learning phase” of this project (June-August), real time genetic analysis was delayed (conducted between 48-96 hours) due to inadequate personnel resources and other logistical problems. By September/October of this project, fish, in near “real time” (within 24-48 hours of the laboratory receiving the samples) were successfully assigned to individual genetic stock estimates and mapped at their harvest location. Preliminary cost estimates for conducting near “real time” analysis and entering all associated data into a data base range from \$40-\$50 per sample.

- Monitoring Wild Salmon Stocks in Near “Real Time” This project demonstrated that stock composition of wild, as well as hatchery salmon stocks captured in commercial fisheries, could be evaluated in near “real time” using GSI analysis. This work provides new opportunities to link freshwater and marine salmon ecosystem research on all life stages of wild salmon.
- Geographic Information Systems (GIS) Maps GIS-based maps were developed that include information on each harvested fish. Maps were designed to provide virtual “real time” information to managers, scientists and other audiences. Using pull down menus, data can be explored and “remapped” based on stock identification, water temperature, harvest dates, areas, depth at capture, and other biological or environmental information. Maps will be accessible at www.ProjectCROOS.com by mid-late May 2007.
- Website Development “Real time” analysis based on GSI information requires a sophisticated website. The CROOS Project has designed a working “prototype” capable of describing the project and reporting information to multiple audiences using a variety of tools, maps and statistical analysis. The working website will be accessible to various audiences via specialized portals by mid-late May 2007 at www.ProjectCROOS.com.
- Scale Analysis and Age of Capture The age composition for the entire set of samples (about 2,000 fish) was 0.1% age-2, 57.0% age-3, 38.5% age-4, 3.9% age-5, and 0.5% age-6. There was a large change in the percentage of age-3 and age-4 fish between August and September with age-3 fish increasing and age-4 fish decreasing.
- Otolith Analysis The otoliths of a subset of Chinook salmon collected during the CROOS project are being examined to determine 1) if, and when, Chinook salmon from different stocks resided in waters with similar chemical characteristics, 2) the temperature history of individual Chinook salmon, 3) if the ratio of $^{87}\text{Sr}/^{86}\text{Sr}$ in otoliths can be used to distinguish fall vs. spring Chinook, and 4) size-at-ocean entrance for Chinook salmon. This work is expected to be completed by late April 2007.
- Oceanographic Data Collection by Autonomous Vessels In September, a successful pilot test was conducted by scientists from OSU’s College of Oceanic and Atmospheric Sciences which showed that autonomous underwater gliders could be used in conjunction with research conducted by commercial fishing vessels. Results indicated that physical conditions in the coastal ocean, as revealed by glider observations, are the result of one of the strongest upwelling seasons in several years and that temperature and salinity were exceedingly cool and salty relative to historical averages.
- Development of an Experimental Fishing Permit (EFP) The success of project CROOS helped to motivate a two-day workshop (September 2006 Portland, Oregon, PFMC Headquarters) with over 40 West Coast participants from NMFS, PSMFC, ODFW, California Fish & Game and industry to discuss development of an experimental fishing permit and plans for a three year West Coast GSI project based on CROOS protocols. In order to provide for sampling in otherwise closed areas and times, PFMC discussed and determined that, if needed, an EFP could be issued on an emergency basis.

Recommendations

- Adjusting and Improving Project Protocols A wide range of protocols may need improvement or adjustment in response to 1) fishery sampling outside of normal operating areas, 2) a continuous season versus short weekly openings, 3) improved catch rates, and 4) coordination of fleet management over the entire West Coast. CROOS project members can work with other West Coast states, industries, and agencies to help design and implement protocols.
- Improving the GAPS Database Continued improvement of the GAPS database (Genetic Analysis of Pacific Salmonids) is critical if GSI is to play a key role in salmon management. For example, there are several rivers with Chinook populations in Southern Oregon and Northern California that have potential to assign incorrectly to the Klamath or California/Oregon Coast. Further characterization of stocks within and adjacent to the Klamath basin are recommended to assess potential inaccurate assignment to this region. Funding to sample Lobster Creek, Hunter, Pistol, and Winchuck Rivers has been sought, but to date has not been awarded.
- Expanding GSI Data Collection and Analysis Coast-Wide Implementing GSI to improve weak stock management will require expanded data collection along the West Coast. Expanded data should be used to identify error structure of GSI samples, identify stock distribution patterns useful for fisheries management, determine if, or whether, there are behavioral differences between hatchery and wild stocks, analyze inshore versus offshore hypotheses regarding differential stock migration patterns, and develop/apply technologies to collect and analyze high-resolution genetic data with other information (time, location, and depth of capture, ocean conditions, scales, etc.).
- Collecting and Integrating Oceanographic Information Oceanographic data will be critical for both short and long-term understanding of migration, feeding behavior, and other spatial/temporal characteristics of salmon stocks. Most oceanography data cannot be cost effectively collected by fishing vessels without major disruption of fishing operations. We recommend projects that combine vessel-based data collection with autonomous underwater gliders to record nine types of oceanographic data (temperature, chlorophyll, salinity, oxygen, etc.). The data should be shared in near “real time” between scientists and fishermen. Together with other biological information, the data should be analyzed to develop predictive models of salmon behavior.
- Improving the Design of Vessel Dataloggers The CROOS project showed that existing commercial digital dataloggers are inadequate given the needs for a tough, waterproof, relatively inexpensive, portable and reprogrammable logger that can be easily used on small fishing vessels by skipper and crew. A national workshop should be conducted to examine common needs across fisheries. Partnerships with private manufactures should be evaluated.

- Designing a Multiuse “Real time” Website The prototype GIS-based website constructed during the CROOS pilot project should be fully designed, developed, and tested to ensure it is secure, protects privacy of data providers, produces reliable information, and can accommodate multiple users. Focus groups and market research should be conducted to determine the “real time” needs of different audiences including scientists, managers, fishermen, seafood markets, and the public.
- Using Barcodes, Traceability, and the Website to Improve Salmon Marketing Test markets should be conducted using CROOS project technologies and data that 1) “link” individual harvest information with producer and consumer, 2) enhance market development, and 3) minimize fraud. Markets can provide near “real time” information on river basin of origin, fishing vessel, time-location of capture, and other quality, safety and sustainability data. Research should be conducted to determine the design of digital information systems that meet the needs of fishermen, wholesalers, retailers, food service, and consumers.
- Developing and Testing GSI-based Salmon Management Models Management models should be developed that incorporate GSI information. Management simulations should be conducted with salmon managers in “real time” to evaluate new in-season management approaches (closing areas, redirecting the fleet, revising harvest limits, etc.). Bioeconomic models should evaluate GSI information and potential incentives for improving management of the salmon fishery that increases industry, community, and regional benefits.

Conclusion

Project CROOS is an effort to implement state-of-the-art genetic information for estimating stock distribution and behavior of fish in the ocean. It is founded on principles that stress collaborative teamwork and integrative “real time” science and management. Although this project may herald new approaches for salmon science, management, and marketing, it is also a “precursor” to applied ecosystem-based fishery management that links behavior of a “top predator” (*Homo sapiens*) with fish migration, life histories, and environmental conditions in freshwater, estuarine, and marine habitats. But Project CROOS also provides a foundation for a comprehensive database that can be used to understand weekly, seasonal, decadal, and longer-term oceanic and environmental change and their impacts on fishery stocks. It is our hope that this type of collaborative and integrated project will be used to improve fishery management, conserve salmon stocks, and maximize economic, social, and environmental benefits from wise use of salmon resources along the entire West Coast of North America.