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EVALUATION OF MIGRATION AND SURVIVAL OF JUVENILE SALMONIDS FOLLOWING TRANSPORTATION

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C29147

TABLE OF CONTENTS

	PAGE
EXECUTIVE SUMMARY	3
OBJECTIVES	5
INTRODUCTION	6
METHODS	9
Objective 1	9
Objective 2	13
Objective 3	15
Statistical Analyses	16
RESULTS	18
Objective 1	18
Objective 2	24
Objective 3	25
DISCUSSION	27
ACKNOWLEDGMENTS	30
LITERATURE CITED	31
TABLES	34
FIGURES	36
APPENDICES	50
I.	51
II.	55

C29148

EXECUTIVE SUMMARY

- Following release, radio-tagged yearling chinook migrated 82-90 miles downstream from Bonneville Dam (river mile 145) to river mile 55.5 in 24-118 hours, consistent with a sustained migration speed of 0.7-3.7 miles per hour. Most fish appeared to reach the estuary (river mile 20) 36-48 h after release.

- Migration speed in the lower Columbia River appeared to be influenced by river flows and fish size. Yearling run-of-the-river (ROR) chinook migrated faster than barged chinook released at the same time under identical flow conditions on four of six release dates (5/15, $p=0.0002$; 5/18, $p=0.0000$; 5/23, $p=0.0003$; 5/24, $p=0.0106$; ANOVA), and speed increased over the course of the migration season for both barged and ROR fish ($p=0.0000$ and 0.0126, respectively; ANOVA).

- Large portions of both barged and ROR chinook successfully migrated to the estuary: 74-100% of radio-tagged barged chinook and 65-96% of ROR chinook were observed at or below river mile 55.5.

- Of all radio-tagged chinook released, 14% (0-25% for each release) of barged fish and 20% (4-40% for each release) of ROR fish were observed, and considered mortalities, on colonies of piscivorous birds located on Rice Island or East Sand Island. This suggests that bird predation may be a significant source of mortality for juvenile salmonids passing through the estuary. There was no difference in observed mortality of barged and ROR fish ($p=0.0716$, logistic regression).

- Movement of radio-tagged juvenile chinook in the lower estuary was influenced by the tide, with individuals moving downstream on the ebb tide and holding or moving upstream on the flood tide.

- Migration routes of radio-tagged yearling chinook fell into three general patterns based on two points of divergent routes. All three of these routes allowed fish to remain in freshwater on outgoing tides almost to the mouth of the river. We found that at least 41% of tracked fish remained in the freshwater lens while moving through the lower

C29149

estuary to the ocean. However, it was unclear as to whether these fish were avoiding saltwater or were passively moving in areas of greatest flow.

* Pre-barged fish collected at Lower Granite Dam had significantly higher levels of circulating cortisol (an indicator of stress) than post-barged and/or ROR fish collected at Bonneville Dam, which were not different than each other, on four of ten release dates (4/29, p=0.0338; 5/15, p=0.0079; 5/23, p=0.0191; 5/24, p=0.0004; ANOVA). Several groups of barged and ROR fish were stressed after transport or dam passage, respectively.

* Cursory information based on gill ATPase and bacterial kidney disease levels suggested that smolts taken by avian predators tended (though not significantly so) to be less smolted and more diseased than other fish collected upstream. Pre-barged fish were significantly less smolted than post-barged or ROR fish (p=0.0005, ANOVA). If indeed the smolts taken by birds are less smolted, then a direct link between fish condition and predation exists, and fish condition is something that can be readily managed in order to decrease avian predation. Also, It should be noted that ATPase levels (indicating smoltification) may be affected by death.

* Prevalence of bacterial kidney disease was low throughout the season, with >86% of all fish having zero or barely detectable levels of infection.

* When given a choice, ROR chinook tended to spend more time in saltwater than barged fish. However, comparisons were not done at the same time in the season and saltwater preference tests should be repeated with barged and ROR fish experimentally paired in time to determine whether fish type or time of season affects saltwater entry to a greater degree.

C29150

OBJECTIVES

The goal of this study is to obtain information that will allow us to make recommendations concerning how the fish transportation program may be managed to minimize the loss of fish in the estuary. Specific objectives of the 1998 project year were as follows:

1) Document migratory behavior and survival of transported and run-of-the-river yearling spring chinook in the lower Columbia River and estuary to the ocean.

2) Determine how the development and health status of migrants collected at Snake River dams and transported relates to their behavior and survival in the Columbia River estuary; relate fish quality and performance of barged fish to performance of run-of-the-river fish.

3) Establish the relationship between fish behavior and physiological indicators of fish quality so that monitoring of fish may be predictive of successful ocean entry after release from barges. Examine the possibility that developmental stage at the time the fish reach the estuary (a function of barging) affects survival, such that incompletely "smolted" fish will delay entering saltwater and thereby be more vulnerable to predators in the estuary.

C29151

INTRODUCTION

The success of transportation is determined by the performance of the transported fish following release. Post-release performance of the fish is a function of the quality of the fish at release, which is itself determined by both the condition of the fish at collection, and the effect of transportation. The condition of fish at collection may be extremely important in affecting success of the program. Condition of fish when they reach the dam is extremely variable in terms of their general quality and health. There is not only variation over the course of the run, but also between individuals collected at any one time. We suspect that this variation in fish quality is reflected in the ability of juvenile salmonids to perform various tasks following transportation, such as migration through the lower Columbia River, and successful passage through the estuary.

Prior research has found that 10-30% of radio-tagged juvenile chinook salmon were taken by piscivorous birds in the Columbia River estuary (Schreck *et al.*, 1996, 1997). If this percentage extends to all migrants, than the total number of Columbia River yearling spring chinook taken by birds near the mouth of the river is enormous. It is not known what factors determine the vulnerability of migrating juvenile salmonids to bird predators, although fish behavior in the estuary clearly has the potential to affect the likelihood of being preyed upon. For example, those individuals who swim higher in the water column, or linger in areas containing many birds, may have a greater risk of predation. A number of factors relating to fish health and development (smoltification) have been shown to influence the behavior of juvenile salmonids, and by extension, survival. For example, stress can reduce the quality of outmigrants in terms of predator avoidance (Olla and Davis 1989; Olla et al. 1992, 1995; Mesa 1994; Schreck et al. 1997), preparedness for saltwater entry (i.e., smoltification; McInerney 1964; Schreck 1982, 1992), and disease resistance ability (Maule et al. 1989; Schreck et al. 1993; Schreck 1996; Maule and VanderKooi 1999), which also negatively affects predator avoidance (Mesa et al. 1998), and smoltification (Schreck 1982; Schreck et al. 1985).

We postulate that the quality of migrants reaching the lower Columbia River (either by barge or in-river migration) relates to subsequent behavior and avoidance of predation. Fish quality may particularly relate to delays in seawater entry in the Columbia estuary. Such delays could result in more predation by increasing the amount of time the

C29152

migrants spend in the freshwater lens, where the fish are exposed to large concentrations of birds and may be easier to catch due to the relatively shallow nature of the freshwater lens. Smoltification, disease, and stress status may all influence the amount of time a fish might be "trapped" in the freshwater lens. Although physiological condition influences behavior, the exact relationship between fish quality indices and behavior is not always intuitive. It has been demonstrated that seawater entry behavior may lag weeks behind physiological readiness to enter seawater as determined by saltwater challenge tests; such tests may be deceptive in that they measure the ability of smolts to tolerate seawater, but not the likelihood that they will actually choose to enter seawater. Once the linkages between fish quality and behavior are understood, the opportunity exists to manage the migration of juvenile salmonids through the Columbia Basin hydropower system to maximize downstream survival. Specifically, how fish are "delivered" to the lower river could affect their ability or propensity to migrate. Hence, delivery systems (i.e., barging, passage of dams, or spill regulation) are tactics that could play various roles in affecting ocean entry success at various times throughout a run.

At present we have very limited information concerning detailed migration behavior of juvenile chinook salmon in the estuary near the Columbia River's mouth. Increased understanding of smolt behavior in the estuary is needed to determine what may be done to minimize avian predation. We did this in 1998 through a variety of work. Radio-tracking of different groups of fish (barged and run-of-the-river) throughout the outmigration season was our primary objective. Radio-tags that transmit depth information were used this year, in addition to standard tags, to better understand vertical distribution of fish in relation to water chemistry (primarily salinity) and avian predators. The observed behavior and survival of these fish was compared to hydrochemistry data taken in the estuary and physiological condition of other fish sampled at dams at the same time as fish were tagged. Smolts taken as prey items by avian predators were collected directly from birds to understand whether the condition (smoltification and disease levels) of these smolts was different from the general population of outmigrants. Because transporting the smolts further downstream is an option for management, we also performed an experiment looking at how this might affect smolt behavior by simulating transport, and therefore inducing increased stress levels, to the estuary. Finally, we ran laboratory experiments looking at how fish type

C29153

(barged and run-of-the-river), time of the season, smoltification levels, and BKD levels might affect saltwater entry and survival.

METHODS

Objective 1. Document migratory behavior and survival of transported and run-of-the-river yearling spring chinook in the lower Columbia River and estuary to the ocean.

The migration behavior of yearling spring chinook in the lower Columbia River downstream from Bonneville Dam was documented using radiotelemetry. We examined migration of both barged fish collected at Lower Granite Dam on the Snake River and run-of-the-river (ROR) yearling chinook collected at Bonneville Dam. Radio transmitters were purchased from **A**dvanced **T**elemetry **S**ystems (**ATS** - Isanti, Minnesota) and operated on the 148-149 megahertz bandwidth. Standard transmitters and depth transmitters were used this year. Standard tags weighed approximately 1.2 g in air and were designed to transmit continuously for a minimum of 7 days. Two tags were placed on each frequency, and were distinguished by different beeping rates (approximately 40 or 60 beeps per minute). This strategy allowed us to cut in half the number of frequencies to be scanned during tracking. Depth tags weighed 1.9 g in air. Before use, all tags were checked for proper functioning following a 24 h immersion in water. To avoid compromising the performance of the fish (*sensu* Winter, 1983), only individuals 18 g in weight (approximately 12.5 cm fork length) or greater were tagged with standard tags and 27 g or greater with the larger depth tags .

Fish to be released from barges were collected from the fish separator at the Lower Granite Dam Juvenile Fish Facility. Individuals were anesthetized in 50 mg/l tricane methanesulfonate (MS222) buffered with 100 mg/l $NaHCO_3$, after which the transmitter was implanted into the stomach (Ward and Miller, 1988). Following tagging, fish were placed in 33 gal live wells (6-7 fish/livewell) and allowed to recover. Livewells were secured in the stern barge holds the night before the start of the trip. Tagged fish were held in the livewells for approximately 12-16 h to monitor for regurgitation of the transmitters or other problems, then released into the barge compartment shortly before the barge departed Lower Granite Dam. For three of 10 releases, the livewells were placed on the barge dock overnight because the barge was unable to dock at the fish facility due to high flows in the tailrace. In the morning, spill was temporarily reduced to allow the barge to dock at the Fish Facility and the livewells were secured in the barge compartments. The livewells remained secured aboard the barge until arrival at the Little

C29155

Goose Juvenile Fish Facility, where the fish were released into the barge compartments. This gave the fish an additional 4 hours or more to recover from any disturbance resulting from moving the livewells. We believe that fish left in livewells on the dock overnight were not different in condition than fish placed immediately into livewells in the barge holds. As the barge reached Bonneville Dam, an observer was placed on board to verify that all tags were transmitting and to record the release time and location. Up to 20 barged fish were tagged with standard transmitters on 10 dates, and up to 6 barged fish were tagged with depth transmitters on 4 of these 10 dates, in order to sample the various components of the spring run (Figure 1A). A more detailed description of numbers and characteristics of radio-tagged fish is contained in Table 1. We termed work for all *Objectives* and groups of fish for each release a "rotation" in tables.

Later in the migration season releases of ROR fish were paired with concurrent releases of barged fish. Fish radio-tagged at Bonneville Dam were released on six dates in May and early June of 1998. Timing of these releases was designed to coincide with peak passage of Snake River juvenile salmonids past Bonneville Dam, so that we could obtain the highest proportion of Snake River fish for tagging. On the dates we tagged, hatchery chinook were passing the dam (Figure 1B), but the exact origin of any given individual implanted with a radio-tag was unknown. Up to 20 ROR fish were tagged with standard transmitters on 6 dates, and 5 ROR fish were tagged with depth transmitters on 3 of the 6 dates. A detailed description of the circumstances of the Bonneville Dam releases is given in Table 1.

Run-of-river yearling chinook to be radio-tagged were obtained at Bonneville Dam First Powerhouse DSM and Second Powerhouse DSM as part of the daily sample collected by NMFS personnel for smolt monitoring purposes. The tagging procedure was identical to that used for barged fish. At release, fish were placed back into the first powerhouse juvenile bypass system. In an effort to standardize the arrival time of barged and ROR migrants in the estuary (which might influence risk of predation from birds), releases at Bonneville Dam were made after the transport barge carrying the paired release group of radio-tagged fish had passed the Bonneville Navigation Lock. Since we have found that ROR migrants often travel through the lower river faster than barged migrants, ROR fish were released from the First Powerhouse DSM (river mile 145.3) approximately 1 h after the barge released fish (river mile 137.9-139.5) on all dates. On the day of each

C29156

release, fish were released from the barge or DSM between 1605 - 0215 h. Timing of tagging and releases between dams for each of the 10 releases is summarized in Table 2.

Following release the locations of radio-tagged individuals were monitored from an aircraft using ATS Challenger 2000 and Lotek SRX_400 (for depth tags) radio receivers. Location data was collected daily for a period of 2-4 days starting on the first or second day following release, depending on river flows. The aircraft used for tracking was equipped with one ATS and one Lotek receiver, each connected to antennas mounted on either wing strut. Flights were conducted at an altitude of 500 ft with an air speed of approximately 100-110 miles per hour. Once a radio signal was detected, the plane circled until its precise location could be determined. The effective distance at which we could detect the tag ranged from approximately 0.25 miles to 1 mile. Due to the extreme width of the river in the estuary our search pattern was a series of north/south transects spaced at 0.5 mile intervals. The transects were used from the mouth of the river up to river mile 30.

The progress of radio-tagged individuals was also recorded at a fixed monitoring station located upstream at river mile 55.5, near the community of Bunker Hill, Washington. At this location the river makes a wide bend and the shipping channel abuts a series of cliffs on the Washington shoreline. It has been our experience that juvenile chinook often are located in or near the shipping channel, and thus can be expected to pass near the Washington shore at this location. Three 6-element YAGI antennas were placed approximately 100 ft above river level on top of a cliff that dropped directly to the water. The antennas were pointed directly to the far side of the river, and were each connected to an ATS (2) or Lotek (1) receiver. The same list of frequencies was loaded into each receiver, but scanning was staggered between the receivers so that the effective time to scan all the frequencies was reduced. This technique also allowed us to have two receivers scanning at all times while the third one could be used to monitor a passing fish. The monitoring station was staffed 24 hours a day during periods when radio-tagged fish were migrating.

Detailed behavior of individual migrants was also examined. Two 20 ft Alumaweld boats, each equipped with a 4-element Yagi antenna and an ATS or Lotek receiver,

C29157

were used to continuously monitor the behavior of barged and ROR individuals in the lower estuary (below river mile 22). As fish were passing through the estuary, the two boats tried to track fish of different types (barged or ROR) to get equal representation, and gave priority to tracking depth-tagged fish. Once tracking began we attempted to keep the boat close to the fish at all times, and used a GPS (Global Positioning System; Garmin GPSMAP 230) unit to obtain and record the location of the boat at approximately 10 minute intervals. Typically, tracking began in the morning and continued until (1) the fish entered seawater, (2) the fish could not be followed because of shallow water or the signal was otherwise lost and could not be reacquired after set search limits, (3) weather or other factors made continued tracking unsafe or (4) the fish was tracked for over 10 hours.

Water quality data was collected during tracking in order to determine the immediate environmental conditions associated with the fish. A Hydrolab Corporation Datasonde IV and a YSI model 85 DO/salinity meter were used to measure water quality parameters such as salinity, temperature, and dissolved oxygen. Readings were taken once per hour unless current or wave conditions or possible loss of the fish being tracked precluded stopping for measurements. Data was collected at five depths for each location: the surface, the bottom, and ¼, ½, and ¾ of the total depth (determined by depth finders on the boats).

In order to get better estimates of mortality due to avian predators, one datalogging station was set up on both Rice and East Sand Islands to monitor for radio-tags that showed up on the islands. This was meant to confirm and supplement the data collected by the aircraft over the islands. A Lotek receiver in a lockbox with a 12 V marine battery was placed on Rice Island and on channel marker Green #3 off the west tip of East Sand Island (US Coast Guard approved) with 4-element Yagi antennas. These stations were set up prior to arrival of fish in the estuary and data was downloaded after fish had moved through. Due to both equipment and/or user error, we were not able to get data from both islands on every rotation.

We also ran an experiment intended to simulate the effects on fish of transportation by barge to the estuary, thus eliminating in-river recovery time of fish released at Bonneville. We had two releases of 6-8 fish (see Table 1) for this simulation experiment.

C29158

Fish were taken off of the barge at Bonneville, radio-tagged, placed in aerated livewells, and transported to Astoria for holding and release. Fish were held at the US Army Corps of Engineers dock in Astoria until release. Release occurred at river mile 24.5 off Miller Sands Island (upstream of Rice Island) when radio-tagged fish used for our normal rotational radio-tracking (released from the barge at Bonneville) were passing through the estuary (~ 48 h after collection of fish for the simulation). At release, one boat tracked a fish from the group of enhanced-stress fish and the other boat tracked a fish released from the barge at Bonneville. The aircraft flew twice a day during these rotations to get more precise counts and locations of all fish in the estuary.

Objective 2. Determine how the development and health status of migrants collected at Snake River dams and transported relates to their behavior and survival in the Columbia River estuary; relate fish quality and performance of barged fish to performance of run-of-the-river fish.

Health status and smoltification were determined in juvenile chinook salmon migrants collected at the same time and place as radio-tagged fish described in *Objective 1.* Barged yearling chinook were collected from the Lower Granite Dam Juvenile Fish Facility (pre-barge sample) and from the barge shortly before release (post-barge sample) which made it possible to compare the quality of fish before and after transportation. At Lower Granite Dam, fish were dipnetted from the flume immediately downstream of the separator. The post-transport sample was collected form the barge while it was in the navigation lock at Bonneville Dam, approximately 1 hour before release. Fish were obtained on the barge by pulling a lift net in the same compartments that held radio-tagged fish. Run-of-the-river yearling chinook were also collected at Bonneville Dam First and Second Powerhouse DSM from NMFS personnel when ROR fish were radio-tagged. A description of fish collected for physiological sampling can be found in Table 1, and a summary of the timing for these samples can be found in Table 2.

Fish were immediately killed with an overdose of anesthetic (200 mg/l MS222 buffered with 500 mg/l $NaHCO_3$). Length, weight, and the presence of fin clips was then recorded for each fish. The fish were bled by severing the caudal peduncle, after which whole blood was collected into ammonium-heparinized capillary tubes. Whole blood

C29159

was centrifuged, and the plasma removed and immediately frozen on dry ice. Plasma was stored at -80 °C. Gill filaments were collected into a buffer solution (Zaugg, 1982) and frozen on dry ice. Kidney tissue of each fish was removed and frozen. Finally, each fish was autopsied and Goede Index was recorded as a measure of fish quality (Goede and Barton, 1990).

We measured plasma cortisol concentration as an index of stress. Plasma cortisol is a widely accepted measure of the primary (endocrine) response to stress (Mazeaud et al., 1977). Thawed plasma samples were assayed for cortisol using a radioimmunoassay (Foster and Dunn, 1974) as modified for use with salmonid plasma (Redding et al., 1984). Degree of smoltification was estimated by measuring gill Na^+/K^+ ATPase. Gill samples were sent to Bill Gale and Robin Schrock (USGS-BRD Northwest Science Center, Columbia River Field Station) for analysis. Kidneys were sent to Ron Pascho and Diane Elliot (USGS-BRD Northwest Science Center, Seattle) to test for the presence of bacterial kidney disease. Presence and severity of infection was measured using the technique of Pascho *et al.* (1993).

Yearling spring chinook were collected on most barge trips in which radio-tagged groups were released (see Table 1). This allowed us to document the health condition for each cohort of radio-tagged fish and measure differences in the response to transportation over the migration season. Health and smoltification indicators were compared to migration behavior (primarily migration speed) and survival of the corresponding radio-tagged groups in an effort to determine if these indicators were predictive of post-release performance.

In addition to the fish sampled while radio-tagging, Dan Roby (Oregon Cooperative Fish and Wildlife Research Unit) and Ken Collis' (Columbia River Inter-Tribal Fish Commission) crew on Rice Island collected 98 fish from Caspian terns as they brought the fish prey back to Rice Island. Gills and kidneys were collected and analyzed from these fish to see if fish taken by avian predators were different from the general population physiologically.

Objective 3. Establish the relationship between fish behavior and physiological indicators of fish quality so that monitoring of fish may be predictive of successful ocean

C29160

entry after release from barges. Examine the possibility that developmental stage at the time the fish reach the estuary (a function of barging) affects survival, such that incompletely "smolted" fish will delay entering saltwater and thereby be more vulnerable to predators in the estuary.

A system for testing salinity preference in a vertical salinity gradient was used. The experimental setup consisted of two 200 L rectangular fiberglass tanks (1.83 x 0.66 x 0.60 m) with acrylic windows in front that were placed in a quiet room and visually isolated by black plastic curtains. The tanks were exposed to a diffused 20W fluorescent light which provided even light intensity over the surface of each tank, with photoperiod adjusted to ambient conditions. During acclimation, flow-through well water was supplied to the tanks. At the start of a test, approximately 100 L of saltwater (Instant Ocean™, 30 ppt) was introduced to the bottom of the tank over a period of approximately 1 hour to establish a salinity gradient. The window of each test tank was marked to show the final dividing line between fresh and saltwater.

Fish to be used for testing were collected at Bonneville Dam and transported to Oregon State University's Oak Creek Laboratory, where 12-13 fish were placed in each test tank and allowed to acclimate for 48 h. Following acclimation, position of fish in the water column was observed for 15 minutes and then saltwater was introduced. Position of fish in the water column was noted every five minutes thereafter for the next 60 minutes and every 10 minutes for the next 70 minutes (150 minute total). At the completion of this test, the freshwater was drained from the tanks and the fish were forced into saltwater for 24 hours ("saltwater challenge"; Blackburn and Clarke, 1987). After this time, survival was noted and fish were sacrificed for measurement of fish condition as described in *Objective 2*.

The purpose of this work was to compare behavioral response to salinity with physiological indices of smoltification and to the behavior of radio-tagged cohorts as they travel through the estuary and into saltwater. The dates, numbers, and types of fish collected for these tests are given in Table 1.

Statistical Analyses

C29161

Statistical analyses were performed on the following groups of fish:

1. "telemetry" fish - barged and ROR radio-tagged spring chinook (Objective 1)
2. "physiology" fish - pre-barged, post-barged, and ROR spring chinook collected for physiological sampling (Objective 2)
3. saltwater preference fish – barged and ROR spring chinook collected for saltwater preference assessment (Objective 3), and
4. "avian prey" fish – spring chinook collected from Caspian terns on Rice Island (Objective 2).

Data for telemetry and physiology fish were compared both within fish types (i.e., barged and ROR fish) between different releases and within different releases between fish types. If the same measure was taken for both telemetry and physiology fish (e.g., length), then all types from both groups were compared within releases because they were collected and measured on the same date and we wanted to determine if our radio-tagged fish were biased from the general population due to tag:body weight constraints of tagging. Saltwater preference fish were not included in these comparisons because they were collected and measured at different times. Saltwater preference fish were compared between dates only, because different types (barged or ROR) of fish were not assessed on the same dates. Avian prey fish were compared to physiology fish, though the physiology fish were pooled across releases for these comparisons.

A single-factor ANOVA was used for most comparisons. If there were only two levels in the comparison, this test was a t-test. If there were less than 30 fish in any comparison, a Kruskal-Wallis comparison of medians (nonparametric ranks) was used. For these tests, if a significant factor effect was found, differences between levels were assessed by Fisher's least significant difference (LSD) procedure at the 95% level. For comparisons of proportions without any replication within levels (i.e., BKD presence in physiology and avian prey fish), a χ^2 test was used for tests with greater than two levels and a Fisher's Exact Test was used for comparisons with two levels. Differences between levels were assessed by an analysis of means test. For comparison of mortality due to avian predators (i.e., survival) and our recapture efficiency of telemetry fish, a logistic regression was used to analyze the proportion data. The test used for the logistic regression was the χ^2 statistic, unless the data were over- or

C29162

underdispersed (determined if $P_D < \alpha_{one\text{-}tailed} = 0.05$, where P_D is the P-value for over- or underdispersion), in which case the standard errors were adjusted and the more conservative F statistic was used. Finally, for the saltwater preference fish, all comparisons were made with the Kruskal-Wallis test, including comparisons of proportions (i.e., BKD presence and proportion of fish in saltwater at certain times, which had replication within levels), though the proportion data were arcsine-transformed for analyses (though not presentation). Simple linear regressions were used to determine relationships between different factors.

C29163

RESULTS

Objective 1. Document migratory behavior and survival of transported and run-of-the-river yearling spring chinook in the lower Columbia River and estuary to the ocean.

In only one release (4/29; p=0.023, ANOVA) were radio-tagged fish heavier than comparable fish sampled for physiological measures (i.e., barged [telemetry] compared to pre- or post-barged [physiology] and ROR [telemetry] compared to ROR [physiology]), which were taken randomly without any size limit (Figure 2A; see Appendix II for all test results). On no dates were radio-tagged fish longer than comparable fish sampled for physiological measures (Figure 2B; see Appendix II for all test results). The lack of size differences between tagged and untagged spring chinook indicates that our telemetry results were not biased to a portion of the population. There were differences in weight and length between radio-tagged barged and ROR fish however. On one of six release dates, barged fish weighed less than ROR fish (5/15; p=0.0006, ANOVA; Figure 2A; see Appendix II for all test results) and on five of six dates, barged fish were shorter than ROR fish (5/15, p=0.0000; 5/23, p=0.0331; 5/24, p=0.0137; 5/30, p=0.0014; 6/1, 0.0023; ANOVA; see Appendix II for all test results). There were no differences in ROR fish weight or length between releases (p=0.6461 and 0.1522, respectively; ANOVA; Figure 2A and 2B; see Appendix I for all test results). There were differences between weight and length of barged fish between releases (p=0.0001 and 0.0023, respectively; ANOVA; Figure 2A and 2B), with fish generally getting larger through time (see Appendix I for differences between releases).

Following release, radio-tagged yearling chinook migrated 82-90 miles downstream to the monitoring station in 24-118 hours, consistent with a sustained migration speed of 0.7-3.7 miles per hour (Figure 3A). Yearling ROR chinook migrated faster than barged chinook released at the same time under identical flow conditions (Figure 3B) on four of six release dates (5/15, p=0.0002; 5/18, p=0.0000; 5/23, p=0.0003; 5/24, p=0.0106; ANOVA; see Appendix II for all test results). Speed generally increased over the course of the migration season for both barged and ROR fish (p=0.0000 and 0.0126, respectively; ANOVA; see Appendix I for differences between releases). Migration speed of barged ($p<0.0001$, $r^2=0.94$; regression) and ROR ($p<0.003$, $r^2=0.91$; regression) fish in the lower Columbia River was influenced by river flow (Figure 4).

C29164

which generally increased through time. Difference in travel time between barged and ROR chinook may be the result of some difference in fish condition; ROR fish were larger than barged fish on five of six dates (see above). Mean size and migration speed of each release of the different fish types (barged and ROR) were significantly related ($p=0.0007$, $r^2=0.5694$; regression).

Large portions of both barged and ROR chinook successfully migrated to the estuary: 74-100% of radio-tagged barged chinook and 65-96% of ROR chinook were observed at or downstream of the exit monitoring station at river mile 55.5 (Figure 5A). Overall, for all releases of both barged and ROR fish, significantly more barged than ROR fish were detected in the estuary ($p=0.0030$, logistic regression [χ^2]; Figure 5A), though the data were marginally over-dispersed ($P_{OD}=0.095$) and, if analyzed in a more conservative fashion, this difference did not exist ($p=0.0822$, logistic regression [F]; Appendix I). There were no trends for either barged or ROR fish (analyzed separately) detection rates between releases ($p=0.7882$ and 0.3763, respectively; logistic regression; Figure 5A; Appendix I). Radio-tagged fish that were never observed accounted for 0-26% of barged fish and 4-35% of ROR fish. All tags were known to be functioning immediately before release, therefore undetected fish most likely resulted from: (1) radio-tags that were regurgitated during the barge trip and sank out of radio range when the barge was emptied, (2) fish that were dead at release and sank out of radio range, (3) fish that were taken by predators after release and whose remains were deposited out of radio range, or (4) individuals that migrated successfully but went undetected. Regardless of the reason, certain individuals were never observed, it was assumed for data analysis purposes that all tags were inside fish, transmitting radio signals, and detectable by radio receivers. If this assumption was false, then the true sample size of observable radio-tagged fish was reduced and the relative proportion of fish reaching the estuary was higher than reported.

Of all radio-tagged chinook, 0-25% (14% for all releases) of barged fish and 4-40% (20% for all releases) of ROR radio-tagged fish were observed in colonies of piscivorous birds on Rice Island or East Sand Island by aircraft, boats, or dataloggers, and were considered mortalities (Figure 5B). Overall, for all releases of both barged and ROR fish, the proportion of fish found in bird colonies did not differ between barged and ROR fish ($p=0.0716$, logistic regression; Figure 5B). There were no trends for either barged

C29165

or ROR fish (analyzed separately) mortality rates between releases (p=0.3982 and 0.4987, respectively; logistic regression; Figure 5B; Appendix I). When barged and ROR chinook data were pooled, mortality ranged from 5-29% for each release, and 17% for the entire season. Distribution of mortalities between the two islands is given in Figure 6. Also included in Figure 6 are the data from the fish used in the experiment to simulate the stress of barge transportation to the lower estuary; their behavior was noticeably different from the barged fish to which they were compared. A greater proportion of these fish ended up on East Sand Island than the other groups, and a disproportionately smaller number (0%) ended up on Rice Island. This may have been a result of behavioral differences of these stressed fish which we did not observe and which made them more vulnerable to cormorants than terns, which exhibit different feeding behaviors. Vulnerability of salmonid migrants could be increased by delay in seawater entry (increasing the exposure time to high concentrations of predators in the estuary), swimming higher in the water column, or other behavior that causes them to be more accessible to birds.

Travel time of migrants could conceivably influence survival in the estuary by determining the time of arrival of fish in areas where birds forage. If migrants were to reach the lower estuary on an ebb tide during hours of darkness, they may traverse many of the areas of highest predation pressure when birds are not foraging. There may be a link between timing of arrival in the estuary and vulnerability to predation based on light levels; if a relationship does exist, timing of smolt arrival in the estuary is something that can be easily managed to increase smolt survival.

Migration routes of radio-tagged yearling chinook observed from the aircraft (Figure 7) and by the boats (Figure 8) fell into three general patterns based on two points of divergent routes. Fish made one "decision" slightly upriver from Rice Island; some stayed within the main shipping channel south of the island, while others followed the old shipping channel north of the island ("North Channel"). Those that were in the North Channel stayed in the Northern part of the estuary (Washington side) until they reached the ocean (migration route 1). Those that remained in the shipping channel had another point of divergence near Tongue Point. Again, some stayed in the shipping channel all of the way to the mouth of the river (migration route 2); however, most crossed from the Oregon to the Washington side under the Astoria Bridge and entered the ocean from the

C29166

northern side of the estuary (migration route 3). These large-scale migration patterns are visible in Figures 7 and 8. The clusters of points on and around Rice and East Sand Islands in Figure 7 represent transmitters heard on the islands and were assumed to be fish consumed by avian predators. Barged (Figure 8a) and ROR (Figure 8b) radio-tagged fish followed each of the three large-scale migration routes.

Figure 9 illustrates two typical tracking days early (3 May) and late (27 May) in the 1998 outmigration. Early in the season we generally started tracking fish near Rice Island and were able to follow them for at least one tidal cycle (>8 h). On 3 May, we tracked two fish, one with each of our boats, and their routes are the two upriver routes on the map. Note that these two fish chose two different migration routes of the three described above. One of the routes is enlarged to illustrate movement of the fish during outgoing, slack, and incoming tides; movement was passive with the current and the fish moved non-linearly when tracking started on a slack tide, moved linearly downstream when the tide was going out, stopped linear movement during the change of tide, and moved linearly upstream when the tide started to move in. Net movement of this fish was minimal compared to the other fish depicted on this map. All fish that did not make it out of the estuary during one tidal cycle held position or moved upstream on the incoming tide. Later in the season, we generally tried to locate radio-tagged fish on a slack tide below Tongue Point, OR and near the Astoria Bridge. Fish picked up in this area generally made it to the mouth of the river or into saltwater in one tidal cycle, as illustrated by the three downriver tracks of 27 May 1998. We believe it typically took fish 2-3 tidal cycles once they reached Miller Sands Island (river mile 24.5) to enter the ocean. We feel this depended on river discharge; earlier in the season when discharge was lower (e.g. 3 May), it may have taken closer to 3 tidal cycles to reach the ocean, whereas later in the season (27 May) fish were moving more quickly through the estuary when discharge was higher.

Tracking of depth-tagged fish posed a few problems for us. We were able to acquire six of 34 depth-tagged fish (out of a possible 24 boat days when depth-tagged fish were in the estuary) with our boats throughout the season. Of the six fish tracked with depth-tags, three gave us measurements that were reasonable and all indicated a migration depth less than 4 m. Unreasonable readings indicated fish moving through sediment below the water column, which was measured by depth finders. Improper detection may

C29167

have been due to malfunctioning tags or receivers, or by not having sufficient signal strength to get a proper reading; the high rate of inaccurate readings make the reasonable ones questionable.

In order to get an idea of tern feeding range, we mapped all fish tracked by plane or boat which made it past Rice Island and were then detected back on the island and assumed to be mortalities. Fish upstream of Rice Island were not plotted because we do not know exact times fish arrived on the island in relation to our sightings. However, those detected downstream were known to get at least that far before being taken. Three fish (two detected by plane and one by boat) were tracked and then taken by terns (or cormorants, which have a small colony on Rice Island). These data indicate terns can forage from Rice Island out to the mouth of the river, 20 miles away. This coincides with other findings of tern range (Don Lyons, Oregon Cooperative Fish and Wildlife Research Unit, OSU, pers. comm.).

From the water quality data taken by boats as they were tracking fish, we determined that a definite saltwater "wedge" exists in the estuary (Figure 11). Figure 11 represents maximum salinity taken at all points by both boats in the estuary throughout the entire season. Therefore, they were a biased view to what the fish were encountering in particular locations and should not be taken to represent the salinity of the estuary at all times, within a day or the season. Also, some locations' (e.g., Baker and Grays Bays) values were extrapolated from nearby data. The maps generally represent the salinity of the estuary on outgoing and slack tides, which was when we primarily tracked fish. At these times, freshwater at the surface extended almost to the mouth of the estuary (Figure 10A), which was why we were able to track radio-tagged fish so far out (radio signals attenuate in even low concentrations of saltwater). At 4 m, at and below which we found no depth-tagged fish, freshwater did not extend as far, though there was still no full-strength saltwater (Figure 10B). However, at the bottom, saltwater extended almost to the Astoria Bridge (Figure 10C). Overlaying the migration routes of fish tracked by boat onto the salinity profiles at different depths revealed that the fish we tracked were most likely at the surface where freshwater was located, at least below the Astoria Bridge where sub-surface salinity increased (Figure 10D). We can infer the ones tracked below the Astoria Bridge were at the surface, even though many did not have depth tags, because freshwater, which allows radio transmission, was only at the

C29168

surface. Fish remaining at the surface were more vulnerable to tern predation. The reasons fish remained at the surface are unknown. They may have been avoiding saltwater as long as possible (i.e., an active "choice") because they were not at the proper level of smoltification, or they may have simply been moving passively with the greatest outflow. We have evidence supporting both eventualities; laboratory tests suggests that less smolted fish prefer freshwater (see *Objective 3*) and Figure 4 suggests fish move passively.

In addition to not knowing whether fish were "choosing" to remain in freshwater, our sampling was biased towards fish that remained in freshwater, because we could continue to receive radio-signals and track the fish. To understand what percentage of fish may have remained in freshwater, we analyzed boat tracking data below the Astoria Bridge where saltwater was present to get an idea of the number of fish we were able to track to East Sand Island, a point close to the mouth of the river which had both freshwater and saltwater (see Figure 10). Seventeen fish were tracked downstream of the Astoria Bridge (river mile 12.5) by boat. We were able to track seven (41%) of these to East Sand Island (river mile 5). Thus, if we assume the fish we were not able to track to East Sand Island were lost because they entered saltwater (which is a large assumption given the tracking conditions in the lower estuary), at least 41% of the fish remained in the freshwater lens while moving through the lower estuary to the ocean.

Objective 2. Determine how the development and health status of migrants collected at Snake River dams and transported relates to their behavior and survival in the Columbia River estuary; relate fish quality and performance of barged fish to performance of run-of-the-river fish.

When plasma cortisol levels of pre-barged, post-barged and ROR yearling chinook were compared, pre-barged fish had significantly higher cortisol levels than post-barged and/or ROR fish, which were not different from each other, on four release dates (4/29, $p=0.0338$; 5/15, $p=0.0079$; 5/23, $p=0.0191$; 5/24, $p=0.0004$; ANOVA; Figure 11A; see Appendix II for all test results). Within each fish group (i.e., pre-barged, post-barged,

C29169

and ROR), there were no differences through time (p=0.1611, 0.2758, and 0.1004, respectively; ANOVA; Appendix I). Gill Na+/K+ ATPase activity levels of pre-barged, post-barged and ROR yearling chinook were compared. Post-barged fish had significantly higher ATPase activities than pre-barged fish on two release dates (5/2, p=0.0065; 5/7, p=0.0118; ANOVA; Figure 11B; see Appendix II for all test results). Within each fish group (i.e., pre-barged, post-barged, and ROR), there were no differences through time (p=0.2540, 0.1626, and 0.3036, respectively; ANOVA; Appendix I). Prevalence of bacterial kidney disease was low throughout the season, with >86% of all fish having zero or low levels of infection. When presence and absence of BKD for individual fish was compared, the only difference for all release dates was that one sample of post-barged fish had a lower infection rate than pre-barged fish (5/7, p=0.0198; Fisher's Exact Test; Figure 11C; see Appendix II for all test results). Within each fish group (i.e., pre-barged, post-barged, and ROR), only pre-barged fish showed a difference through time (p=0.0175, 0.0618, and 0.1918, respectively; ANOVA; Appendix I), when fish on one date had a lower infection rate than all other dates (5/23; χ^2 Analysis of Means; Appendix I). BKD levels were low and consistent throughout the 1998 outmigration, which contrasts with other years when BKD levels were higher and had a greater impact on fish condition.

When the fish sampled for physiological analyses were pooled by group (i.e., pre-barged, post-barged, and ROR) and then compared to fish taken by avian predators, several differences between groups were apparent. First, pre-barged and ROR fish weighed more overall than post-barged fish (p=0.0000, ANOVA; Figure 12A; Appendix II), although only ROR fish were longer than pre-barged, post-barged, and avian prey fish (p=0.0000, ANOVA; Figure 12B; Appendix II). ATPase levels of post-barged and ROR fish were higher than pre-barged fish, and avian prey fish were no different from any of these groups (p=0.0005; ANOVA; Figure 12C; Appendix II). There was no difference in BKD presence between groups (p=0.2203; ANOVA; Figure 12D; Appendix II). Although avian prey fish were not different than other groups statistically for these measures, they tended to be smaller, less smolted, and with higher infection levels (Figure 12). There may have been no difference for these fish because the sample size of fish from avian predators was so small (see Appendix II, "N" values). If this trend were investigated further in future years, and became significant with larger sample sizes, this has important consequences for the issue of avian predation on salmon

C29170

smolts in the estuary, and supports our hypothesis that condition affects behavior and predation susceptibility. Fish condition is also something that can be managed to therefore decrease mortality due to avian predators in the estuary. We should point out though, that ATPase levels can be affected by death; the state of samples from these fish taken by avian predators still needs to be analyzed.

Objective 3. Establish the relationship between fish behavior and physiological indicators of fish quality so that monitoring of fish may be predictive of successful ocean entry after release from barges. Examine the possibility that developmental stage at the time the fish reach the estuary (a function of barging) affects survival, such that incompletely "smolted" fish will delay entering saltwater and thereby be more vulnerable to predators in the estuary.

Saltwater preference experiments indicated no significant differences between experimental dates for fish weight, length, or BKD presence (p=0.1017, 0.1801, and 0.8510, respectively; Kruskal-Wallis Test; Figure 13; Appendix I). There was also no difference between groups in the experimental response variables, proportion of fish in saltwater at 60 and 120 minutes (p=0.6201 and 0.1229, respectively; Kruskal-Wallis Test; Figure 14; Appendix I). However, ROR fish tested on the last date (5/31) tended to be larger and have a greater proportion in saltwater than the barged fish tested on 5/1 and 5/17. The small replicate size (N=2) for this experiment may be the cause of a lack in statistically significant results; replication should be increased in future years. This trend indicates that fish later in the season, or ROR fish (we could not determine which because barged and ROR fish were not paired in time; no barged fish were available on 5/31), were better prepared to enter saltwater. In the future, direct saltwater preference comparisons between barged and ROR fish, with better controls on fish size, would help us understand whether time of season or dam passage method increases the likelihood of fish to enter saltwater immediately. They would also help to make sound management decisions regarding timing of releases of these fish.

When the saltwater preference test was concluded, the fish were subjected to a saltwater challenge test (see *Methods*). For all three experimental dates, there were no mortalities over the 24 h period of the saltwater challenge.

C29171

DISCUSSION

Timing of yearling chinook smolt arrival in the estuary seems to be the most important factor affecting their survival. Survival is determined by two main factors in the estuary: avian predators and saltwater adaptability/entry. Timing is therefore important on two scales: the smolt has to be properly prepared for arrival on a physiological time scale for saltwater entry, and the smolt should also arrive at a daily or tidally beneficial time to avoid predation. These two timings may also be inter-related. If a smolt is ill prepared to enter saltwater, it may behave in such a manner as to keep it more vulnerable to avian predators. On the other hand, the hydrodynamics of the estuary may give smolts little choice to avoid saltwater if not prepared to be in it. Thus, even if they avoid avian predators, they may be "flushed" into saltwater in a condition that does not allow them to survive. Although we did not observe any mortality of chinook forced into saltwater in the challenge tests, we did not measure behavioral effects of this stressed situation and the experiments were not done in full strength saltwater (removing freshwater disturbed the cline and caused some mixing). The experiments should also be repeated and run for a longer period of time to understand long-term effects of forced saltwater entry.

Our research this year and in previous years supports these findings. A link between fish smoltification and bird predation may exist, in that smolts taken by avian predators tended (though not significantly) to be less smolted than fish released from Bonneville Dam; however, this link needs to be more firmly established with further sampling. If it does exist, the likely conclusion from this is that these fish were avoiding entry into saltwater by remaining at the surface of the water column, thus making them more susceptible to avian predators. Saltwater preference testing, as conducted here and in other research (Seals and Schreck, unpublished data), is suggestive that more smolted fish are more likely to enter saltwater. Thus, less smolted fish may avoid saltwater and remain in freshwater, which we have demonstrated is at the surface in the estuary. Boat tracking in the estuary indicates that *at least* 41% of radio-tagged fish remain in freshwater as long as possible.

There were very few differences in this year, or previous years, between ROR and barged fish. The only observable difference was for migration speed, and this was mostly due to the artificially imposed (by us) size difference between the two groups.

C29172

Migration patterns and saltwater entry in the estuary were not different. Cortisol, ATPase, and BKD levels were not different between post-barged and ROR fish sampled at Bonneville at the same times. Experimentally, there were major differences between barged and ROR fish in the saltwater preference tests, but the fact that tests were done at different times in the outmigration may account for these differences. However, within the barged and ROR groups we do see a large amount of variability in physiological condition. Thus, although the groups may not be different, individuals certainly are. This argues that a whole system approach to management should be used, which gets us back to the issue of timing of smolt arrival in the estuary.

If smolt arrival in the estuary is timed correctly, a significant amount of mortality may be avoided. Better smolted fish prefer saltwater and will therefore enter it more quickly, avoiding predation. We have also demonstrated that larger fish migrate faster and can presumably move through the estuary faster and avoid predation. Delivery systems of fish, both barged and ROR, can easily be managed to increase the smoltification level and size of fish that are outmigrating. This includes barge timing, passage of dams, and spill regulation. Discharge can be used to increase speed of fish and passage through the estuary. We observed a relationship between discharge and speed. We also noticed that fish moved through the estuary faster when flows were higher later in the season. Although we found no relationship this year between smoltification, stress, and BKD and release date (i.e., time of season), this is not surprising given the large number of hatchery stocks from which the outmigrating chinook population are originating. However, previous years work has found differences through time. Thus, if fish are managed so they are at a proper smoltification level, possibly at the originating hatchery, prior to release, we may be able to deliver them to the estuary at a beneficial time. We could also time barge releases with discharge rates, or vise versa, in order to allow smolts to arrive at the estuary at times when terns and cormorants are not feeding (i.e., darkness). Barging itself is probably not deleterious to fish survival in all likelihood; it is the timing of barging that may be harmful to the chinook outmigrants.

Further research and data analyses need to be completed before specific management recommendations can be made. More work should be done around the timing issues described above, the above descriptions of which are simply possibilities and not specific recommendations. We also need to better understand the relationship between

C29173

stress, smoltification, and BKD as it relates to the Columbia River hydropower system. This can be done by a combination of further data analysis, more fieldwork, and laboratory experiments looking at these factors and especially their interactions. We have already researched the migration of yearling chinook between Bonneville Dam and into the estuary (Schreck *et al.*, 1993, 1996, 1997), which most yearling chinook successfully migrate. We also know that migration behavior of juvenile salmonids is influenced by river conditions such as flow (a function of dam discharge) and tidal stage. A critical area that remains unexplored is at the mouth of the river; we have limited information concerning detailed migration behavior of juvenile chinook salmon into saltwater. Increased understanding of smolt behavior at the freshwater/saltwater interface, which is miles long, is needed to determine what may be done to minimize rates of avian predation and limit forced saltwater entry of under-developed fish. Data should be collected in multiple years to account for annual variability that characterizes the Columbia River system and in the laboratory to control for variables that cannot be done in the field. Another area which remains unexplored is how survival into saltwater ultimately affects returning spawner populations. An existing life-history model for salmonids should be developed and validated for the outmigrating juvenile stage. It can then be used to predict adult populations and effects of management decisions concerning the hydropower system and other areas of concern such as avian predators. Once the relationship between fish quality and behavior, as affected by river and estuary conditions, is understood, the opportunity exists to manage the migration of juvenile salmonids through the Columbia Basin hydropower system in such a way that their subsequent survival is maximized.

C29174

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C29175

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C29178

Table 1. Summary of numbers of fish used during the 1998 field season for physiological sampling ("Physiol."), radio-tracking ("Tagging"), saltwater preference experiments ("SW Expt."), and the stress simulation experiment ("Stress Sim.") are given for each release of fish. Fish group, location of work ("Loc"), and total numbers for the season are also given. Entries with "+" indicate: standard+depth tags ("Tagging"), replicates ("SW Expt."), and sampled+tagged fish ("Stress Sim.").

			Release Date										
	Fish Group	Loc	4/29	5/2	5/7	5/10	5/15	5/18	5/23	5/24	5/30	6/1	Total
Physiol.	Pre-Barge	LWG	10	10	10	10	10	10	10	10	5	0	85
	Post-Barge	BON	10	10	10	8	10	10	0	6	2	6	72
	ROR	BON					10	3	10	10	10	1	44
Tagging	Barged	LWG	20+4	20	20+6	19	20+4	19	20	20+5	14	16	207
	ROR	BON					20+5	18	20+5	20	19+5	15	127
SW Expt.	Barged	OSU	12+12				12+12						48
	ROR	OSU									13+12		25
Stress Sim.	Barged	AST			9+6	10+8							33

BON – Bonneville Dam
LWG – Lower Granite Dam
OSU – Oregon State University Fish Performance and Genetics Laboratory
AST – Astoria/estuary
ROR – Run-of-the-River

C29179

Table 2. Summary of timing (columns) and location (cells) of work (rows) in relation to other work for any particular release of fish (N=10) in 1998. Note that all fish types were released on the same day, but not tagged (barged and ROR) or sampled for health condition (pre- and post-barge and ROR) on the same date or at the same location. Notes refer to tagged fish only.

	Day 1	Day 2	Day 3
Physiol.	• Pre-Barged @ LWG		• Post-Barged @ BON on Barge • ROR @ BON
Tagging	• Barged @ LWG	• ROR @ BON	
Notes	• Barged Fish Collected	• Barge Departs LWG • ROR Fish Collected	• Barged + ROR Fish Released

BON – Bonneville Dam
LWG – Lower Granite Dam

C29180

Figure 1. Daily 1998 collections of (*A*) juvenile salmonids at Lower Granite Dam and (*B*) hatchery spring chinook at Bonneville Dam. Dates on which barged and run-of-the-river (ROR), respectively, yearling spring chinook salmon were collected for radio-tagging are indicated by asterisks (*). Data were taken from the DART Smolt Index ("**www.cqs.washington.edu/dart/pass_com.html**") which uses data from the Fish Passage Center (Portland, OR).

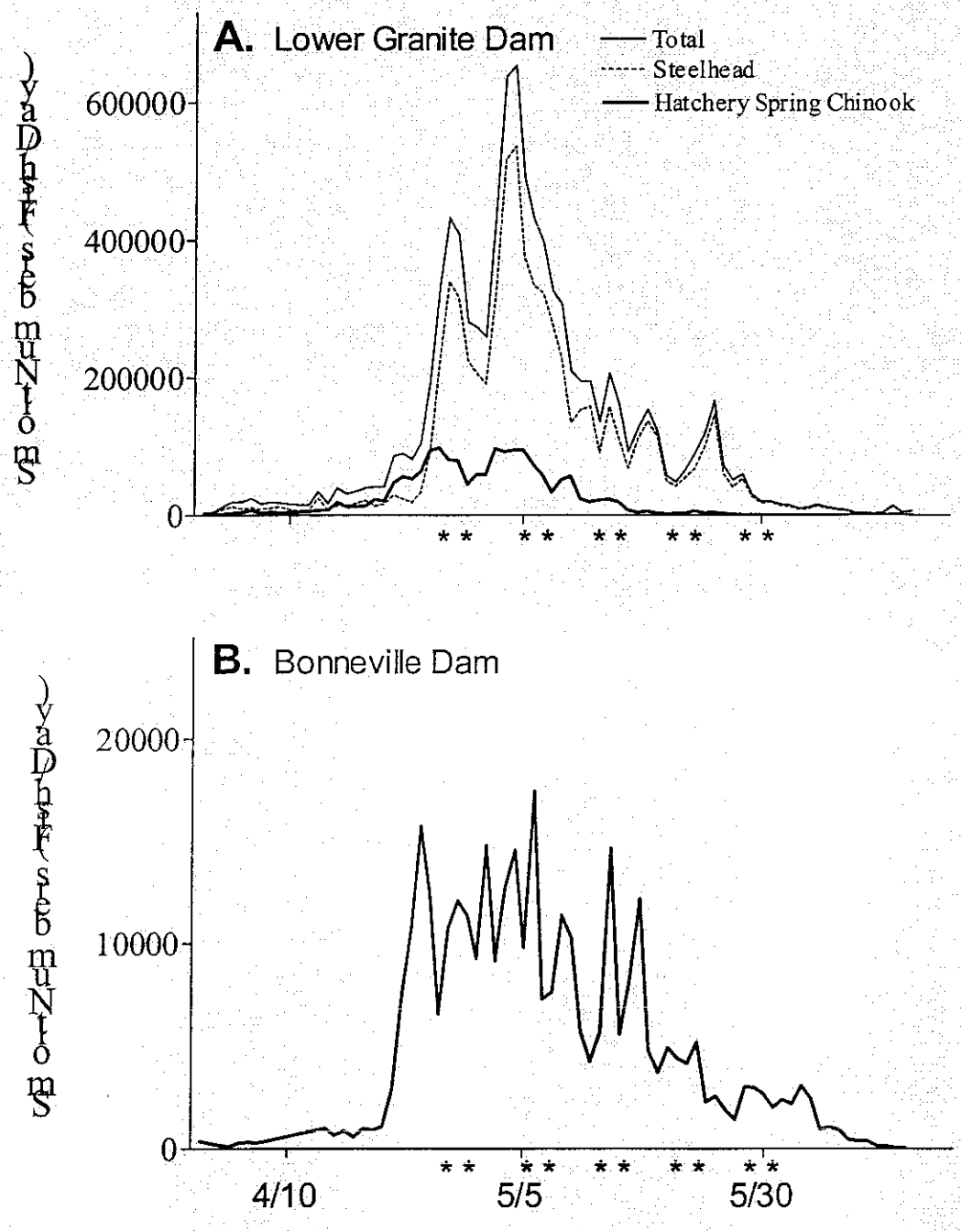
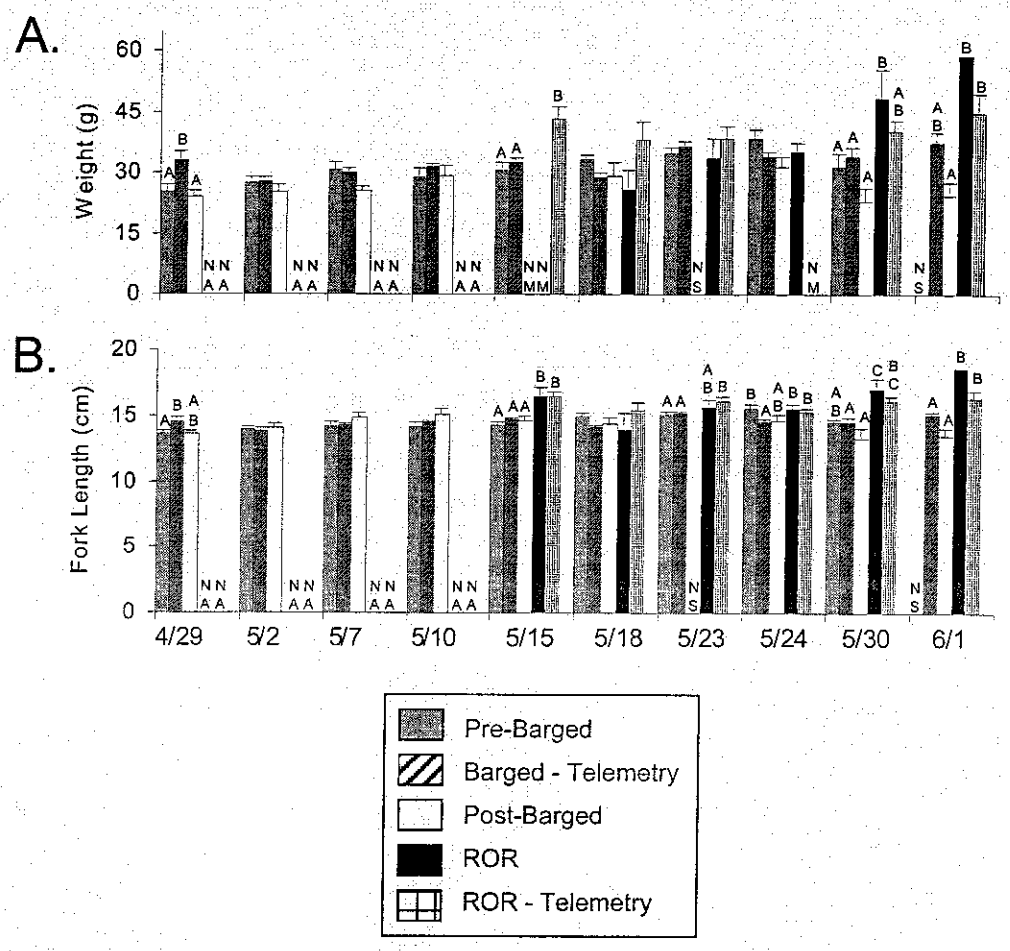
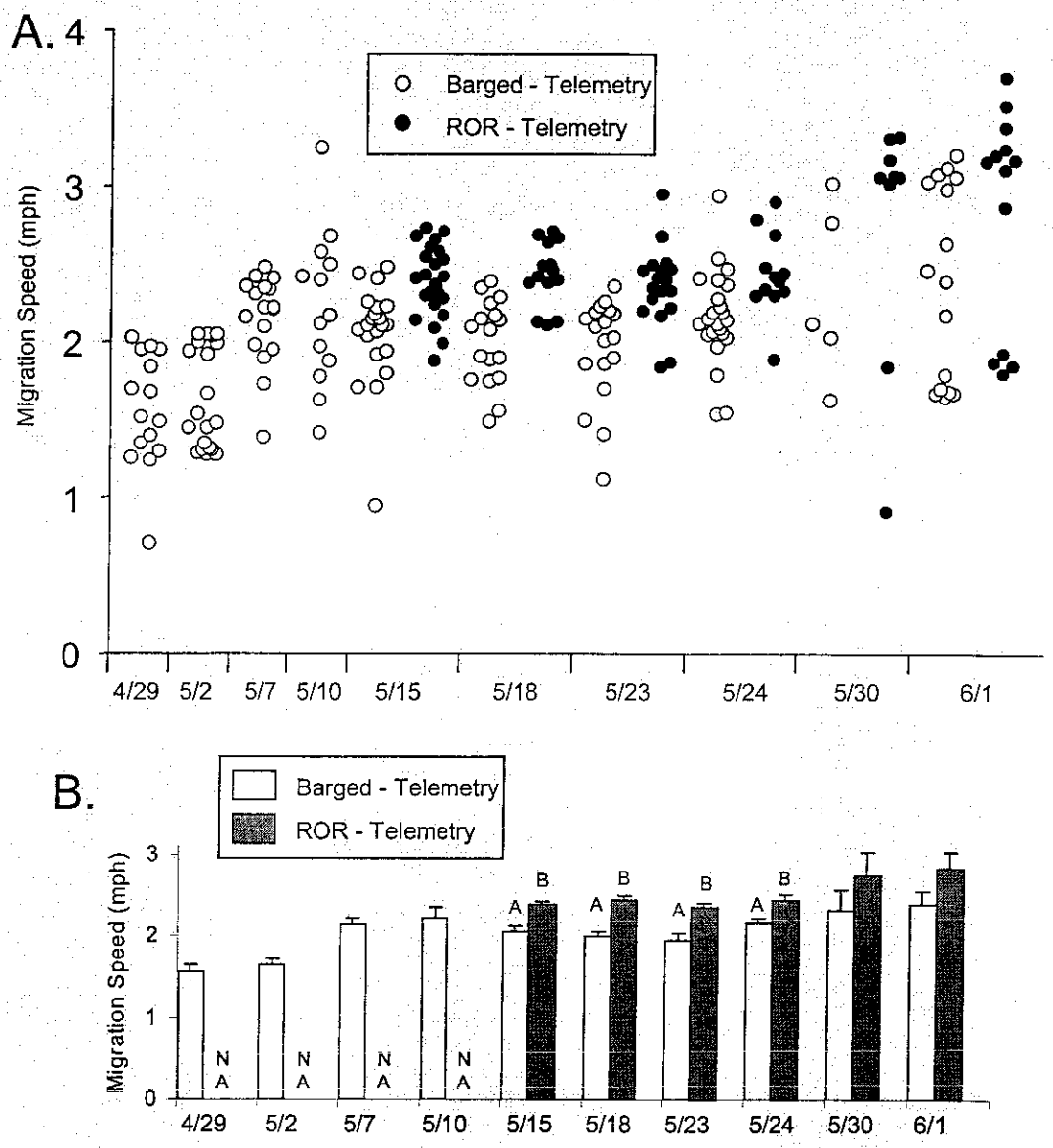


Figure 2. (*A*) Mean weight (g, +SE) and (*B*) fork length (cm, +SE) of spring chinook used for physiological analyses ("Pre-Barged", "Post-Barged", and "ROR") and radiotelemetry ("Barged – Telemetry" and "ROR – Telemetry") in 1998. All releases are indicated. Groups of fish not used for a given release ("NA"), not sampled, due to lack of availability, for a given release ("NS"), or not measured (though available) for a given release ("NM") are indicated. Within each release date, differences between types of fish were compared (ANOVA), and if an effect was present at α=0.05, differences between groups within the date are indicated with letters above the values (LSD Test). Different letters indicate significantly different measures; letters cannot be compared between dates. Statistical results within dates and between groups are summarized in Appendix II, while results within groups between dates are summarized in Appendix I.



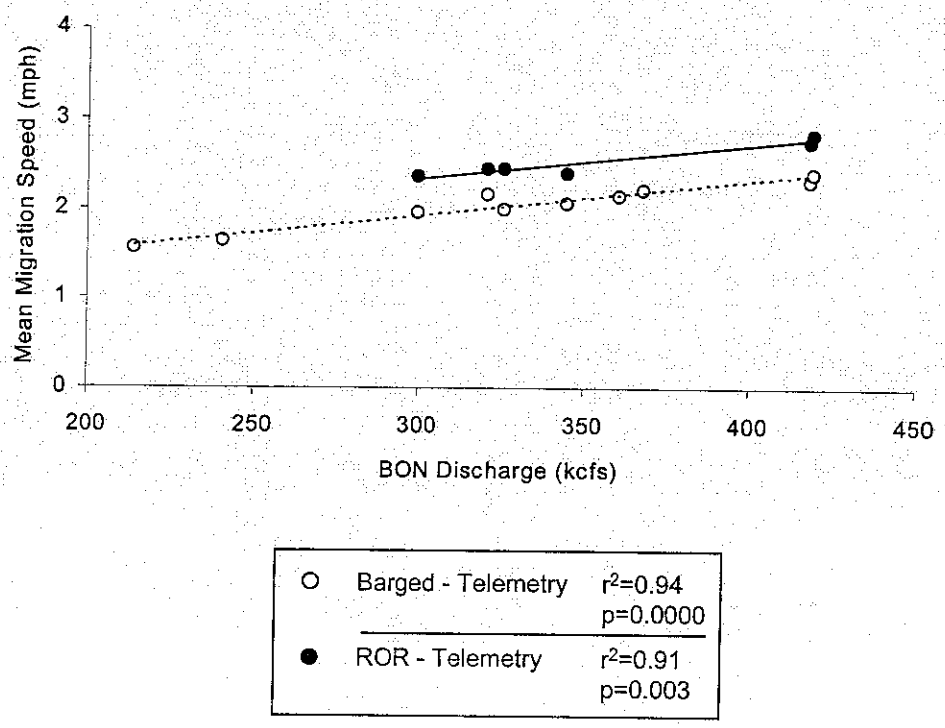
C29182

Figure 3. (*A*) Speed (mph) of all fish and (*B*) mean speed (mph, +SE) for each release of radio-tagged barged ("Barged – Telemetry") and ROR ("ROR – Telemetry") yearling chinook salmon in 1998. Speed was measured from the release site below Bonneville Dam to a monitoring station near the upstream end of the Columbia River Estuary (river mile 55.5). All releases are indicated. Groups of fish not used for a given release ("NA") are indicated. Within each release date with both barged and ROR fish, differences between types of fish were compared (ANOVA or Kruskal-Wallis Test), and if an effect was present at α=0.05, differences between groups within the date are indicated with letters above the values (LSD Test). Different letters indicate significantly different measures; letters cannot be compared between dates. Statistical results within dates and between groups are summarized in Appendix II, while results within groups between dates are summarized in Appendix I.



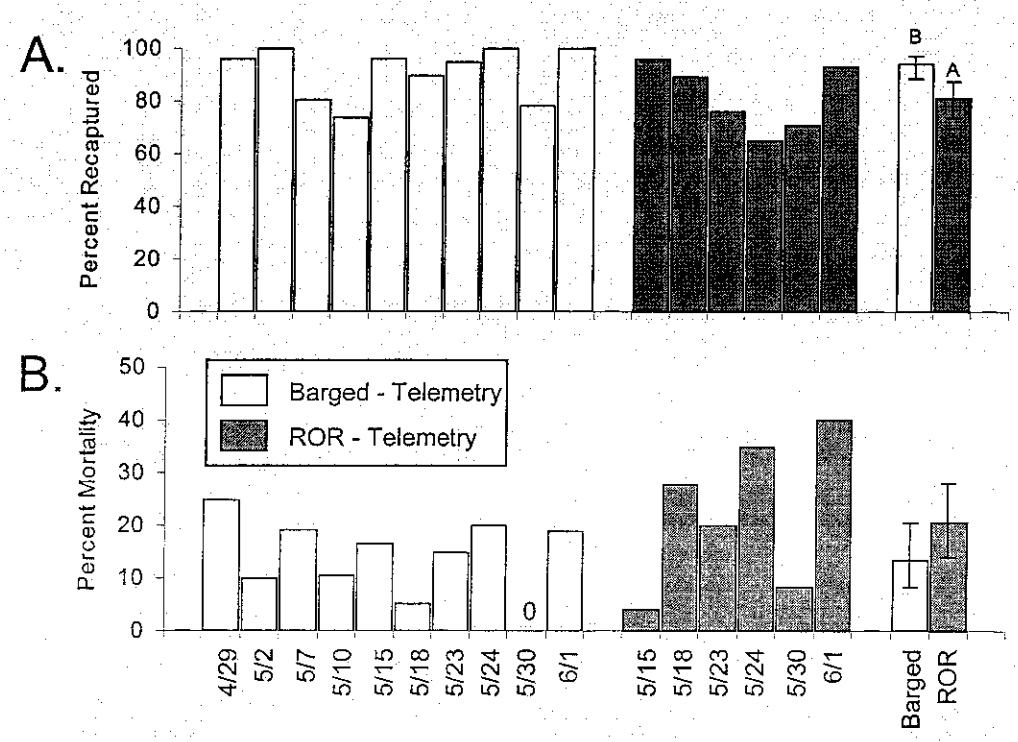
C29183

Figure 4. Average daily discharge (kcfs) at Bonneville Dam on the dates radio-tagged chinook were released into the lower Columbia River versus mean migration speed (mph) in 1998. Barged and ROR chinook are each indicated with regression lines and statistics. Data were taken from the DART River Environment (**"http://www.cqs.washington.edu/dart/river.html"**) which uses data from the US Army Corps of Engineers, Northwestern Division (Portland, OR).



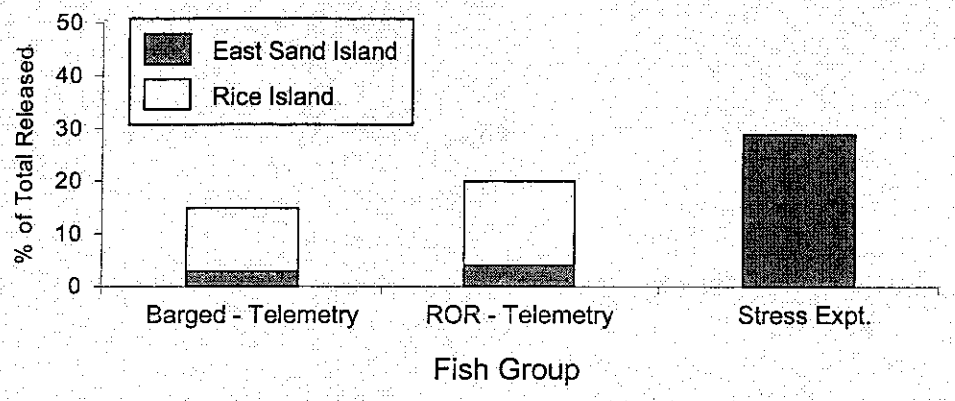
C29184

Figure 5. (*A*) Percent of radio-tagged barged ("Barged – Telemetry") and ROR ("ROR – Telemetry") spring chinook recaptured (detected) at or downstream of the exit monitoring station at river mile 55.5 after release below Bonneville Dam in 1998 , and (*B*) percent of radio-tagged barged and ROR spring chinook taken by avian predators in the lower Columbia River estuary in 1998, for each release and overall (for releases of both barged and ROR fish). Overall, differences between types of fish were compared (logistic regression), and if an effect was present at α=0.05, differences between groups are indicated with letters above the values (last two bars in each graph are overall group values; 95% confidence intervals based on binomial variation after pooling over all releases are presented for these data). Different letters indicate significantly different values. Trends for either barged or ROR fish (analyzed separately) across dates were also analyzed (logistic regression), though no trends existed at α=0.05. Statistical results are summarized in Appendix I.



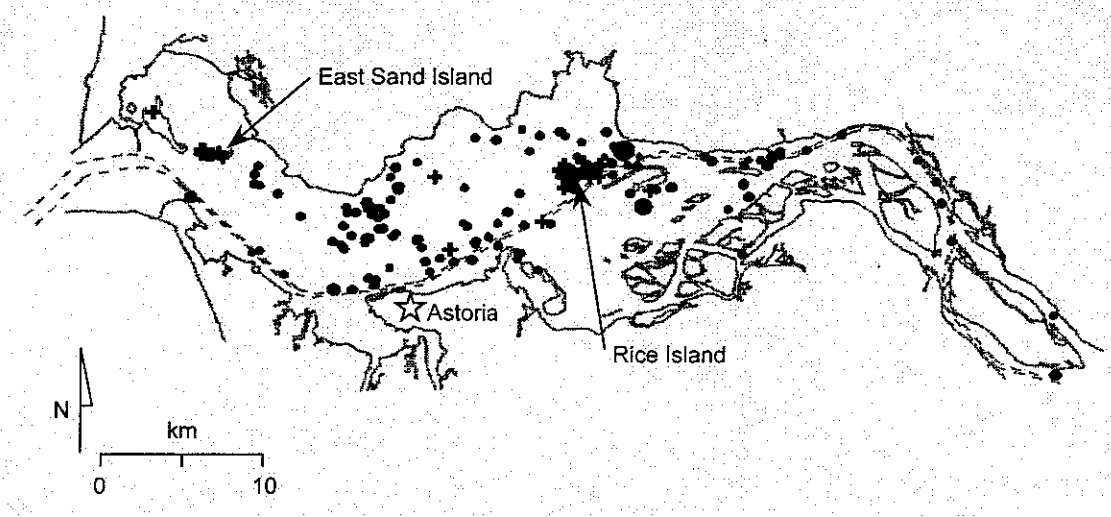
C29185

Figure 6. Specific distribution between avian predator colonies of radio-tagged barged ("Barged – Telemetry"), ROR ("ROR – Telemetry"), and stress experiment ("Stress Expt.") yearling chinook mortalities for all 1998 releases combined.



C29186

Figure 7. Locations of radio-tagged yearling chinook salmon from all releases in the lower Columbia River estuary as observed from aircraft in 1998. Note clusters of chinook mortalities on Rice and East Sand Islands.



C29187

Figure 8. Migration routes of (*A*) barged and (*B*) ROR radio-tagged yearling chinook salmon tracked by boats from all 1998 releases in the lower Columbia River estuary. The main shipping channel, Astoria Bridge, East Sand Island, and Rice Island are labeled on (*A*), and included on all subsequent maps.

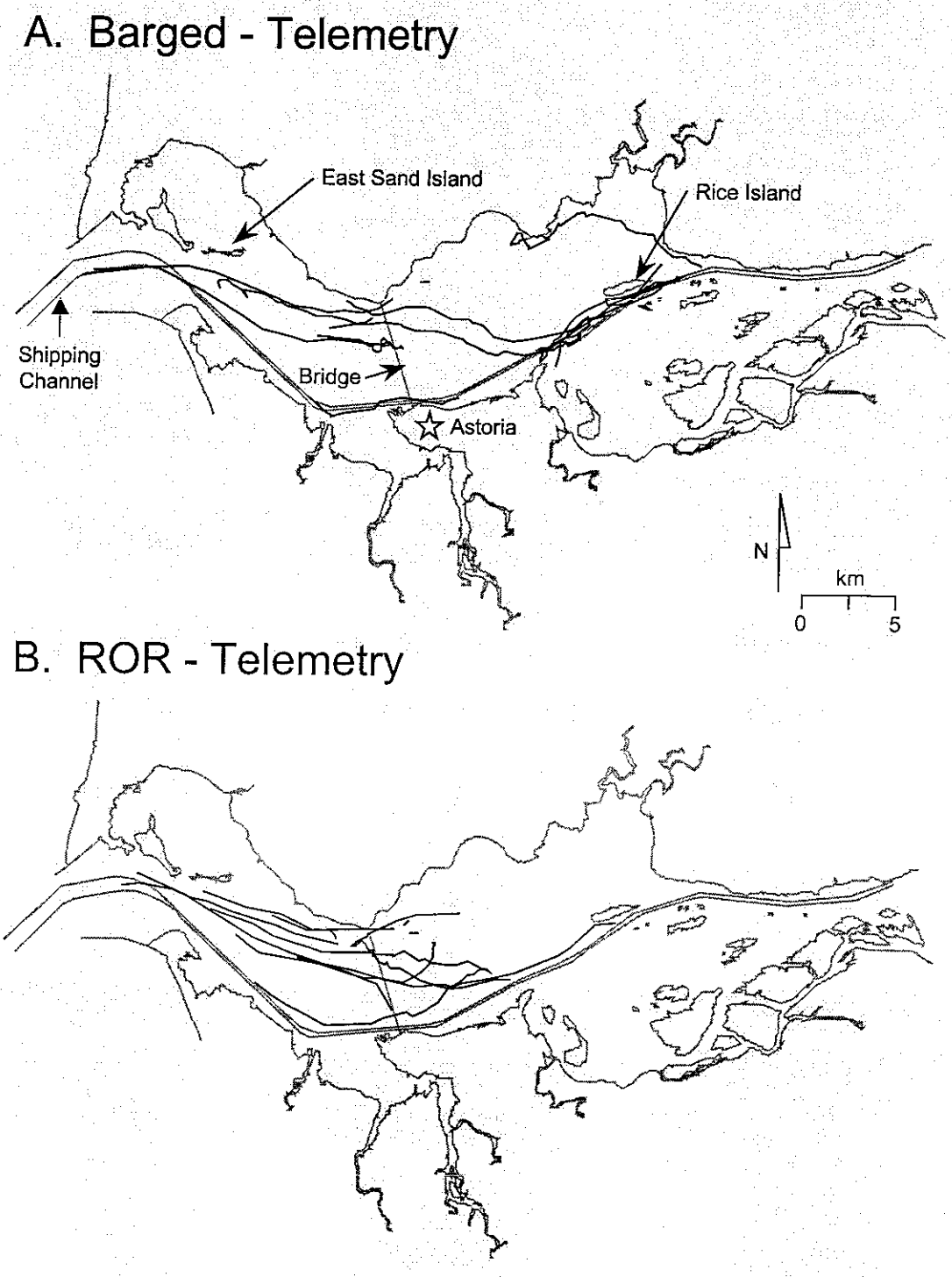


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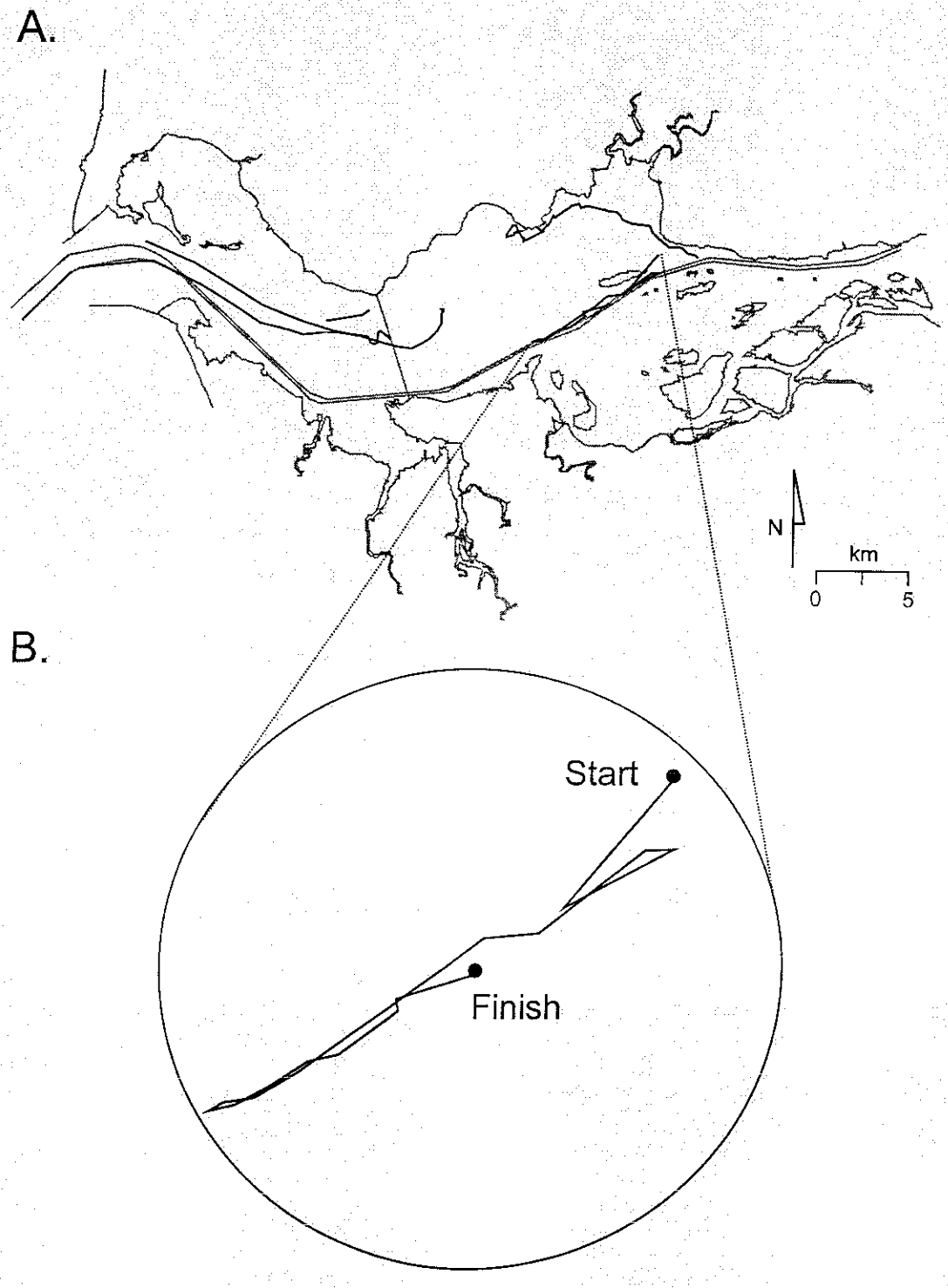
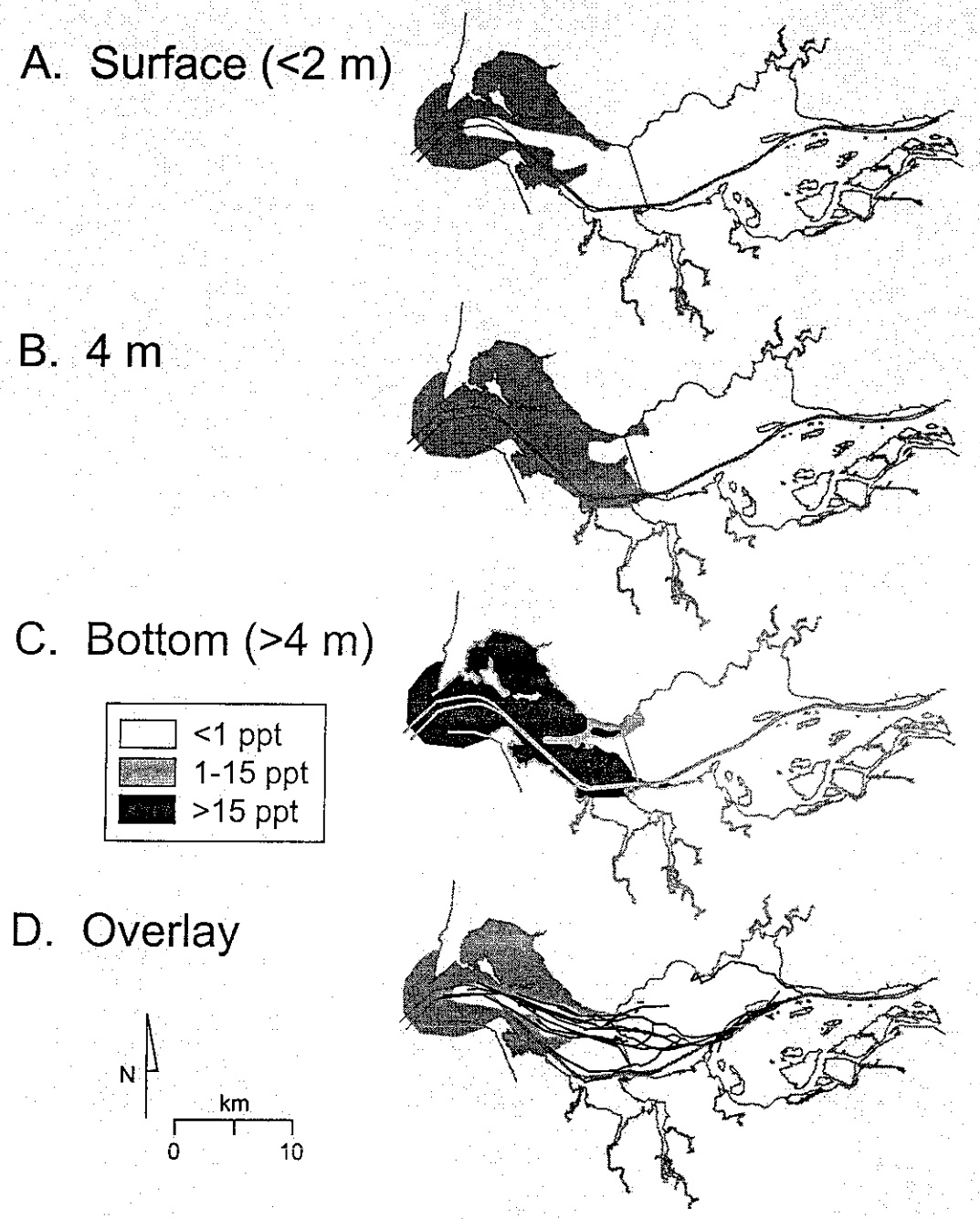
Figure 9. (*A*) Typical fish migration routes, as determined by boat tracking, early (3 May 1998; two upriver routes) and late (27 May 1998; three downriver routes) in the salmon outmigration. (*B*) Magnified view of one fish's route; note that the fish moved upstream on incoming tides (i.e., movement was passive).



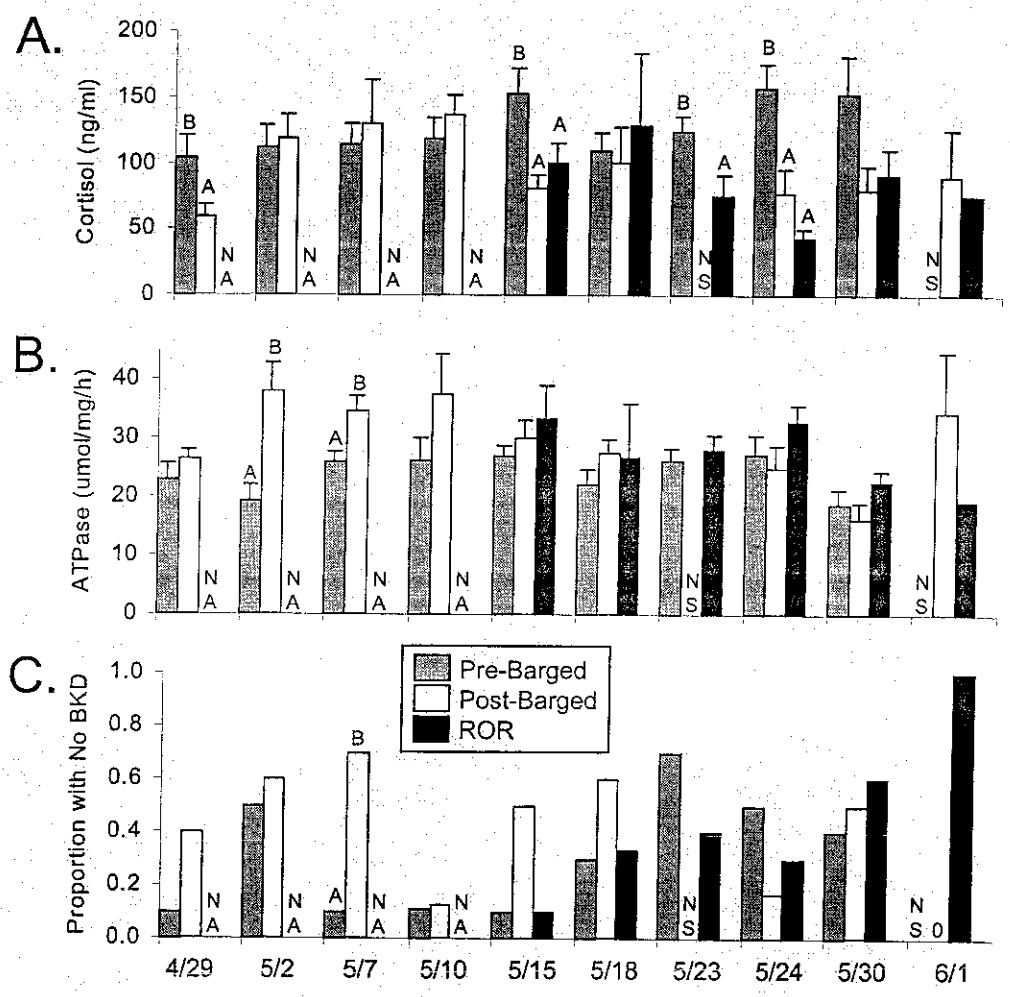
C29189

Figure 10. (*A-C*) Maximum salinity (ppt) throughout the 1998 field season in the lower Columbia River estuary at (*A*) the surface, (*B*) 4 m, and (*C*) bottom of the water column. Data are a compilation of all readings taken throughout the season by boat crews while tracking fish. (*D*) Overlay of all boat-tracked fish migration routes (Figure 8) with the surface salinity profile (*A*) of the lower Columbia River estuary. The surface profile coincides with our ability to track the fish (i.e., in order to hear the radio signal, fish had to be in very low salinity-water [<2 ppt], which was not present at 4 m or the bottom).



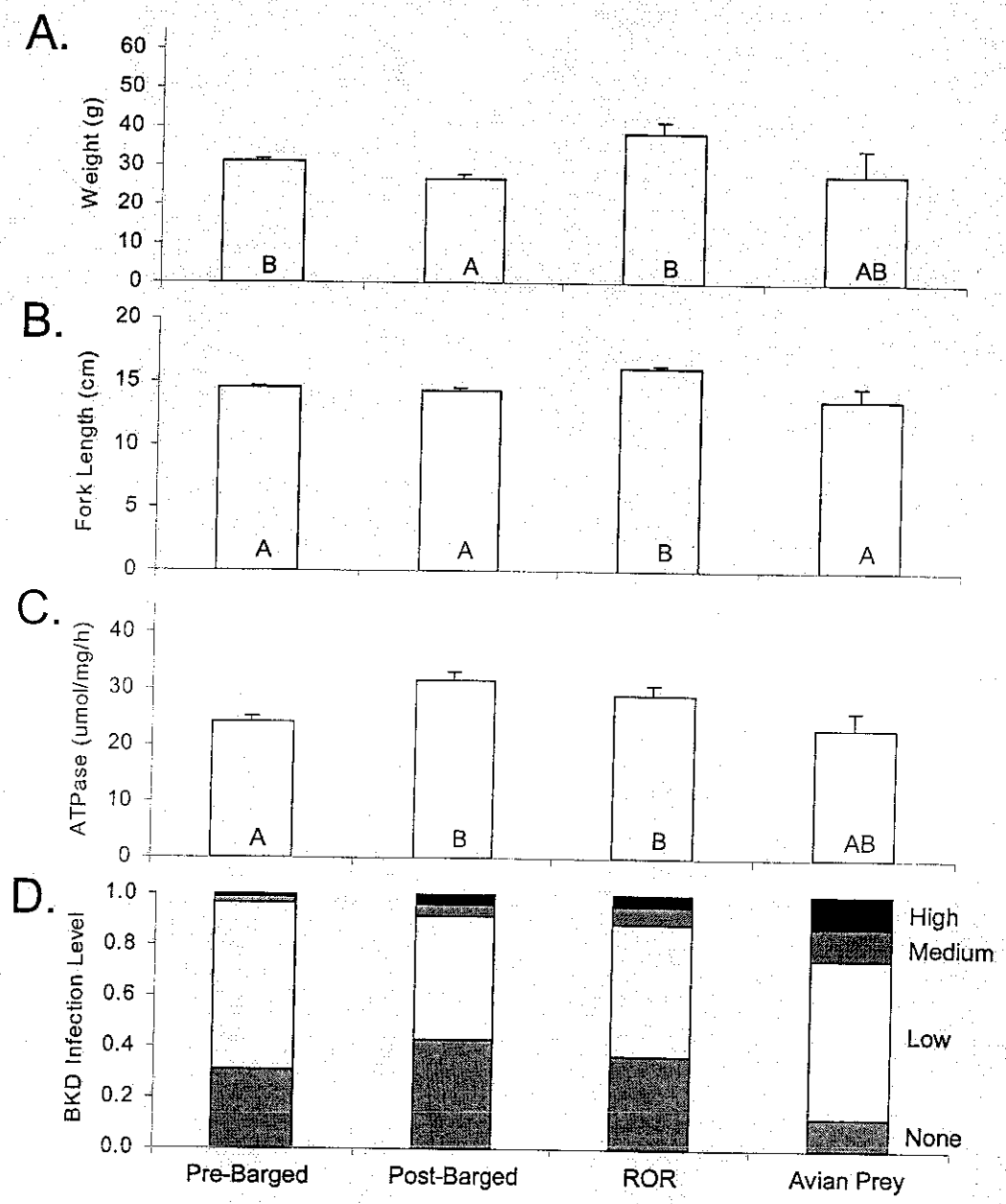
C29190

Figure 11. (*A*) Mean plasma cortisol (ng/ml, +SE), (*B*) mean gill Na+/K+ ATPase (μmol Pi/mg protein/h, +SE), and (*C*) proportion not infected with bacterial kidney disease ("BKD") of juvenile chinook collected for physiological analyses in 1998. These fish were collected at Lower Granite Dam ("Pre-Barged"), after barging on dates when radio-tagged fish were released ("Post-Barged"), and when radio-tagged ROR fish were released ("ROR"). All releases are indicated. Groups of fish not used for a given release ("NA"), not sampled, due to lack of availability, for a given release ("NS"), or with zero values for a given release ("0") are indicated. Within each release date, differences between types of fish were compared (ANOVA or Kruskal-Wallis Test for cortisol and ATPase; χ^2 or Fisher's Exact Test for BKD Infection), and if an effect was present at α=0.05, differences between groups within the date are indicated with letters above the values (LSD Test for cortisol and ATPase and analysis of means for BKD Infection). Different letters indicate significantly different measures; letters cannot be compared between dates. Statistical results within dates and between groups are summarized in Appendix II, while results within groups between dates are summarized in Appendix I.



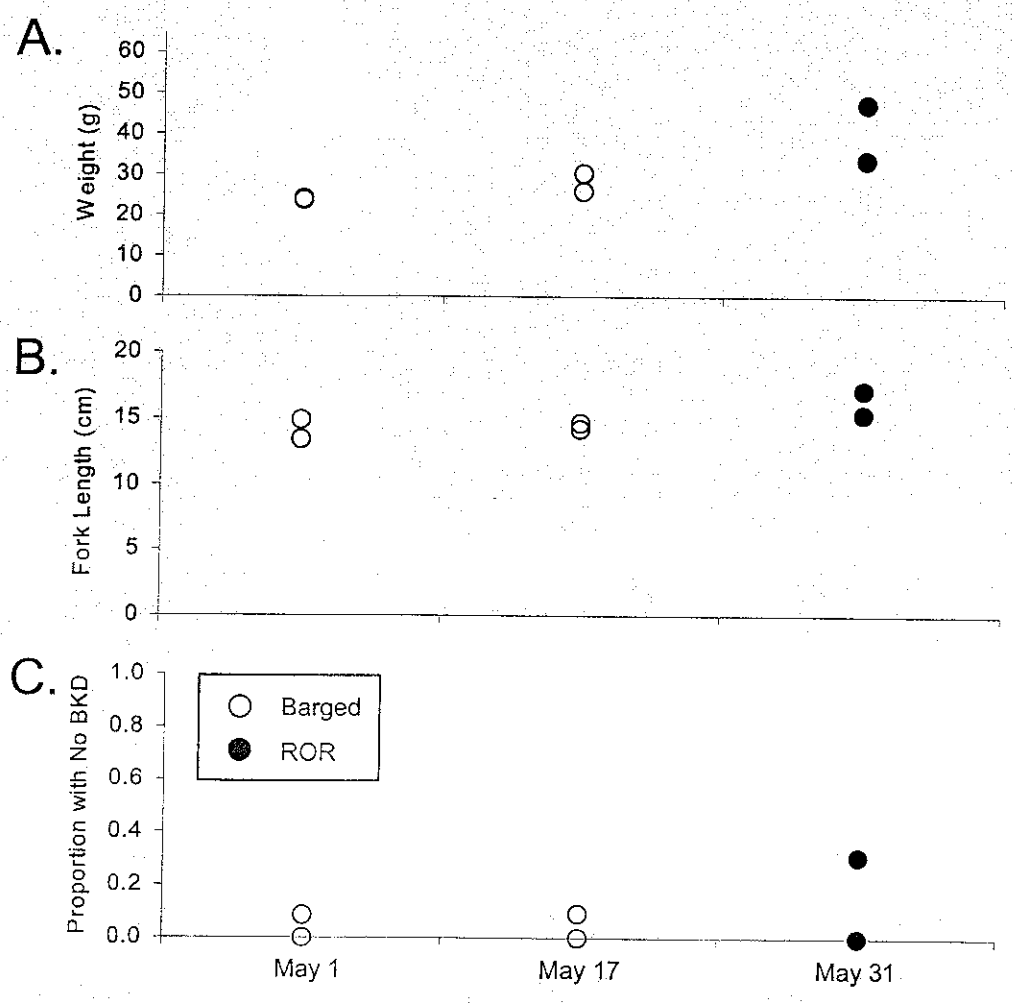
C29191

Figure 12. (*A*) Mean weight (g, +SE), (*B*) mean length (cm, +SE), (*C*) mean gill Na+/K+ ATPase (μmol Pi/mg protein/h, +SE), and (*D*) proportion infected with various levels of bacterial kidney disease ("BKD") of juvenile chinook collected in 1998 for physiological analyses ("Pre-Barged", "Post-Barged", and "ROR") and from Caspian terns on Rice Island ("Avian Prey"). Data from fish collected for physiological analyses are pooled across all releases. Differences between types of fish were compared (ANOVA for weight, length, and ATPase; χ^2 for BKD Infection), and if an effect was present at α=0.05, differences between groups are indicated with letters at the base of the bars (LSD Test for weight, length, and ATPase). Different letters indicate significantly different measures. Statistical results are summarized in Appendix II.



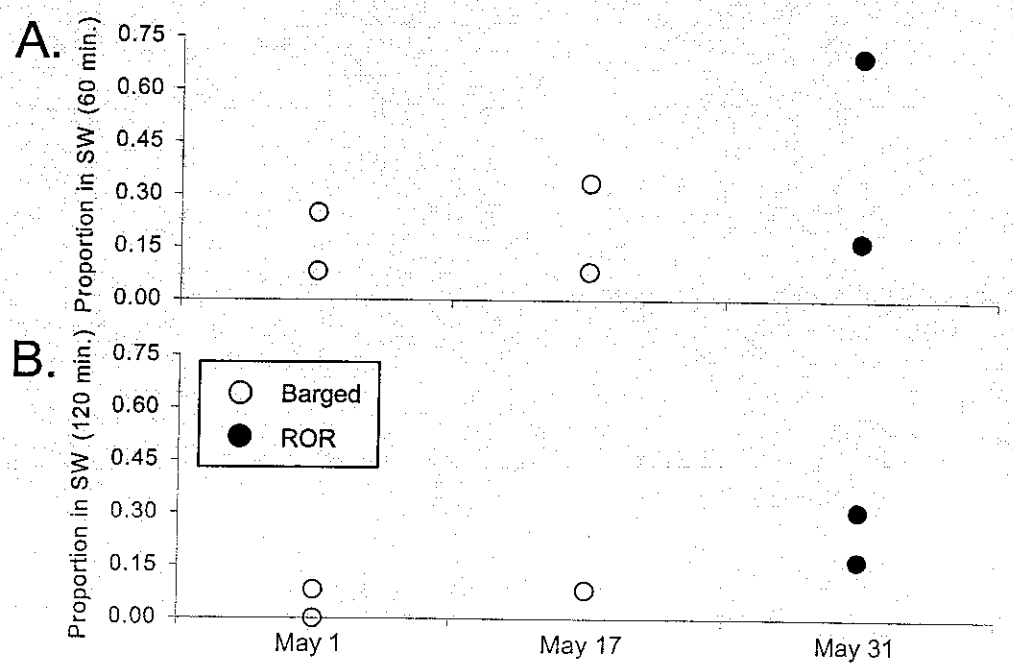
C29192

Figure 13. (*A*) Weight (g), (*B*) length (cm), and (*C*) proportion not infected with bacterial kidney disease ("BKD") of juvenile chinook used in saltwater preference testing on three dates in 1998. Barged fish were used on the first two dates and ROR fish were used on the last date. Replicate means (N=2/date) were used for analyses and the means of these are shown below. Differences between dates were compared (Kruskal-Wallis Test; BKD data were arcsine transformed); no differences existed at α=0.05. Statistical results are summarized in Appendix I.



C29193

Figure 14. (*A*) Proportion in saltwater after 60 minutes and (*B*) proportion in saltwater after 120 minutes of juvenile chinook used in saltwater preference testing on three dates in 1998. Freshwater was also present in each tank used for testing. Barged fish were used on the first two dates and ROR fish were used on the last date. Replicate means (N=2/date) were used for analyses and the means of these are shown below. Differences between dates were compared (Kruskal-Wallis Test; data were arcsine transformed); no differences existed at α=0.05. Statistical results are summarized in Appendix I.



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Appendices

I. Statistical results for tests within a fish type and between release dates for various measures. Also included are statistical results from saltwater preference tests and telemetry findings for recapture ("Telemetry-Recap.") and avian predation ("Telemetry-Surv."). Individual statistical tests are separated by horizontal lines. For each statistical test, the measure tested (response variable), type of test, p value, and total number of fish used in the analysis ("T") are given. Also, the different levels in the test ("Release") are given with their respective value, standard error ("SE"), sample size ("N"), and, if applicable, the differences between levels ("Diff.s"), as determined by a multiple comparison test, if the overall test result was significant ($p<\alpha=0.05$). A single factor ANOVA ("ANOVA") with a 95% LSD Test for multiple comparisons was used for most measures within fish types. A χ^2 test with an analysis of means test for multiple comparisons was used for BKD measures. The Kruskal-Wallis Test ("K-W") was used to analyze saltwater preference assessments and logisitc regression was used to analyze telemetry results. Groups of fish not sampled, due to lack of availability, for a given release ("NS") or not measured (though available) for a given release ("NM") are indicated. "NA" indicates non-applicability for the given column, and "NT" indicates that no statistical test or multiple comparison was conducted. Although arcsine-transformed data were used in saltwater preference testing proportional data (BKD and number in saltwater after 60 ["60"] and 120 ["120"] minutes), "Values" given are the actual proportions. Also, "Values" given in the saltwater preference results are means of replicate means; there were two replicates per date (indicated under "N") and 12-13 fish were in each replicate. For BKD measures and telemetry tests ("Telemetry-Recap." and "Telemetry-Surv." in the "Type" column), "N" indicates the number of fish used in the proportion or percentage listed in the "Value" column. For telemetry tests ("Telemetry-Recap." and "Telemetry-Surv." in the "Type" column), the type of test statistic used (F or χ^2) in the logistic regression ("LR") is indicated in the "Test" column. Also, the "T" column indicates the number of values used in the logistic regression (though these are weighted by the values given in the "N" column) and the "Measure" column indicates the factors used in the test (note that "Release" factors are categorical and "Rel. Date" factors are continuous). Figure to which each statistical test refers is also indicated.

II. Statistical results for tests within release dates and between fish types for various measures. Also included are statistical results from seasonal comparisons between fish types. Individual statistical tests are separated by horizontal lines. For each statistical test, the measure tested (response variable), type of test, p value, and total number of fish used in the analysis ("T") are given. Also, the different levels in the test ("Type") are given with their respective value, standard error ("SE"), sample size ("N"), and, if applicable, the differences between levels ("Diff.s"), as determined by a multiple comparison test, if the overall test result was significant ($p<\alpha=0.05$). A single factor ANOVA ("ANOVA"), or a Kruskal-Wallis Test if $T<30$, with a 95% LSD Test for multiple comparisons was used for most measures within fish types. A χ^2 test, or Fisher's Exact Test ("Fisher's") if there were only two levels, with an analysis of means test for multiple comparisons was used for BKD measures. Groups of fish not sampled, due to lack of availability, for a given release ("NS") or not measured (though available) for a given release ("NM") are indicated. "NA" indicates non-applicability for the given column or that a type of fish was not used for a given release, and "NT" indicates that no statistical test or multiple comparison was conducted. For BKD measures, "N" indicates the number of fish used in the proportion listed in the "Value" column. Figure to which each statistical test refers is also indicated.

C29195

Appendix I

Type	Measure	Test	P value	T	Release	Value	SE	N	Diff.s	Figure
ROR-Telemetry	Weight (g)	ANOVA	0.6461	93	5/15/98	43.45	2.98	23	NT	2A
					5/18/98	38.34	4.29	18		
					5/23/98	38.51	2.99	14		
					5/24/98	NM	NM	NM		
					5/30/98	40.42	2.63	24		
					6/1/98	44.89	4.95	14		
	Length (cm)	ANOVA	0.1522	127	5/15/98	16.46	0.37	25	NT	2B
					5/18/98	15.46	0.50	18		
					5/23/98	16.15	0.29	25		
					5/24/98	15.28	0.25	20		
					5/30/98	16.12	0.32	24		
					6/1/98	16.37	0.54	15		
	Migration Speed (mph)	ANOVA	0.0126	90	5/15/98	2.39	0.05	24	A	3B
					5/18/98	2.44	0.05	14	AB	
					5/23/98	2.36	0.06	18	A	
					5/24/98	2.44	0.08	12	AB	
					5/30/98	2.75	0.27	9	BC	
					6/1/98	2.83	0.19	13	C	
Barge-Telemetry	Weight (g)	ANOVA	0.0001	207	4/29/98	33.00	2.42	24	BCDE	2A
					5/2/98	27.74	1.10	20	A	
					5/7/98	30.00	1.09	26	ABC	
					5/10/98	31.48	0.99	19	ABCD	
					5/15/98	32.55	1.26	24	BCD	
					5/18/98	28.89	1.06	19	AB	
					5/23/98	36.91	1.11	20	EF	
					5/24/98	33.99	1.19	25	DEF	
					5/30/98	34.08	2.28	14	CDEF	
					6/1/98	37.63	2.43	16	F	
	Length (cm)	ANOVA	0.0023	207	4/29/98	14.53	0.30	24	BC	2B
					5/2/98	13.89	0.17	20	A	
					5/7/98	14.25	0.17	26	AB	
					5/10/98	14.49	0.19	19	ABC	
					5/15/98	14.70	0.20	24	BCD	
					5/18/98	14.15	0.18	19	AB	
					5/23/98	15.15	0.20	20	D	
					5/24/98	14.54	0.15	25	BC	
					5/30/98	14.57	0.31	14	BCD	
					6/1/98	15.06	0.30	16	CD	
	Migration Speed (mph)	ANOVA	0.0000	165	4/29/98	1.56	0.09	15	A	3B
					5/2/98	1.64	0.07	20	A	
					5/7/98	2.15	0.07	17	BC	
					5/10/98	2.22	0.14	13	BC	
					5/15/98	2.05	0.07	21	B	
					5/18/98	2.00	0.07	17	B	
					5/23/98	1.95	0.08	18	B	
					5/24/98	2.16	0.06	23	BC	
					5/30/98	2.31	0.25	5	BC	
					6/1/98	2.39	0.16	16	C	
Post-Barge	Weight (g)	ANOVA	0.2447	62	4/29/98	24.32	1.19	10	NT	2A
					5/2/98	25.10	1.97	10		
					5/7/98	25.63	1.29	10		
					5/10/98	29.48	2.54	8		
					5/15/98	NM	NM	NM		
					5/18/98	29.34	3.24	10		
					5/23/98	NS	NS	NS		
					5/24/98	31.67	2.54	6		
					5/30/98	22.85	3.45	2		
					6/1/98	24.33	3.36	6		
	Length (cm)	ANOVA	0.0611	72	4/29/98	13.60	0.24	10	NT	2B
					5/2/98	14.05	0.38	10		
					5/7/98	14.90	0.32	10		
					5/10/98	15.06	0.47	8		
					5/15/98	14.60	0.35	10		
					5/18/98	14.45	0.42	10		
					5/23/98	NS	NS	NS		
					5/24/98	14.58	0.45	6		

C29196

					5/30/98	13.30	0.80	2		
					6/1/98	13.48	0.57	6		
	Cortisol	ANOVA	0.2758	68	4/29/98	59.20	9.10	9	NT	11A
					5/2/98	118.92	18.66	10		
					5/7/98	130.36	33.54	10		
					5/10/98	136.79	14.83	7		
					5/15/98	81.16	10.64	10		
					5/18/98	100.35	27.40	10		
					5/23/98	NS	NS	NS		
					5/24/98	77.40	18.50	5		
					5/30/98	80.16	18.16	2		
					6/1/98	90.06	35.93	5		
	ATPase	ANOVA	0.1626	67	4/29/98	26.46	1.52	9	NT	11B
					5/2/98	38.13	4.69	10		
					5/7/98	34.60	2.72	9		
					5/10/98	37.55	7.06	8		
					5/15/98	30.20	3.08	10		
					5/18/98	27.62	2.14	9		
					5/23/98	NS	NS	NS		
					5/24/98	24.89	3.82	5		
					5/30/98	16.27	2.70	2		
					6/1/98	34.48	10.24	5		
	BKD	χ^2	0.0618	9	4/29/98	0.400	NA	10	NT	11C
					5/2/98	0.600	NA	10		
					5/7/98	0.700	NA	10		
					5/10/98	0.125	NA	8		
					5/15/98	0.500	NA	10		
					5/18/98	0.600	NA	10		
					5/23/98	NS	NA	NS		
					5/24/98	0.167	NA	6		
					5/30/98	0.500	NA	2		
					6/1/98	0.000	NA	6		
Pre-Barge	Weight (g)	ANOVA	0.0002	84	4/29/98	25.36	1.68	10	A	2A
					5/2/98	27.64	1.38	10	AB	
					5/7/98	30.75	2.09	10	BCD	
					5/10/98	29.13	1.94	9	ABC	
					5/15/98	30.89	1.87	10	BCD	
					5/18/98	33.41	1.26	10	CDE	
					5/23/98	34.85	1.63	10	DE	
					5/24/98	38.60	2.44	10	E	
					5/30/98	31.46	3.61	5	ABCD	
					6/1/98	NS	NS	NS	NS	
	Length (cm)	ANOVA	0.0001	84	4/29/98	13.56	0.29	10	A	2B
					5/2/98	13.92	0.27	10	A	
					5/7/98	14.19	0.33	10	A	
					5/10/98	14.21	0.31	9	AB	
					5/15/98	14.29	0.27	10	ABC	
					5/18/98	15.01	0.22	10	BCD	
					5/23/98	15.06	0.26	10	CD	
					5/24/98	15.54	0.31	10	D	
					5/30/98	14.46	0.31	5	ABC	
					6/1/98	NS	NS	NS	NS	
	Cortisol	ANOVA	0.1611	84	4/29/98	103.75	17.88	10	NT	11A
					5/2/98	112.55	16.79	10		
					5/7/98	114.75	14.97	10		
					5/10/98	118.62	16.12	9		
					5/15/98	153.16	19.21	10		
					5/18/98	110.04	13.18	10		
					5/23/98	124.15	12.27	10		
					5/24/98	158.18	17.57	10		
					5/30/98	153.26	28.45	5		
					6/1/98	NS	NS	NS		
	ATPase	ANOVA	0.2540	80	4/29/98	22.85	2.94	8	NT	11B
					5/2/98	19.37	2.68	10		
					5/7/98	26.09	1.61	9		
					5/10/98	26.13	3.91	9		
					5/15/98	26.95	1.77	9		
					5/18/98	22.06	2.56	10		
					5/23/98	26.24	2.00	10		

C29197

					5/24/98	27.17	3.47	10		
					5/30/98	18.65	2.71	5		
					6/1/98	NS	NS	NS		
	BKD	χ^2	0.0175	9	4/29/98	0.100	NA	10	A	11C
					5/2/98	0.500	NA	10	A	
					5/7/98	0.100	NA	10	A	
					5/10/98	0.111	NA	9	A	
					5/15/98	0.100	NA	10	A	
					5/18/98	0.300	NA	10	A	
					5/23/98	0.700	NA	10	B	
					5/24/98	0.500	NA	10	A	
					5/30/98	0.400	NA	5	A	
					6/1/98	NS	NA	NS	NS	
ROR	Weight (g)	ANOVA	0.0962	34	5/15/98	NM	NM	NM	NT	2A
					5/18/98	25.93	4.94	3		
					5/23/98	33.81	4.90	10		
					5/24/98	35.26	2.43	10		
					5/30/98	48.59	7.14	10		
					6/1/98	59.00	NA	1		
	Length (cm)	ANOVA	0.1390	44	5/15/98	16.45	0.68	10	NT	2B
					5/18/98	14.00	1.15	3		
					5/23/98	15.65	0.52	10		
					5/24/98	15.49	0.36	10		
					5/30/98	17.04	0.84	10		
					6/1/98	18.60	NA	1		
	Cortisol	ANOVA	0.1004	44	5/15/98	100.34	15.30	10	NT	11A
					5/18/98	128.70	55.51	3		
					5/23/98	75.86	15.46	10		
					5/24/98	43.04	7.09	10		
					5/30/98	91.38	19.55	10		
					6/1/98	75.64	NA	1		
	ATPase	ANOVA	0.3036	40	5/15/98	33.37	5.75	9	NT	11B
					5/18/98	26.69	9.20	3		
					5/23/98	28.00	2.61	9		
					5/24/98	33.02	2.71	10		
					5/30/98	22.55	1.88	8		
					6/1/98	19.27	NA	1		
	BKD	χ^2	0.1918	6	5/15/98	0.100	NA	10	NT	11C
					5/18/98	0.333	NA	3		
					5/23/98	0.400	NA	10		
					5/24/98	0.300	NA	10		
					5/30/98	0.600	NA	10		
					6/1/98	1.000	NA	1		
SW Preference	Weight (g)	K-W	0.1017	6	5/1-Barge	24.02	0.14	2	NT	13A
					5/17-Barge	28.07	2.25	2		
					5/31-ROR	40.54	6.85	2		
	Length (cm)	K-W	0.1801	6	5/1-Barge	14.14	0.73	2	NT	13B
					5/17-Barge	14.38	0.22	2		
					5/31-ROR	16.21	0.92	2		
	Arcsin(BKD)	K-W	0.8510	6	5/1-Barge	0.04	0.04	2	NT	13C
					5/17-Barge	0.05	0.05	2		
					5/31-ROR	0.15	0.15	2		
	Arcsin(60)	K-W	0.6201	6	5/1-Barge	0.17	0.08	2	NT	14A
					5/17-Barge	0.21	0.13	2		
					5/31-ROR	0.43	0.26	2		
	Arcsin(120)	K-W	0.1229	6	5/1-Barge	0.04	0.04	2	NT	14B
					5/17-Barge	0.08	0.00	2		
					5/31-ROR	0.24	0.07	2		
Telemetry-Recap.	Type	LR-χ^2	0.0030	2	Barge	94.07	NA	118	B	5A
					ROR	81.10	NA	127	A	
	Release		0.0186	6	5/15/98	95.9	NA	49	B	
					5/18/98	89.2	NA	37	AB	
					5/23/98	84.4	NA	45	AB	
					5/24/98	84.4	NA	45	AB	
					5/30/98	73.7	NA	38	A	
					6/1/98	96.8	NA	31	B	
	Type	LR-F	0.0822	2	Barge	94.07	NA	118	NT	5A
					ROR	81.10	NA	127		

C29198

	Release		0.3469	6	5/15/98	95.9	NA	49	NT	
					5/18/98	89.2	NA	37		
					5/23/98	84.4	NA	45		
					5/24/98	84.4	NA	45		
					5/30/98	73.7	NA	38		
					6/1/98	96.8	NA	31		
	Brg. Rel. Date	LR-F	0.7882	10	4/29/98	95.8	NA	24	NT	5A
					5/2/98	100.0	NA	20		
					5/7/98	80.8	NA	26		
					5/10/98	73.7	NA	19		
					5/15/98	95.8	NA	24		
					5/18/98	89.5	NA	19		
					5/23/98	95.0	NA	20		
					5/24/98	100.0	NA	25		
					5/30/98	78.6	NA	14		
					6/1/98	100.0	NA	16		
	ROR Rel. Date	LR-F	0.3763	6	5/15/98	96.0	NA	25	NT	5A
					5/18/98	88.9	NA	18		
					5/23/98	76.0	NA	25		
					5/24/98	65.0	NA	20		
					5/30/98	70.8	NA	24		
					6/1/98	93.3	NA	15		
Telemetry-Surv.	Type	LR-χ^2	0.0716	2	Barge	13.56	NA	118	NT	5B
					ROR	20.47	NA	127		
	Release		0.0340	6	5/15/98	10.2	NA	49	A	
					5/18/98	16.2	NA	37	AB	
					5/23/98	17.8	NA	45	AB	
					5/24/98	26.7	NA	45	B	
					5/30/98	5.3	NA	38	A	
					6/1/98	29.0	NA	31	B	
	Brg. Rel. Date	LR-χ^2	0.3982	10	4/29/98	25.0	NA	24	NT	5B
					5/2/98	10.0	NA	20		
					5/7/98	19.2	NA	26		
					5/10/98	10.5	NA	19		
					5/15/98	16.7	NA	24		
					5/18/98	5.3	NA	19		
					5/23/98	15.0	NA	20		
					5/24/98	20.0	NA	25		
					5/30/98	0.0	NA	14		
					6/1/98	18.8	NA	16		
	ROR Rel. Date	LR-F	0.4987	6	5/15/98	4.0	NA	25	NT	5B
					5/18/98	27.8	NA	18		
					5/23/98	20.0	NA	25		
					5/24/98	35.0	NA	20		
					5/30/98	8.3	NA	24		
					6/1/98	40.0	NA	15		

C29199

Appendix II.

Release	Measure	Test	P value	T	Type	Value	SE	N	Diff.s	Figure
4/29/98	Weight (g)	ANOVA	0.023	44	ROR-Telemetry	NA	NA	NA	NA	2A
					Barge-Telemetry	33.00	2.42	24	B	
					Post-Barge	24.32	1.19	10	A	
					Pre-Barge	25.36	1.68	10	A	
					ROR	NA	NA	NA	NA	
	Length (cm)	ANOVA	0.0492	44	ROR-Telemetry	NA	NA	NA	NA	2B
					Barge-Telemetry	14.53	0.30	24	B	
					Post-Barge	13.60	0.24	10	AB	
					Pre-Barge	13.56	0.29	10	A	
					ROR	NA	NA	NA	NA	
	Cortisol	K-W	0.0338	19	ROR-Telemetry	NA	NA	NA	NA	11A
					Barge-Telemetry	NA	NA	NA	NA	
					Post-Barge	59.20	9.10	9	A	
					Pre-Barge	103.75	17.88	10	B	
					ROR	NA	NA	NA	NA	
	ATPase	K-W	0.1489	17	ROR-Telemetry	NA	NA	NA	NT	11B
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	26.46	1.52	9		
					Pre-Barge	22.85	2.94	8		
					ROR	NA	NA	NA		
	BKD	Fisher's	0.3034	2	ROR-Telemetry	NA	NA	NA	NT	11C
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	0.400	NA	10		
					Pre-Barge	0.100	NA	10		
					ROR	NA	NA	NA		
	Migration Speed (mph)	ANOVA	NT	NT	ROR-Telemetry	NA	NA	NA	NT	3B
					Barge-Telemetry	1.56	0.09	15		
					Post-Barge	NA	NA	NA		
					Pre-Barge	NA	NA	NA		
					ROR	NA	NA	NA		
5/2/98	Weight (g)	ANOVA	0.3907	40	ROR-Telemetry	NA	NA	NA	NT	2A
					Barge-Telemetry	27.74	1.10	20		
					Post-Barge	25.10	1.97	10		
					Pre-Barge	27.64	1.38	10		
					ROR	NA	NA	NA		
	Length (cm)	ANOVA	0.894	40	ROR-Telemetry	NA	NA	NA	NT	2B
					Barge-Telemetry	13.89	0.17	20		
					Post-Barge	14.05	0.38	10		
					Pre-Barge	13.92	0.27	10		
					ROR	NA	NA	NA		
	Cortisol	K-W	0.8798	20	ROR-Telemetry	NA	NA	NA	NT	11A
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	118.92	18.66	10		
					Pre-Barge	112.55	16.79	10		
					ROR	NA	NA	NA		
	ATPase	K-W	0.0065	20	ROR-Telemetry	NA	NA	NA	NA	11B
					Barge-Telemetry	NA	NA	NA	NA	
					Post-Barge	38.13	4.69	10	B	
					Pre-Barge	19.37	2.68	10	A	
					ROR	NA	NA	NA	NA	
	BKD	Fisher's	0.6849	2	ROR-Telemetry	NA	NA	NA	NT	11C
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	0.600	NA	10		
					Pre-Barge	0.500	NA	10		
					ROR	NA	NA	NA		
	Migration Speed (mph)	ANOVA	NT	NT	ROR-Telemetry	NA	NA	NA	NT	3B
					Barge-Telemetry	1.64	0.07	20		
					Post-Barge	NA	NA	NA		
					Pre-Barge	NA	NA	NA		
					ROR	NA	NA	NA		
5/7/98	Weight (g)	ANOVA	0.0744	46	ROR-Telemetry	NA	NA	NA	NT	2A
					Barge-Telemetry	30.00	1.09	26		
					Post-Barge	25.63	1.29	10		
					Pre-Barge	30.75	2.09	10		
					ROR	NA	NA	NA		

C29200

	Length (cm)	ANOVA	0.1423	46	ROR-Telemetry	NA	NA	NA	NT	2B
					Barge-Telemetry	14.25	0.17	26		
					Post-Barge	14.90	0.32	10		
					Pre-Barge	14.19	0.33	10		
					ROR	NA	NA	NA		
	Cortisol	K-W	0.7624	20	ROR-Telemetry	NA	NA	NA	NT	11A
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	130.36	33.54	10		
					Pre-Barge	114.75	14.97	10		
					ROR	NA	NA	NA		
	ATPase	K-W	0.0118	18	ROR-Telemetry	NA	NA	NA	NA	11B
					Barge-Telemetry	NA	NA	NA	NA	
					Post-Barge	34.60	2.72	9	B	
					Pre-Barge	26.09	1.61	9	A	
					ROR	NA	NA	NA	NA	
	BKD	Fisher's	0.0198	2	ROR-Telemetry	NA	NA	NA	NA	11C
					Barge-Telemetry	NA	NA	NA	NA	
					Post-Barge	0.700	NA	10	B	
					Pre-Barge	0.100	NA	10	A	
					ROR	NA	NA	NA	NA	
	Migration Speed (mph)	ANOVA	NT	NT	ROR-Telemetry	NA	NA	NA	NT	3B
					Barge-Telemetry	2.15	0.07	17		
					Post-Barge	NA	NA	NA		
					Pre-Barge	NA	NA	NA		
					ROR	NA	NA	NA		
5/10/98	Weight (g)	ANOVA	0.4849	36	ROR-Telemetry	NA	NA	NA	NT	2A
					Barge-Telemetry	31.48	0.99	19		
					Post-Barge	29.48	2.54	8		
					Pre-Barge	29.13	1.94	9		
					ROR	NA	NA	NA		
	Length (cm)	ANOVA	0.2007	36	ROR-Telemetry	NA	NA	NA	NT	2B
					Barge-Telemetry	14.49	0.19	19		
					Post-Barge	15.06	0.47	8		
					Pre-Barge	14.21	0.31	9		
					ROR	NA	NA	NA		
	Cortisol	K-W	0.4914	16	ROR-Telemetry	NA	NA	NA	NT	11A
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	136.79	14.83	7		
					Pre-Barge	118.62	16.12	9		
					ROR	NA	NA	NA		
	ATPase	K-W	0.1779	17	ROR-Telemetry	NA	NA	NA	NT	11B
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	37.55	7.06	8		
					Pre-Barge	26.13	3.91	9		
					ROR	NA	NA	NA		
	BKD	Fisher's	0.7941	2	ROR-Telemetry	NA	NA	NA	NT	11C
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	0.125	NA	8		
					Pre-Barge	0.111	NA	9		
					ROR	NA	NA	NA		
	Migration Speed (mph)	ANOVA	NT	NT	ROR-Telemetry	NA	NA	NA	NT	3B
					Barge-Telemetry	2.22	0.14	13		
					Post-Barge	NA	NA	NA		
					Pre-Barge	NA	NA	NA		
					ROR	NA	NA	NA		
5/15/98	Weight (g)	ANOVA	0.0006	57	ROR-Telemetry	43.45	2.98	23	B	2A
					Barge-Telemetry	32.55	1.26	24	A	
					Post-Barge	NM	NM	NM	NM	
					Pre-Barge	30.89	1.87	10	A	
					ROR	NM	NM	NM	NM	
	Length (cm)	ANOVA	0.0000	79	ROR-Telemetry	16.46	0.37	25	B	2B
					Barge-Telemetry	14.70	0.20	24	A	
					Post-Barge	14.60	0.35	10	A	
					Pre-Barge	14.29	0.27	10	A	
					ROR	16.45	0.68	10	B	
	Cortisol	ANOVA	0.0079	30	ROR-Telemetry	NA	NA	NA	NA	11A
					Barge-Telemetry	NA	NA	NA	NA	
					Post-Barge	81.16	10.64	10	A	
					Pre-Barge	153.16	19.21	10	B	

C29201

					ROR	100.34	15.30	10	A	
	ATPase	K-W	0.5596	28	ROR-Telemetry	NA	NA	NA	NT	11B
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	30.20	3.08	10		
					Pre-Barge	26.95	1.77	9		
					ROR	33.37	5.75	9		
	BKD	χ^2	0.0507	3	ROR-Telemetry	NA	NA	NA	NT	11C
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	0.500	NA	10		
					Pre-Barge	0.100	NA	10		
					ROR	0.100	NA	10		
	Migration Speed (mph)	ANOVA	0.0002	45	ROR-Telemetry	2.39	0.05	24	B	3B
					Barge-Telemetry	2.05	0.07	21	A	
					Post-Barge	NA	NA	NA	NA	
					Pre-Barge	NA	NA	NA	NA	
					ROR	NA	NA	NA	NA	
5/18/98	Weight (g)	ANOVA	0.0952	60	ROR-Telemetry	38.34	4.29	18	NT	2A
					Barge-Telemetry	28.89	1.06	19		
					Post-Barge	29.34	3.24	10		
					Pre-Barge	33.41	1.26	10		
					ROR	25.93	4.94	3		
	Length (cm)	ANOVA	0.0722	60	ROR-Telemetry	15.46	0.50	18	NT	2B
					Barge-Telemetry	14.15	0.18	19		
					Post-Barge	14.45	0.42	10		
					Pre-Barge	15.01	0.22	10		
					ROR	14.00	1.15	3		
	Cortisol	K-W	0.4518	23	ROR-Telemetry	NA	NA	NA	NT	11A
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	100.35	27.40	10		
					Pre-Barge	110.04	13.18	10		
					ROR	128.70	55.51	3		
	ATPase	K-W	0.5152	22	ROR-Telemetry	NA	NA	NA	NT	11B
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	27.62	2.14	9		
					Pre-Barge	22.06	2.56	10		
					ROR	26.69	9.20	3		
	BKD	χ^2	0.3724	3	ROR-Telemetry	NA	NA	NA	NT	11C
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	0.600	NA	10		
					Pre-Barge	0.300	NA	10		
					ROR	0.333	NA	3		
	Migration Speed (mph)	ANOVA	0.0000	31	ROR-Telemetry	2.44	0.05	14	B	3B
					Barge-Telemetry	2.00	0.07	17	A	
					Post-Barge	NA	NA	NA	NA	
					Pre-Barge	NA	NA	NA	NA	
					ROR	NA	NA	NA	NA	
5/23/98	Weight (g)	ANOVA	0.6253	54	ROR-Telemetry	38.51	2.99	14	NT	2A
					Barge-Telemetry	36.91	1.11	20		
					Post-Barge	NS	NS	NS		
					Pre-Barge	34.85	1.63	10		
					ROR	33.81	4.90	10		
	Length (cm)	ANOVA	0.0331	65	ROR-Telemetry	16.15	0.29	25	B	2B
					Barge-Telemetry	15.15	0.20	20	A	
					Post-Barge	NS	NS	NS	NS	
					Pre-Barge	15.06	0.26	10	A	
					ROR	15.65	0.52	10	AB	
	Cortisol	K-W	0.0191	20	ROR-Telemetry	NA	NA	NA	NA	11A
					Barge-Telemetry	NA	NA	NA	NA	
					Post-Barge	NS	NS	NS	NS	
					Pre-Barge	124.15	12.27	10	B	
					ROR	75.86	15.46	10	A	
	ATPase	K-W	0.6831	19	ROR-Telemetry	NA	NA	NA	NT	11B
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	NS	NS	NS		
					Pre-Barge	26.24	2.00	10		
					ROR	28.00	2.61	9		
	BKD	Fisher's	0.3699	2	ROR-Telemetry	NA	NA	NA	NT	11C
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	NS	NS	NS		

					Pre-Barge	0.700	NA	10		
					ROR	0.400	NA	10		
	Migration Speed (mph)	ANOVA	0.0003	36	ROR-Telemetry	2.36	0.06	18	B	3B
					Barge-Telemetry	1.95	0.08	18	A	
					Post-Barge	NA	NA	NA	NA	
					Pre-Barge	NA	NA	NA	NA	
					ROR	NA	NA	NA	NA	
5/24/98	Weight (g)	ANOVA	0.1931	51	ROR-Telemetry	NM	NM	NM	NT	2A
					Barge-Telemetry	33.99	1.19	25		
					Post-Barge	31.67	2.54	6		
					Pre-Barge	38.60	2.44	10		
					ROR	35.26	2.43	10		
	Length (cm)	ANOVA	0.0137	71	ROR-Telemetry	15.28	0.25	20	B	2B
					Barge-Telemetry	14.54	0.15	25	A	
					Post-Barge	14.58	0.45	6	AB	
					Pre-Barge	15.54	0.31	10	B	
					ROR	15.49	0.36	10	B	
	Cortisol	K-W	0.0004	25	ROR-Telemetry	NA	NA	NA	NA	11A
					Barge-Telemetry	NA	NA	NA	NA	
					Post-Barge	77.40	18.50	5	A	
					Pre-Barge	158.18	17.57	10	B	
					ROR	43.04	7.09	10	A	
	ATPase	K-W	0.1442	25	ROR-Telemetry	NA	NA	NA	NT	11B
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	24.89	3.82	5		
					Pre-Barge	27.17	3.47	10		
					ROR	33.02	2.71	10		
	BKD	χ^2	0.369	3	ROR-Telemetry	NA	NA	NA	NT	11C
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	0.167	NA	6		
					Pre-Barge	0.500	NA	10		
					ROR	0.300	NA	10		
	Migration Speed (mph)	ANOVA	0.0106	35	ROR-Telemetry	2.44	0.08	12	B	3B
					Barge-Telemetry	2.16	0.06	23	A	
					Post-Barge	NA	NA	NA	NA	
					Pre-Barge	NA	NA	NA	NA	
					ROR	NA	NA	NA	NA	
5/30/98	Weight (g)	ANOVA	0.0389	55	ROR-Telemetry	40.42	2.63	24	AB	2A
					Barge-Telemetry	34.08	2.28	14	A	
					Post-Barge	22.85	3.45	2	A	
					Pre-Barge	31.46	3.61	5	A	
					ROR	48.59	7.14	10	B	
	Length (cm)	ANOVA	0.0014	55	ROR-Telemetry	16.12	0.32	24	BC	2B
					Barge-Telemetry	14.57	0.31	14	A	
					Post-Barge	13.30	0.80	2	A	
					Pre-Barge	14.46	0.31	5	AB	
					ROR	17.04	0.84	10	C	
	Cortisol	K-W	0.1294	17	ROR-Telemetry	NA	NA	NA	NT	11A
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	80.16	18.16	2		
					Pre-Barge	153.26	28.45	5		
					ROR	91.38	19.55	10		
	ATPase	K-W	0.1075	15	ROR-Telemetry	NA	NA	NA	NT	11B
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	16.27	2.70	2		
					Pre-Barge	18.65	2.71	5		
					ROR	22.55	1.88	8		
	BKD	χ^2	0.7622	3	ROR-Telemetry	NA	NA	NA	NT	11C
					Barge-Telemetry	NA	NA	NA		
					Post-Barge	0.500	NA	2		
					Pre-Barge	0.400	NA	5		
					ROR	0.600	NA	10		
	Migration Speed (mph)	K-W	0.0956	14	ROR-Telemetry	2.75	0.27	9	NT	3B
					Barge-Telemetry	2.31	0.25	5		
					Post-Barge	NA	NA	NA		
					Pre-Barge	NA	NA	NA		
					ROR	NA	NA	NA		
6/1/98	Weight (g)	ANOVA	0.0172	37	ROR-Telemetry	44.89	4.95	14	B	2A
					Barge-Telemetry	37.63	2.43	16	AB	

C29203

					Post-Barge	24.33	3.36	6	A		
					Pre-Barge	NS	NS	NS	NS		
					ROR	59.00	NA	1	B		
	Length (cm)	ANOVA	0.0023	38	ROR-Telemetry	16.37	0.54	15	B	2B	
					Barge-Telemetry	15.06	0.30	16	A		
					Post-Barge	13.48	0.57	6	A		
					Pre-Barge	NS	NS	NS	NS		
					ROR	18.60	NA	1	B		
	Cortisol	K-W	0.7697	6	ROR-Telemetry	NA	NA	NA	NT	11A	
					Barge-Telemetry	NA	NA	NA			
					Post-Barge	90.06	35.93	5			
					Pre-Barge	NS	NS	NS			
					ROR	75.64	NA	1			
	ATPase	K-W	0.3798	6	ROR-Telemetry	NA	NA	NA	NT	11B	
					Barge-Telemetry	NA	NA	NA			
					Post-Barge	34.48	10.24	5			
					Pre-Barge	NS	NS	NS			
					ROR	19.27	NA	1			
	BKD	Fisher's	0.1429	2	ROR-Telemetry	NA	NA	NA	NT	11C	
					Barge-Telemetry	NA	NA	NA			
					Post-Barge	0.000	NA	6			
					Pre-Barge	NS	NA	NS			
					ROR	1.000	NA	1			
	Migration Speed (mph)	K-W	0.0179	29	ROR-Telemetry	2.83	0.19	13	B	3B	
					Barge-Telemetry	2.39	0.16	16	A		
					Post-Barge	NA	NA	NA	NA		
					Pre-Barge	NA	NA	NA	NA		
					ROR	NA	NA	NA	NA		
Season	Weight (g)	ANOVA	0.0000	189	Avian Prey	28.00	6.68	9	AB	12A	
					Post-Barge	26.80	0.88	62	A		
					Pre-Barge	31.36	0.74	84	B		
					ROR	38.63	2.94	34	C		
	Length (cm)	ANOVA	0.0000	209	Avian Prey	13.59	1.00	9	A	12B	
					Post-Barge	14.33	0.14	72	A		
					Pre-Barge	14.48	0.11	84	A		
					ROR	16.07	0.31	44	B		
	ATPase	ANOVA	0.0005	193	Avian Prey	23.13	3.13	6	AB	12C	
					Post-Barge	31.51	1.58	67	B		
					Pre-Barge	24.21	0.94	80	A		
					ROR	29.06	1.79	40	B		
	BKD	χ^2	0.2203	4	Avian Prey	0.13	NA	8	NT	12D	
					Post-Barge	0.43	NA	72			
					Pre-Barge	0.31	NA	84			
					ROR	0.36	NA	44			

C29204