Fishery Manuscript Series No. 14-02

# Studies of Coho Salmon and Other *Oncorhynchus* Species at Ford Arm Creek, 1982–2009

by

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**Weights and measures (metric)**

| | |
|---|---|
| centimeter | cm |
| deciliter | dL |
| gram | g |
| hectare | ha |
| kilogram | kg |
| kilometer | km |
| liter | L |
| meter | m |
| milliliter | mL |
| millimeter | mm |

**Weights and measures (English)**

| | |
|---|---|
| cubic feet per second | $ft^3/s$ |
| foot | ft |
| gallon | gal |
| inch | in |
| mile | mi |
| nautical mile | nmi |
| ounce | oz |
| pound | lb |
| quart | qt |
| yard | yd |

**Time and temperature**

| | |
|---|---|
| day | d |
| degrees Celsius | °C |
| degrees Fahrenheit | °F |
| degrees kelvin | K |
| hour | h |
| minute | min |
| second | s |

**Physics and chemistry**

| | |
|---|---|
| all atomic symbols | |
| alternating current | AC |
| ampere | A |
| calorie | cal |
| direct current | DC |
| hertz | Hz |
| horsepower | hp |
| hydrogen ion activity (negative log of) | pH |
| parts per million | ppm |
| parts per thousand | ppt, ‰ |
| volts | V |
| watts | W |

**General**

| | |
|---|---|
| Alaska Administrative Code | AAC |
| all commonly accepted abbreviations | e.g., Mr., Mrs., AM, PM, etc. |
| all commonly accepted professional titles | e.g., Dr., Ph.D., R.N., etc. |
| at | @ |
| compass directions: | |
| east | E |
| north | N |
| south | S |
| west | W |
| copyright | © |
| corporate suffixes: | |
| Company | Co. |
| Corporation | Corp. |
| Incorporated | Inc. |
| Limited | Ltd. |
| District of Columbia | D.C. |
| et alii (and others) | et al. |
| et cetera (and so forth) | etc. |
| exempli gratia (for example) | e.g. |
| Federal Information Code | FIC |
| id est (that is) | i.e. |
| latitude or longitude | lat. or long. |
| monetary symbols (U.S.) | $, ¢ |
| months (tables and figures): first three letters | Jan,...,Dec |
| registered trademark | ® |
| trademark | ™ |
| United States (adjective) | U.S. |
| United States of America (noun) | USA |
| U.S.C. | United States Code |
| U.S. state | use two-letter abbreviations (e.g., AK, WA) |

**Mathematics, statistics**

| | |
|---|---|
| *all standard mathematical signs, symbols and abbreviations* | |
| alternate hypothesis | $H_A$ |
| base of natural logarithm | *e* |
| catch per unit effort | CPUE |
| coefficient of variation | CV |
| common test statistics | (F, t, $\chi^2$, etc.) |
| confidence interval | CI |
| correlation coefficient (multiple) | R |
| correlation coefficient (simple) | r |
| covariance | cov |
| degree (angular ) | ° |
| degrees of freedom | df |
| expected value | *E* |
| greater than | > |
| greater than or equal to | ≥ |
| harvest per unit effort | HPUE |
| less than | < |
| less than or equal to | ≤ |
| logarithm (natural) | ln |
| logarithm (base 10) | log |
| logarithm (specify base) | $log_2$, etc. |
| minute (angular) | ' |
| not significant | NS |
| null hypothesis | $H_O$ |
| percent | % |
| probability | P |
| probability of a type I error (rejection of the null hypothesis when true) | α |
| probability of a type II error (acceptance of the null hypothesis when false) | β |
| second (angular) | " |
| standard deviation | SD |
| standard error | SE |
| variance | |
| population | Var |
| sample | var |

# *FISHERY MANUSCRIPT SERIES NO. 14-02*

# STUDIES OF COHO SALMON AND OTHER *ONCORHYNCHUS* SPECIES AT FORD ARM CREEK, 1982–2009

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# ABSTRACT

The coho salmon population in Ford Arm Creek was studied as an indicator for fishery management during 1980–2009. The estimated presmolt population averaged 80,576 fish (range: 38,509–134,640) and survival to adulthood averaged 11.2% (range: 4.6–21.9%). A robust trend in presmolt abundance and survival increased at respective rates of 4.6% and 0.6% of the initial reference point per year. Adult returns averaged 8,612 fish (range: 3,233–16,124). Escapements were consistently within or above the *biological* escapement goal (BEG) of 1,300–2,900 spawners. Spawner-recruit analysis using a conventional Beverton-Holt model and a bent hockey stick model (incorporating pink salmon escapement) both support a BEG near the current goal. Based on the latter model, the nutrient subsidy from pink salmon was more influential, explaining 57% of variation in abundance compared with 5% explained by parent escapement. Analysis using a logistic hockey stick model predicts doubling of the coho return as the pink salmon escapement increases from a low index count of 10 thousand spawners to a nominal saturation point at 116 thousand spawners. The biomass density of all species at 90–99% of maximum coho salmon production was estimated at 1.30–1.93 pink salmon equivalents per $m^2$. Although the average exploitation rate of 60% (53% troll, 4% seine, 3% marine sport) was well below model estimates of the equilibrium exploitation rate at MSY (72–85%), management effectiveness in achieving MSY was estimated to be high (79–93%) due in part to a positive linear relationship between escapement and return. We include a watershed inventory, escapement counts for other species, and additional information on sockeye salmon (catch, age composition, spawner-recruit relationship, sibling forecast). Ford Arm Creek demonstrates the potential for a small, pristine, structurally complex system to produce large, diverse fishery benefits while functioning near its full ecological potential.



Key words: Coho salmon, *Oncorhynchus kisutch*, sockeye, pink, chum, steelhead, escapement, escapement goals, spawner-recruit, exploitation rates, marine derived nutrients, Ford Arm Creek, Southeast Alaska.


# INTRODUCTION

The coho salmon (*Oncorhynchus kisutch*) population in Ford Arm Creek is one of four wild coho salmon stocks in Southeast Alaska that have been monitored by the Alaska Department of Fish and Game (ADF&G) for over 25 years. In the 1970s and 1980s, substantial concern arose among fishery managers about the sustainability of the region's coho salmon fisheries because of the extensive gauntlet of commercial troll, net, and sport fisheries encountered by many stocks. In order to address this concern, juvenile marking and adult recovery projects were implemented to evaluate migration patterns, timing, and exploitation rates. The studies were first carried out in streams in inside areas of northern Southeast Alaska using fluorescent pigment to mark specific stocks (Gray et al. 1978) and were later expanded using coded-wire tags to mark stocks in outer coastal and southern areas of the region (Shaul et al. 1985). Ford Arm Creek was initially chosen for study because, based on its central location in the area of most intensive commercial trolling, it appeared representative of stocks subjected to potentially very high, unsustainable exploitation rates. In May 1982, a panel of salmon research experts was convened to chart the future of coho salmon research in Southeast Alaska (ADF&G 1983). The panel recommended that detailed, long-term studies be undertaken on specific streams in the region, including Ford Arm Creek.

Since 1982, Ford Arm Creek has served as the primary indicator stock for management of wild coho salmon populations on the outer coast of northern Southeast Alaska. A detailed study of population and fishery parameters has been conducted annually at Ford Arm Creek since 1980 (Shaul 1994, Shaul et al. 1985, 1986, 1991, 2005, 2008 and 2011), with the exception that presmolt tagging was not conducted in 1982 and the adult weir was not operated in 1984. An escapement goal was established in 1994 from a Ricker spawner-recruit analysis by Clark et al. (1994), based on seven paired estimates of brood year escapement and return. Studies at Ford Arm Creek have been supplemented by escapement index counts on five streams in the nearby Sitka Area (Shaul and Tydingco 2006) and detailed population studies conducted for shorter periods on two systems in Sitka Sound—a full indicator-stock study conducted annually on the

Nakwasina River since 2000 (Brookover et al. 2001 and 2003; Tydingco 2003, 2005a, 2005b, 2006 and 2010; Tydingco and Fowler 2010) and similar studies conducted intermittently at Salmon Lake (Schmidt 1996; Tydingco et al. 2006 and 2008).

In this report, we will update biological and fishery information collected for the Ford Arm Creek coho salmon stock through the 2009 return and compare findings with other wild coho indicator stocks in Auke Creek, Berners River and Hugh Smith Lake. We will review the current *biological escapement goal* (BEG) developed by Clark et al. (1994) and recommend a revised goal based on (1) updated escapement and production data, (2) revised freshwater age estimates informed by recent aging validation work, and (3) spawner-recruit models more appropriate for coho salmon than the standard Ricker model. We will examine temporal change in carrying capacity in the system in relation to inputs of marine derived nutrients from salmon carcasses. We will also examine the migratory characteristics of the stock and changes in rates and patterns of exploitation over a period of 2½ decades. We will present and discuss methods developed to forecast the total adult return and spawning escapement to Ford Arm Creek during the fishing season. We will also present abundance and age and sex information collected incidentally for other *Oncorhynchus* species, including sockeye (*O. nerka*; Appendix B), pink (*O. gorbuscha*), and chum (*O. keta*) salmon and steelhead (*O. mykiss*; Appendix C). Finally, we will present results of surveys to quantitatively map anadromous fish habitat in the system (Appendix D).

# STUDY SITE

Ford Arm Creek (55° 36’ N, 135° 53’ W) is situated 72 km north of Sitka in Ford Arm on the outer coast of Chichagof Island in Southeast Alaska (Figure 1). Nearly the entire accessible drainage, including the lake and inlet and outlet streams, provides excellent rearing habitat for coho salmon. A detailed description of the physical characteristics of the watershed and fish habitat is presented in Appendix D and by Nichols and Williams (2012).

Ford Arm Lake is surrounded by mountains, has a drainage area of 2,540 ha and is supplied by four tributaries with significant fish habitat (Figure 2 and Appendixes D1–D8). The lake (Figure 3) has a surface area of 39.4 ha, a total volume of $1.03 \times 10^7$ $m^3$, a mean depth of 11 m, and a maximum depth of 25 m. The lake water is organically stained: Schmidt (1974) reported secchi disc visibility of 4.2 m on 31 July 1973, and a slightly acidic pH of 6.7. The southern end of the lake, near the outlet, is shallow and has abundant aquatic vegetation, whereas the upper basin is deeper and has a steeper slope at the margins. Fallen timber around the shoreline provides important habitat structure for rearing coho salmon. Coho salmon also rear in a small beaver pond, called Mouse Pond, located northeast of the lake on Stream C, and have been observed spawning in all four of the primary inlet streams (A, B, C, and D) as well as in the outlet stream (Figure 2). No spawning by sockeye salmon has been observed in the inlet streams—most spawning by that species occurs along lakeshore beaches and to a lesser extent in the outlet between the weir and lake.

The lake is approximately 1.6 km in length and is just long enough to safely land and depart in a floatplane appropriately designed and powered for short take-offs, and carrying a reasonable load. There are significant obstacles at either end of the lake. Weather conditions for flying to and from Ford Arm Lake are some of the most unreliable to be found along the coast of Southeast Alaska and British Columbia because of build-up of ocean fog during calm, sunny conditions, in addition to the normal clouds and fog that typically materialize during periods of low atmospheric pressure. Windy conditions combined with the steep surrounding terrain can create dangerous drafts for approaching or departing aircraft.

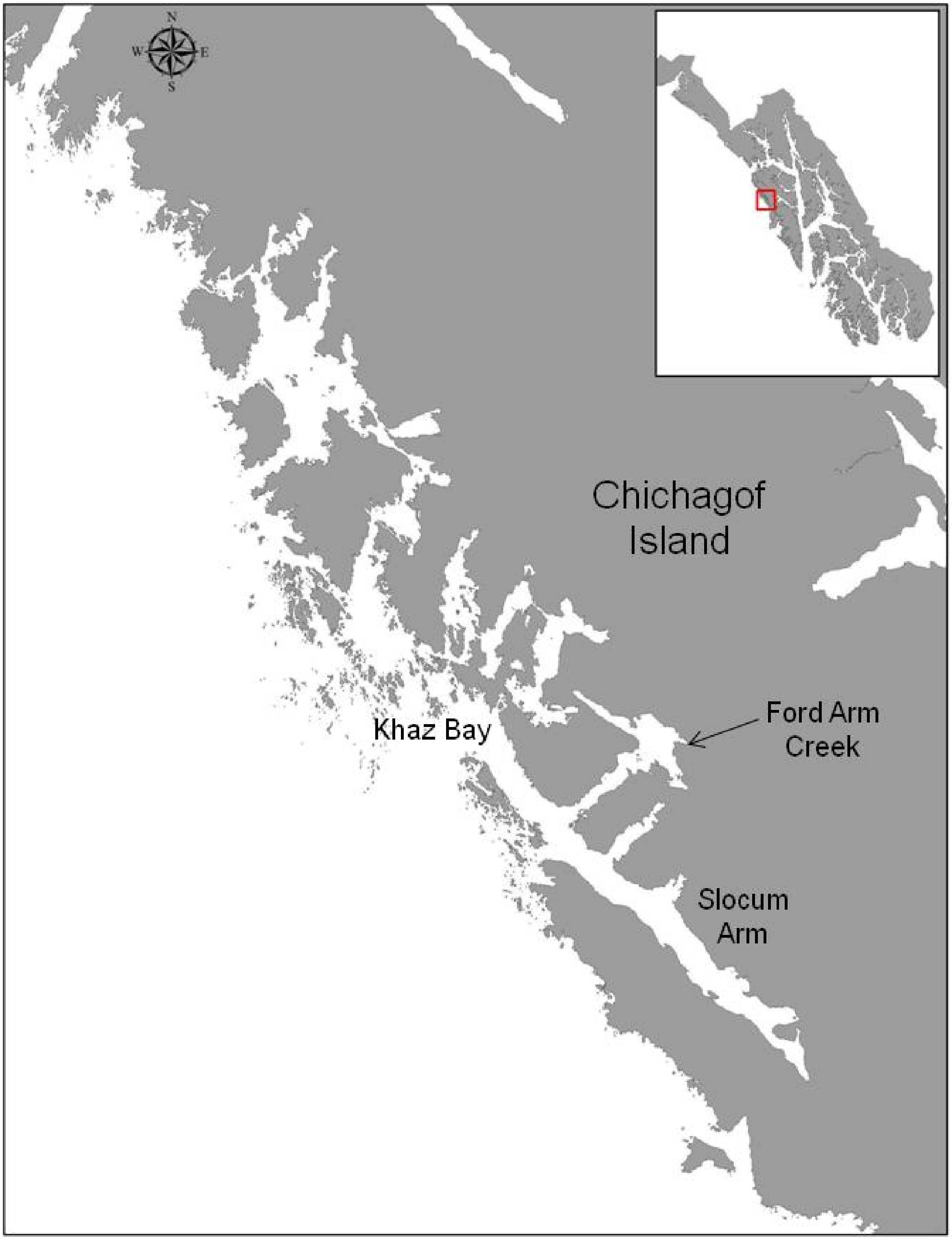


Figure 1.–The location of Ford Arm Creek in Southeast Alaska.

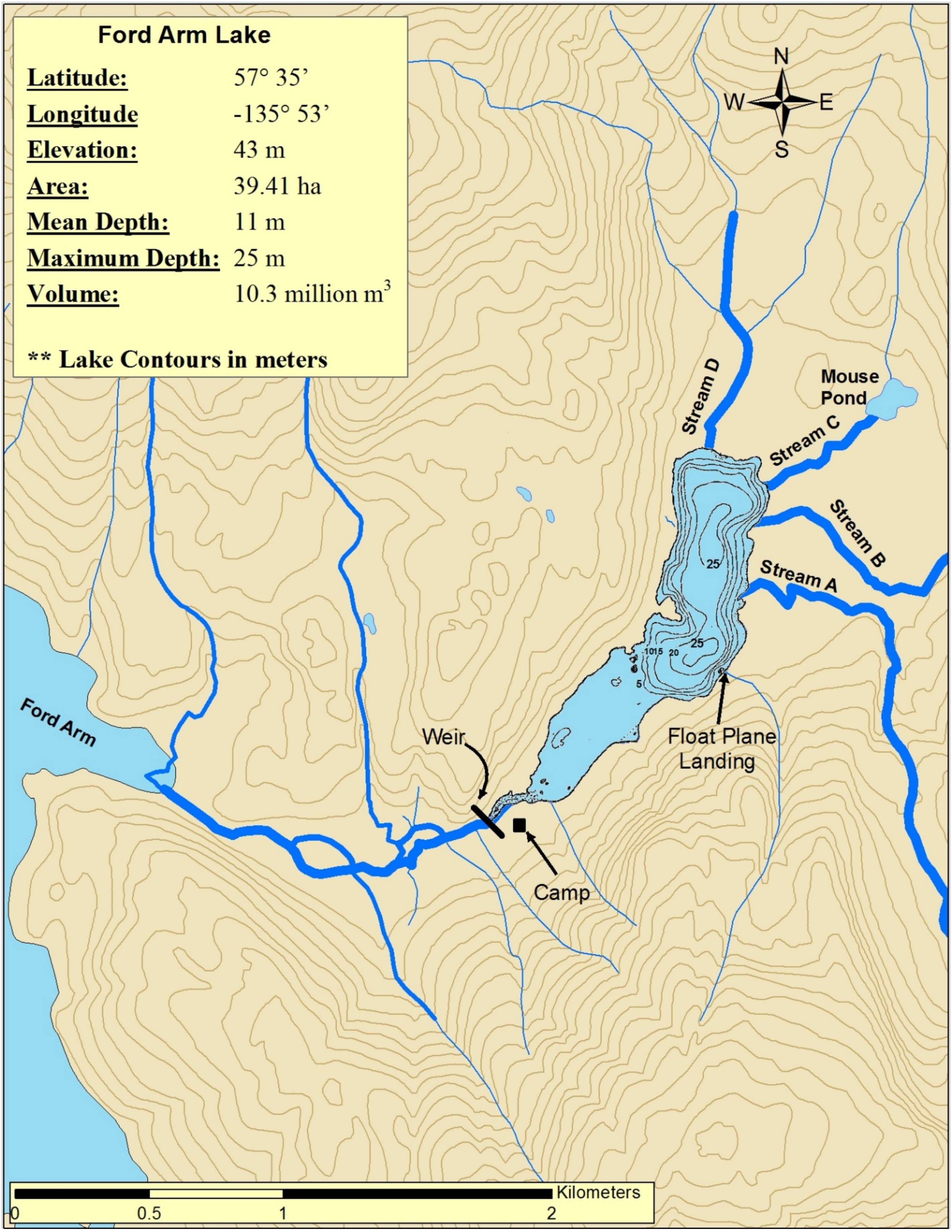


Figure 2.–Map of the Ford Arm Creek drainage, Southeast Alaska, showing the location of the weir, camp, lake (with bathymetric contours) and inlet and outlet streams.

Figure 3.–Ford Arm Lake looking upstream from the outlet. (©2009 ADF&G/photo by Leon Shaul.)

The accessible channel length of tributary streams totals 10.75 km (Appendix D). There are also 4.9 km of lake and pond shoreline in the system. If the relatively narrow lake and Mouse Pond are viewed as wide stream sections, all reaches accessible to salmon total to 13.2 km in total length.

Ford Arm Creek, the outlet stream from the lake, enters Ford Arm, which connects with the Gulf of Alaska through Slocum Arm and Khaz Bay (Figure 1). The average width of the creek is about 15 m and average depth is about 0.6 m. Over a distance of 1.7 km, the creek splits into braided channels totaling 2.7 km that contain excellent spawning gravel, deep pools, and numerous windfalls. The creek banks are partly shaded with alder, devils club, and salmonberry, and the surrounding spruce forest has an open understory.

The drainage, located entirely within the West Chichagof-Yakobi Wilderness area, appears in pristine condition. A narrow canyon, combined with large boulders spaced across the stream near the estuary, likely spared large riparian spruce from removal by bulldozers under the Spruce Log Program that supplied wood for World War II aircraft (Rakestraw 1981). Some exceptionally large Sitka spruce trees occur in the drainage, including one specimen located north of the lake between streams C and D that we measured at 9.4 m in circumference at 1.5 m above ground.

Ford Arm Creek has long been used as a subsistence fishing site by the Tlingit, primarily the T'akdeintaan Clan and to a lesser extent the Kaagwaantaan Clan (Goldschmidt and Haas 1998).

It remains an important subsistence sockeye salmon fishing location although participation since 1985 has varied substantially within a range of 1–55 (average 12) permits reported fished (Appendix B2). Ford Arm Creek is relatively remote compared with several other sockeye salmon fishing locations in the Sitka area. However, its early run timing provides an important subsistence fishing opportunity in early to mid-July before most other local runs materialize. It has been most intensively fished in years when fishing was poor or closed at Redoubt Lake, a more accessible early-run system in Sitka Sound. Since the fishery occurs early in the year, only sockeye salmon and occasional chum salmon are usually reported in the subsistence catch. Although the system has undoubtedly had occasional visitation by freshwater sport fishermen during late summer and fall, historical mail-out survey records indicate only occasional trace levels of coho salmon harvest (Mike Jaenicke, ADF&G, Division of Sport Fish, personal communication).

The first record of commercial exploitation of salmon runs in the Ford Arm Creek system dates to 1911 when the Cape Edward Cannery was constructed at tidewater west of Ford Arm Creek (Rich and Ball 1933). The cannery was operated until 1924, and only weathered pilings remain. During 1911–1927, recorded harvests in Ford Arm ranged as high as 3,121 coho, 11,204 chum, 25,689 pink, and 4,876 sockeye salmon. Averages for years with reported landings were 1,320 coho, 2,390 chum, 4,901 pink, and 1,330 sockeye salmon. These catches were well within the range of recent runs of these species, as documented in this report. Sockeye salmon escapements were estimated for 1983–2009 (excluding 1984), based primarily on mark-recapture methods (Appendix B2).

Substantial runs of pink salmon and summer and early-fall chum salmon spawn primarily in the outlet stream, below the weir, and have been routinely surveyed but not completely enumerated. There has been a strong increasing trend in escapements of both species since the early 1980s (Appendix C1). Pink salmon enter the stream during August and typically reach peak abundance in the creek near the end of the month. The early chum salmon run enters the stream in July and early August and spawns primarily during early to mid-August, and the later run arrives from mid-August through mid-September, with average peak passage at the weir occurring in the first week of September.

The system also provides excellent rearing habitat for juvenile steelhead and hosts a dense population of the species. Repeated snorkel surveys have been conducted in the spring annually since 1997 (Harding 2012). A summary of steelhead peak counts and observations in this system is also included in Appendix C. There are abundant populations of both Dolly Varden (*Salvelinus malma*) and coastal cutthroat trout (*O. clarkii*).

Coho salmon production from Ford Arm Creek is high relative to surface area compared with other Southeast Alaska lake systems (Shaul et al. 1985) and very high for the length of stream and shoreline area (Shaul and Van Alen 2001). Most returning adult coho salmon enter the lake from mid-August through early-October and spawn from early October through November (Shaul et al. 1985).

# METHODS

## PRESMOLT CAPTURE AND TAGGING

During 1980–2007 (except 1982), as many rearing coho salmon presmolts as practical were captured using baited wire mesh minnow traps. The fish were adipose clipped, coded-wire tagged, and released in the system. Tagging trips were usually scheduled for a 12-day period during early to mid-July. In 1983 and 1985, however, presmolt tagging was conducted in conjunction with the weir operation in August. The objective was to tag about 10,000 presmolts, or about 10% or more of the population.

Figure 4.–The adult salmon weir installed on Ford Arm Creek near the outlet of the lake. (©2009 ADF&G/photo by Leon Shaul.)

The minnow traps were baited with salmon roe that was disinfected prior to use by immersion in a 5% Betadine solution for 15 minutes. Fifty traps were set and checked four times daily at 2-hour intervals under normal water conditions, and left to soak overnight. Up to 100 traps were set and checked twice daily under cold water conditions (less than 11° C) when fish were less active. Gray and Marriott (1986) described the minnow trapping method in detail. Juvenile coho salmon of 62 mm snout-fork length and larger were removed for tagging, while smaller fish and recaptured tagged fish were released immediately. Juveniles were held in pens before tagging until 1,000 to 4,000 were captured, but not for a period longer than 3 days.

A 4-person crew worked in pairs to systematically trap suitable habitat throughout the lake and outlet and inlet streams. One pair worked from a boat in the lake, while the other pair usually started trapping the outlet on foot. Suitable habitat in the inlet streams was also trapped on foot and a small raft or inflatable canoe was usually used to trap in Mouse Pond. Traps were set near suitable appearing habitat—around woody debris, under stream banks, or in aquatic vegetation—

and moved frequently in an attempt to maximize the overall catch. Each trap was fished in a given location until the number of new fish caught declined to a level at which further trapping in that location was judged to be no longer worthwhile due to diminishing return on effort.

Figure 5.–Ford Arm Creek adult salmon weir: wood and plant debris from a receding early fall freshet (left) and Tess, a female brown bear that frequented the weir for nearly two decades, foraging on accumulating carcasses (right). (©2009 ADF&G/photos by Ken Koolmo.)

In earlier years, only standard minnow traps made by the Cuba Specialty Manufacturing Co. were employed. In more recent years, several large, custom-made minnow traps described by Magnus et al. (2006) were added to the string of traps fished in the lake.

Koerner (1977) and Magnus et al. (2006) provided field guides for the tagging process, which involved anesthetization, sorting fish into three size groups, removal of the adipose fin, and injecting a coded-wire tag into the cartilage in the snout. After tagging, fish were transported back to the approximate area where they had been captured and released near suitable cover.

## ESCAPEMENT ESTIMATION AND SAMPLING

An adult salmon weir was operated in Ford Arm Creek during 1982–2009 (except 1984) at a point just downstream from the lake outlet where the water body first narrows and begins to increase in velocity (Figures 4 and 5). The weir and its trap were constructed of vertical pickets of ¾” EMT conduit supported in three 8’ sections of aluminum channel drilled to accommodate 43 evenly spaced pickets per section, with a larger hole on each end for 1” inside diameter black-iron pipe used to join weir sections together. To provide extra height in high water, the weir was extended from the top of the pickets to a wooden catwalk handrail using 2” × 2” 10 gauge or 12 gauge galvanized hardware cloth. The weir structure spanned 46 m and was supported every 8’ by 18 wooden tripods anchored upstream to the streambed using cable, turnbuckles, and sections of black-iron pipe. A trap constructed primarily of the same channel and conduit was installed near the deepest location on the upstream side of the weir.

The length of the project season varied over the years. The weir crew usually traveled to the lake on 8 or 9 August to install the weir, which, on average, became fully operational on 11 August. In 1982 and 1983, weir operation was terminated on 17 November. The ending date was moved progressively earlier, however, based on run timing observed during the initial years of the project: 27 October–5 November during 1985–1987, 21–25 October during 1988–1999, and 17–21 October during 2000–2009. Periodic downstream survey counts of spawners below the weir were conducted beginning in late September. The number of adults counted past the weir after each survey was subtracted from the survey count, and the highest resulting number was used to represent the number of spawners that entered the system but did not pass above the weir during the period of operation. That number was added to the count or estimate of adults that migrated above the weir during operation to obtain a total escapement estimate.

Mark-recapture population estimate studies were conducted annually as insurance against incomplete escapement counts caused by a breach or failure of the weir. Freshets accompanied by extreme flows are common in the fall at this location, although the lake helps to buffer variation in flow and reduce velocity. All healthy coho salmon that passed through the weir were captured in an 8’× 8’ trap, sampled for coded-wire tags, and marked with an appropriate mark before being released upstream. In recent years, a second 8’ × 8’ trap was installed beside the primary trap. The purpose of the secondary trap was to allow abundant pink and chum salmon to swim through both traps and out an upstream outlet in the secondary trap while capturing all coho and sockeye salmon for marking and sampling. Before the advent of a second trap, the risk of coho salmon moving quickly through the trap and escaping upstream unsampled was too high to leave an open upstream outlet, and pink and chum salmon had to be laboriously netted and pitched over the upright pickets of the weir and back into the stream. With the dual trap, one crew member stood guard by the trap outlet, counting departing pink and chum salmon, and closed the trap outlet when the other crew member, who was watching entering fish in the first trap, spotted a coho or sockeye salmon. Coho salmon were then removed for sampling and marking before the outlet in the second trap was reopened. Sockeye salmon were not sampled but were counted and given a dorsal fin clip.

Although a mark-recapture technique was used to estimate coho salmon escapement in most years, specific methods varied. Additional details for specific years are given in the results section. In 1982 and 1983, fish were tagged with numbered Floy tags (Shaul et al. 1985 and 1986). In 1982, all recovery effort was focused in spawning areas. The inlet streams were walked frequently in late October and November and mark-recovery effort was primarily conducted using dip nets and a beach seine. No correlation ($R^2$ = 0.03; $P$ = 0.95) was found between the date tagged at the weir and date recovered in spawning streams, and the estimated residence time of 91 fish in the lake averaged 26 days and varied from 1–78 days (Shaul et al. 1985). In 1983, spawners did not enter spawning streams until after mid-November; however, a two-person crew caught and sampled 71 adults from the shoreline at Stream B using spinning gear (primarily 1/4–3/8 oz. spoons and spinners) during 15–18 November. Sport fishing has since proven effective at several other locations around the shore and in the outlet area above the weir and has become the primary method used for mark-recovery sampling.

Based on the finding of a very poor temporal correlation between weir passage and spawning in 1982, all mark-recapture estimates were based on a single stratum estimator (Chapman's modification of Petersen's estimator for closed populations, Seber 1982, p. 60). Before 1988, mark recovery sampling was conducted only when problems occurred that were judged likely to allow fish to pass uncounted. Beginning in 1988, limited sampling for marks was conducted routinely before the weir was removed for the season. Sampling of fish in the lake before entry into spawning streams made it possible to routinely obtain a recovery sample and to validate the weir count without extending the field season beyond late October. Mark-recovery sampling was usually initiated in the lake around 10–12 October, when fish passage at the weir neared completion. Recovery sampling was conducted until a sample of at least 50 adults was obtained. If any unmarked fish were found in the sample, indicating leakage past the weir, the minimum sampling objective was increased to 100 adults.

Beginning in 1988, a partial dorsal clip was applied to all adults and jacks passed upstream of the weir before mark-recapture sampling commenced in the lake. The dorsal clip was accomplished by shearing the posterior 3 rays of the dorsal fin approximately 1 cm above the fish's back with wire cutters. Once mark-recovery sampling was initiated, usually around 10–12 October, all coho salmon passing the weir were marked only with a left opercular punch. All fish sampled above the weir were given a single right opercular punch for a secondary mark and released. All marks on new recovery samples were recorded and the fish were classified as adults (age .1) or jacks (age .0). The mark-recapture estimate was based only on unmarked fish in the recovery sample and recoveries of those fish that had been marked with a partial dorsal clip (before initiation of mark recovery sampling). The number of adults marked at the weir with a left opercular punch after the start of sampling was added to the estimate and excluded from the mark-recapture sample.

A record was made of every individual coho salmon captured in the weir trap. Fish were classified by sex and as jacks or adults based on length. Initially, males less than 450 mm (mideye to tail fork length) were classified as jacks, and females and males larger than 450 mm were classified as adults. However, the length distribution of early migrants was plotted and a different (usually smaller) length criterion was applied in some years when fish were unusually small, based on the least frequently observed length (distribution node) occurring between the peaks for age-.0 jacks and age-.1 adults (see Figure 9 for a composite length distribution for all years). In 1999, for example, the length used to discriminate between jacks and adults was reduced to 410 mm. On average, the optimal division point for classification of ocean age has been about 430 mm. The count of jacks was likely incomplete in all years because smaller jacks were often small enough to pass between the weir pickets.

All coho salmon captured in the trap were sampled for the presence or absence of an adipose fin, as an external marker indicating probable presence of a coded-wire tag. In initial years of the project (1982–1983), a sample of 20–27 adipose clipped adults was sacrificed, a numbered cinch tag was attached to each head, and the heads were sent to the ADF&G Mark, Tag and Age Laboratory in Juneau for tag removal and decoding. These small samples limited the impact of sampling mortality on the spawning population but provided an imprecise estimate of tag retention. During 1985–2009, all adipose clipped fish were examined with a magnetic field detector to determine if a tag was present. A trough style detector was used in earlier years prior to development of a more portable and water resistant wand style detector. Before 2004, fish that did not elicit a consistent signal on the magnetic field detector were sacrificed and their heads sent to the laboratory for further examination, whereas those that elicited a consistent signal were released. The laboratory results from several years indicated that an experienced crew could accurately determine the absence of a tag with a wand detector. Therefore, all adipose clipped fish examined after 2003 were released live after sampling with the wand, and marked fish that did not register a positive signal on the detector were assumed not to have a tag and were released rather than sacrificed.

The total season objective for age-length-sex samples was initially established at 600 fish, distributed as evenly as possible throughout the run. In earlier years, the sampling rate was initially established near or at 100% at the beginning of the run and reduced based on evidence that the escapement was substantially larger than the season sampling goal. Beginning in the mid-1990s, a total goal of 650 samples from adults and jacks combined was apportioned across fixed period targets based on average run timing. The goal began at 20 fish sampled during 10–23 August and increased to 70 during 24–30 August and 120 per week during 31 August–20 September before decreasing to 90 during 21–27 September, 80 during 28 September–4 October, and 30 during 5–25 October. Samples were selected randomly between adults and jacks, with the purpose of the combined goal of 650 samples being to achieve a sample of approximately 600 adults.

Each fish sampled for age-length-sex was anesthetized in a solution of tricaine methanesulfonate (MS-222) or clove oil (Woolsey et al. 2004), placed in a padded measuring trough and measured to the nearest millimeter (mideye to tail fork length). Four scales were taken from the left side of the fish approximately two rows above the lateral line in an area posterior of the dorsal fin to anterior of the anal fin (INPFC 1963). Scales were mounted on gum cards and impressions were later made in cellulose acetate (Clutter and Whitesel 1956).

## Estimation of Gross Escapement

The total number of adult coho salmon estimated to have entered Ford Arm Creek (i.e., gross escapement) was used to estimate total return (annual and by brood year), fishery exploitation rate, and survival rate. In most years, the gross escapement estimate was based on a Chapman mark-recapture estimate (Seber 1982, p. 60) of adults that passed the weir. Added to the mark-recapture estimate were fish marked and passed after the period of the estimate, fish estimated to have remained below the weir, and mortalities resulting from the weir operation that were not included in the mark-recapture estimate. The latter included fish sacrificed for samples, those found dead in the trap or observed killed by bears before being counted, and unspawned marked adults that washed up on the weir. All unspawned marked wash-ups were assumed to have died as a result of handing and sampling, and were subtracted from the number of marks released above the weir ($M$) but added to the mark-recapture estimate to generate the estimate of gross escapement. This assumption may be conservative, as some of these fish were injured or heavily diseased upon arrival at the weir. All coho salmon observed (or found as remains) caught by bears from the trap or on the downstream side of the weir were noted as mortalities and added to the count, while those caught by bears outside the trap on the upstream side of the weir were presumed to have been previously included in the count or estimate.

The number of fish that entered the system but did not pass upstream of the weir was estimated by taking the greatest result from subtracting the number of fish counted at the weir following each downstream count from the respective survey count and adding the sum of carcasses observed below the weir on previous surveys (assuming that 100% of carcasses were flushed out or removed by scavengers between surveys).

In years when no mark-recapture estimate was made (1985–1987) or when the estimate was the same or less than the count (1993, 2004, 2007), gross escapement was estimated as the sum of (a) all fish counted at the weir and (b) the estimate of the number that entered the system but did not pass above the weir (described in the previous paragraph).

If no fish were found to have passed the weir uncounted, the gross adult (age .1) escapement estimate included the sum of the following: (1) total weir count including all weir mortalities and fish sacrificed for samples; (2) the greatest difference between a downstream survey count and the weir count after the survey was made; and (3) the sum of pre-spawning mortalities observed in downstream surveys. If fish were found to have passed the weir uncounted, the gross estimate included the sum of the following: (1) Chapman estimate of the population above the weir when recovery sampling was initiated; (2) fish counted upstream and marked with a left opercular punch after recovery sampling is initiated; (3) upstream migrant mortalities that occur at the weir including fish that die in the trap or are killed there by bears and fish that are sacrificed as samples; (4) unspawned wash-ups on the weir (assumed to be handling mortalities and not included in the Chapman estimate); (5) the greatest difference between a downstream survey count and the weir count after the survey was made; and (6) the sum of pre-spawning mortalities observed in downstream surveys.

## Estimation of Net Escapement

Accurate spawner-recruit analysis depends on a consistent measure of effective spawning escapement, hereafter referred to as “net escapement”. This is particularly true at Ford Arm Creek where highly variable pre-spawn mortality, reaching as high as 35% of gross escapement, has occurred around periods of intense oxygen depletion in the outlet stream. Net escapement is the gross escapement estimate minus pre-spawning mortalities that include trap mortalities, bear kills at the weir, coded wire tag samples, unspawned wash-ups and pre-spawning mortality documented downstream of the weir. Net escapement was used to estimate brood year escapement for stock-recruitment analysis.

Net escapement was calculated by subtracting “Type 2” mortalities from the gross escapement estimate. Type 2 mortalities were differentiated in two ways from “Type 1” natural mortalities that were assumed to have occurred anyway had the weir and mark-recapture project not been carried out, and barring unusual pre-spawn mortality. Type 2 mortalities included documented mortalities assumed to have been associated with the stock assessment project (including bear kills on the weir) and those observed among pre-spawning fish downstream of the weir.

Most of the latter mortalities were observed during outlet stream surveys conducted immediately following mass-mortality events as a result of oxygen depletion in the stream, usually during periods of low rainfall and high pink salmon abundance. Also included were the few mortalities among fresh, bright fish observed primarily during stream surveys in August and early September. Most of these mortalities were thought to have resulted from osmoregulatory stress during the transition from marine to fresh water. No attempt was made to separate mortalities resulting from oxygen depletion and osmoregulatory stress—both were combined in Type 2 mortalities. Total documented Type 2 mortalities were subtracted from the gross escapement estimate to obtain an estimate of net escapement for spawner-recruit analysis.

Operation of the stock assessment project has resulted in relatively low but variable mortality from unintentional handling mortalities as well as fish sacrificed for coded-wire tag recovery and biological samples. The weir also provides an attractive feeding location for brown bears (Figure 5), particularly subdominant animals that adapt to the human presence at the weir and thereby benefit from easier fishing and avoidance of aggressive encounters with dominant bears at other fishing locations.

Measures have been developed to reduce the vulnerability of coho salmon to bear predation in the confined trap, and fish recovering from anesthetic. As soon as the extent of the predation problem was discovered, the trap was opened to pass fish only during the day. However predation remained a problem during periods when the weir was unattended. Bear predation in the trap itself was greatly reduced after the mid-1980s with placement of removable barriers horizontally and vertically across access to the trap, whenever the weir was left unattended. Initially, two panels were constructed of 2” × 2” 10 gauge or 12 gauge hardware cloth with 2” × 6” wooden frames. In recent years, the horizontal panel has been replaced with 2” × 10” planks.

Whenever the crew was not at the weir, one panel was attached over the horizontal opening to the trap above the weir itself and the other panel was extended and tied upward to the top of the vertical 10’ pickets that surround the other three sides of the trap. This measure has proven effective in excluding brown bears from the trap at Ford Arm Creek, although it has been considerably less successful with the more agile and determined black bears found at Hugh Smith Lake (Molly Kemp, ADF&G fisheries technician, personal communication).

In addition to the removable barriers on the trap, the crew developed a recovery area that shielded fish from direct view by bears. Bears were attracted to the activity of capturing, handling and releasing fish, particularly late in the season when the more abundant and easily captured species were no longer available. The crew initially established dominance and gained compliance by firing a signal flare at a bear when it approached too close or attempted to capture recovering fish. Thereafter, more subtle gestures usually remained effective with individual bears over the long-term, such as clearing the throat and turning the head slightly toward a bear approaching too close. New arrivals presented a potential problem. However, those that displayed behavior of concern to the crew usually also attracted the attention of and were driven off by one of the well-known sows that returned to the weir over many years (Figure 5). Over the 27 seasons of operation reported here, no aggressive encounters with bears occurred at the weir and camp site that made the crew feel seriously in danger, among thousands of total encounters over that period. However, occasional aggressive surprise encounters occurred during work conducted away from camp along the outlet stream and in other parts of the drainage.

## ESTIMATION OF PRESMOLT PRODUCTION AND HARVEST

Returning adults were sampled for coded-wire tags to generate a Chapman estimate of presmolt abundance and to estimate the proportion of the population that carried coded-wire tags implanted at Ford Arm Creek ($\theta$). The estimated harvest of coded-wire tagged fish was then divided by $\hat{\theta}$ to estimate the total contribution of the stock by area, time, and gear type.

### Estimation of Presmolt Abundance

The abundance of coho salmon presmolts was estimated using Chapman’s modification of Petersen’s estimator for closed populations (Seber 1982, p. 60). A sample of presmolts was marked with adipose clips and a sample of adults returning 2 years later was inspected for marks.

During the period between marking and recovery the population was open to mortality but was assumed closed to recruitment. The abundance of coho salmon presmolts ($N_S$) was estimated as,

$$\hat{N}_S = \frac{(M+1)(C+1)}{(R+1)} - 1, \tag{1}$$

where $M$ is the number of presmolts marked and released in a year and $R$ is the number of adipose clip marks in a sample of $C$ returning adult spawners inspected for marks.

In this equation, $R$ is the random variable, and $C$ and $M$ are assumed to be constants. In mark-recapture sampling, $R$ follows a hyper geometric distribution by definition, which can be approximated with the Poisson distribution (Thompson 1992). By simplifying the Chapman mark-recapture equation, we have

$$\frac{1}{\hat{N}_S} \approx \frac{R}{C\,M}. \tag{2}$$

In the Poisson approximation for $R$, the mean and variance are the same, so that the variance (var), standard error (SE), and coefficient of variation (CV) of $\frac{1}{\hat{N}}$ are calculated as follows:

$$\mathrm{var}(\frac{1}{\hat{N}_S}) \approx \frac{R}{(C\,M)^2}; \tag{3}$$

$$\mathrm{SE}(\frac{1}{\hat{N}_S}) = \frac{\sqrt{R}}{C\,M} \text{; and,} \tag{4}$$

$$\mathrm{CV}(\frac{1}{\hat{N}_S}) = \frac{1}{\sqrt{R}} \cdot 100. \tag{5}$$

If the numbers of mark-recoveries are moderate or large, the pooled Chapman estimate should meet the criteria outlined above. The distribution for $R$ can then be approximated with the normal distribution. Under these circumstances, we will assume $\frac{1}{\hat{N}_S}$ is approximately normally distributed, and we will generate 95% confidence intervals for $\frac{1}{N_S}$ as,

$$\frac{1}{\hat{N}_S} \pm 1.96 \cdot \mathrm{SE}(\frac{1}{\hat{N}_S}). \tag{6}$$

Finally, 95% confidence intervals for $N_S$ were generated by inverting the confidence intervals for $\frac{1}{N_S}$.

The adult return sometimes included a small proportion that had been tagged 3 years prior to their return as adults, having remained in freshwater an additional year after tagging. Also, in one year a fish classified as an adult (568 mm) was recovered from the troll fishery 1 year after tagging, indicating it had likely smolted the summer it was tagged. In those cases, the combined sample of fishery recoveries of tagged adults returning to Ford Arm Creek was used to apportion the number of tagged adults passing the weir to estimate $R$ attributable to a particular presmolt year. When recoveries from tagging in the prior year occurred, a substitute estimate of $R$ for equation (1) was generated by multiplying the number of adipose clips in the escapement sample by the proportion of tags recovered in the inriver sample that were tagged 2 years prior to adulthood ($T_{(i\text{-}2)}$) compared with adult recoveries from tags implanted 1 or 3 years prior to adulthood ($T_{(i\text{-}1)}$ or $T_{(i\text{-}3)}$):

$$\hat{R} = R\left(\frac{T_{(i-2)}}{T_{(i-1)} + T_{(i-2)} + T_{(i-3)}}\right). \tag{7}$$

$M$ (equation 1) represents the number of adipose clipped fish released without an adjustment for estimated tag loss at the time of release. Tag loss was estimated based on the proportion of fish in the escapement that registered no signal with the field detector and/or were found not to contain a tag upon further examination at the ADF&G Mark, Tag and Age Laboratory, under an inherent assumption of no natural incidence of adipose clips. Tag loss was assumed to be equal among all tagged groups.

## Estimation of Harvest

The harvest ($H$) of Ford Arm Creek coho salmon in mixed stock fisheries was estimated from recoveries of coded-wire tags. Data on recoveries in Alaska fisheries were obtained from a computer database maintained by the ADF&G Mark, Tag, and Age Laboratory. Recovery data for Canadian fisheries were downloaded from the Regional Mark Processing Center database maintained by the Pacific States Marine Fisheries Commission. Methods described in Bernard and Clark (1996) were used to estimate the commercial and marine sport harvest of coho salmon from Ford Arm Lake using information from stratified catch sampling programs. Commercial catch and sample data for Alaska net fisheries were summarized by ADF&G statistical week and district (Figure 6). Tag recoveries from the Alaska troll fishery were expanded by period and quadrant for most basic parameter estimates but by statistical week and quadrant for analysis of harvest timing. Tag recoveries from random dockside sampling of the marine sport harvest were expanded by port over biweekly periods. Tag recoveries from troll and net fisheries in British Columbia were expanded by gear type, catch region, and statistical week. Resultant estimates of the harvest of coded-wire tags were divided by the proportion tagged ($\hat{\theta}$) to estimate the contribution by the stock to the fishery in each stratum.

## Estimation of Run Size, Exploitation Rate, and Marine Survival

Estimates of the run size ($N_A$) of adult coho salmon returning to Ford Arm Lake and associated exploitation rates ($U$) in commercial and sport fisheries were based on the sum of estimates of harvest ($H$) and escapement ($E$):

$$\hat{N}_A = \hat{H} + \hat{E}\text{, and} \tag{8}$$

$$\hat{U} = \frac{\hat{H}}{\hat{H} + \hat{E}}. \tag{9}$$

The survival rate of presmolts to adults ($\mu$) was estimated as:

$$\hat{\mu} = \frac{\hat{N}_A}{\hat{N}_S}. \tag{10}$$

## SPAWNER-RECRUIT ANALYSIS

We evaluated the spawner-recruit relationship for Ford Arm Creek coho salmon by applying three models (logistic hockey stick, Beverton-Holt, and Ricker) to paired estimates of net escapement and production. In order to filter out variation in post-tagging survival, which was assumed to be density independent, we adjusted adult returns to reflect a constant average survival rate using a method similar to that employed by Clark et al. (1994) and Shaul et al. (2009). The adjustment to a constant survival rate was calculated by dividing estimated adult production in a particular return year by the corresponding estimated presmolt–adult survival rate, and multiplying the result by the average survival rate over all years. Age composition estimates based on scale samples taken at the weir were then applied to apportion total adult production by brood year. In effect, we estimated presmolt production by brood year and converted presmolts to adults (based on average survival) to compute the brood year return.

The period of freshwater residence, about 10 months between tagging and sea-migration, suggests that density-dependent population adjustment in the stream environment may not be fully complete by the presmolt stage. Therefore, support for the assumption of density independence is not as strong as it would have been if marking had been done at the smolt stage, providing a clear delineation between stream and ocean effects.

The relatively high average survival of tagged Ford Arm Creek presmolts compared with smolts from other systems, however, suggests that the vast majority of freshwater mortality occurred prior to marking. For example, tagged Ford Arm pre-smolts survived to adulthood at an average rate of 11.7% for the 2000–2007 return years compared with only 9.3% for smolts from the nearby Nakwasina River during the same period (Shaul et al. 2008). The coefficient of variation of survival estimates during that period was similar between Ford Arm Lake presmolts (0.26) and Nakwasina River smolts (0.24).

The simple hockey stick model (Barrowman and Myers 2000, Bradford et al. 2000) transitions abruptly from a proportionate response in the return to varying escapement at low spawning population sizes to a constant return (independent of escapement) above a fixed reference point. Although the simple hockey stick (HS) model transitions abruptly between these functions, a logistic version allows a smoother transition. We applied the logistic hockey stick (LHS) model using the method presented by Barrowman and Myers (2000).

The second model applied was the Beverton–Holt model (Beverton and Holt 1957). This model is usually compatible with data sets showing an overall positive relationship between escapement and production, without over-compensation. Barrowman et al. (2003) fitted the Beverton–Holt model to the same coho salmon stocks analyzed by Bradford et al. (2000) using the HS model. Although both models adequately described the spawner-recruit relationship for many stocks, each appeared to produce a better fit for specific stocks. The Beverton-Holt model produced the best fit for the Hugh Smith Lake stock (Shaul et al. 2009).

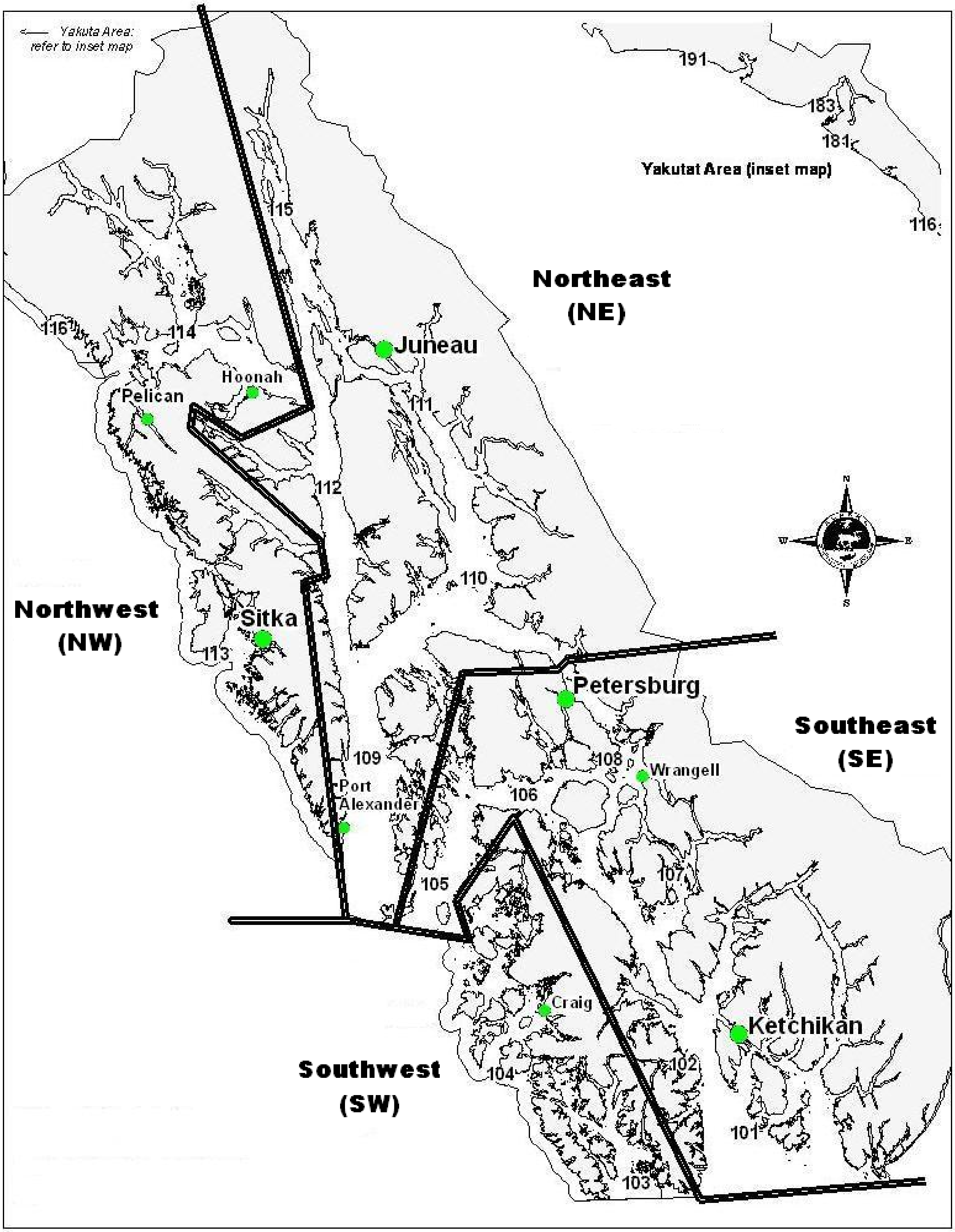


Figure 6.–Map of Southeast Alaska showing fishing districts used to expand seine and gillnet coded-wire tag recoveries, quadrants used to expand troll recoveries and ports used to expand marine sport fishery recoveries.

For comparison, we applied the Ricker model that has been widely adopted for salmon populations, using methods presented in Ricker (1975). The Ricker model has an over-compensation feature that predicts declining production from higher levels of escapement above a peak population size. However, over-compensation appears inconsistent with most spawner–recruit datasets for coho salmon (Barrowman et al. 2003).

Finally, we applied a combined model (described below) that incorporated the effect of the number of pink salmon spawning in the system. The adjusted coho spawner-recruit relationship was fitted with a "Bent Hockey Stick" model (Shaul et al. 2013).

## Estimation of Total Salmon Spawner Biomass

The total weight of pink, chum, sockeye, and coho salmon entering the Ford Arm system during 1982, 1983 and 1985–2009 was estimated in order to explore relationships with coho salmon production and spawner-recruit residuals. For coho salmon, best gross escapement estimates based on weir counts or mark-recapture estimates were used as described above. Total sockeye salmon escapement estimates were available for most years, based primarily on mark-recapture methods (Appendix B).

Peak annual survey counts of pink and chum salmon spawners (Appendix C) were multiplied by a constant expansion factor in order to estimate total spawner abundance for those species. The expansion of 2.5 for pink salmon was based on studies by Dangel and Jones (1988), which showed that aerial observers counted an average of 40% of the fish present in a stream at the time of the survey. We also examined more recent survey calibration results, both published (Jones et al. 1998) and unpublished (Steve Heinl, ADF&G Regional Research Biologist, personal communication). Results from individual studies were, overall, consistent with the value of 2.5, with the average factor for all individual comparisons being slightly higher at 2.7 and the median being lower at 1.9. We found an expansion factor of 2.5 for the peak survey count of pink salmon to be reasonable based on our experience observing the population in Ford Arm Creek over more than 2 decades. We applied an expansion factor of 6.2 to peak counts for chum salmon, based on the average estimate for studies conducted in Southeast Alaska (Steve Heinl, ADF&G Regional Research Biologist, personal communication). A greater expansion factor is appropriate because chum salmon have a shorter average stream life compared with pink salmon. Also, the Ford Arm Creek chum salmon run is relatively protracted and appears to include early and late components spawning from late-July to mid-August and late-August into September, respectively. During some years, peak downstream counts of over 1,000 chum salmon have occurred during the first survey as early as 8–12 August, with some fish already spawned and dead by that time. However, 1 September is the average historical mid-point of the total count of chum salmon at the weir, with 67%, on average, passing during 22 August–11 September.

The mean-average weekly weight of salmon caught by common property commercial seine, drift gillnet and set gillnet fisheries in Southeast Alaska each year was used to approximate the average weight of spawners of each species returning to the Ford Arm Creek system. Average weights for coho salmon were computed only for the first week of September (statistical week 36) and later weeks, because coho salmon exhibit a substantial increase in weight during the fishing season. The resultant average weight approximations in kg were multiplied by the estimated number of spawners in the Ford Arm system to estimate total spawner biomass in kg. Spawned-out carcass weights were probably considerably lower, but we included gonad weight because salmon eggs and fry are both important food for juvenile coho salmon (Hunter 1959, Bilby et al. 1998), and eggs that neither hatch nor are consumed also contribute marine nutrients to the system. In order to examine carcass inputs on a numerical basis and compare results with Wipfli et al. (2003), we also converted other species to "pink salmon" equivalents by totaling their estimated weight and dividing by the average weight of pink salmon.

# RESULTS AND DISCUSSION

## PRESMOLT ESTIMATES

Estimated presmolt abundance at Ford Arm Creek averaged 80,576 fish, and ranged from 38,509 (1983) to 134,640 (1993; Table 1). The relative precision ($P$ = 0.05) of estimates averaged 13% (range 8–23%) over the period and showed no trend, averaging 13% in both the first and second halves of the period. Presmolt abundance increased substantially during the study. Estimated presmolt abundance averaged 55% higher after 1991 (average 94,208; range 62,444–134,640) compared with 1980–1991 (average 60,748; range 33,632–67,886). Averages grouped by decadal period were 61,011 presmolts during 1980–1989, 87,326 presmolts during 1990–1999, and 94,149 presmolts during 2000–2007. The density of presmolts within the 13.2 km of accessible stream and lake length in the system averaged 6,104 fish/km over all years of the study.

A best-fit exponential trend in presmolt production showed an annual increase of 2.2%, and a linear regression fit to annual presmolt production (Figure 7) increased at a rate of about 2.9% of the initial reference point of 56,022 presmolts per year, or an increase of 1,645 presmolts per year over the entire 28-year period. A robust trend computed after Geiger and Zhang (2002) showed an even steeper increasing trend at a rate of 4.6% of the initial reference point of 48,380 presmolts per year or an increase of 2,240 presmolts per year over the period.

## SURVIVAL

The estimated presmolt–adult survival rate of tagged fish was highly variable, and ranged from 4.6% for the 1985 return to 21.9% for the 1991 return (Table 1; Figure 8). Survival followed a slight positive trend: a linear regression trend in survival rate increased at 1.1% of the initial reference point per year, and a robust trend increased at 0.6% of the initial reference point per year. The average survival rate increased substantially from 8.6% for the 1982–1989 returns to 12.5% for the 1990–1999 returns, and decreased slightly to 11.6% for the 2000–2009 returns.

The average survival rate of tagged presmolts compared favorably with survival rates of fish tagged as full-term smolts at other studied systems. For example, the survival rate of Ford Arm presmolts tagged in July over the 8-year period from 2000–2007 averaged 11.7% compared with an average 12.2% for smolts migrating from six other Southeast Alaska systems (Shaul et al. 2008), including Auke Creek (20.9%), Berners River (13.5%), Taku River (8.6%), Nakwasina River (9.3%), Chuck Creek (10.1%) and Hugh Smith Lake (10.5%). Ford Arm presmolts survived at a higher average rate than smolts from four of those six other systems, including the Nakwasina River, an outer coastal system located only 42 km south of Ford Arm Creek.

These data suggest that Ford Arm Creek smolts likely survive at a high average rate compared with other systems and that the vast majority of freshwater mortality has occurred by the presmolt stage, 10 months in advance of smoltification. However, it is also likely that presmolts captured in minnow traps in July represent a selective sample favoring larger, older fish that have a potentially above-average survival rate. Presmolt tagging likely under-represented smaller, age 0 fish that were below the 62 mm threshold length for tagging in July but attained sufficient growth to smolt by the following spring. Presmolt tagging likely also includes fry that exit the system as nomads, attain smolt size in estuarine and marine waters, and overwinter in freshwater (Shaul et al. 2013). However, given that presmolt tagging and adult recovery were conducted in a relatively consistent manner, it is likely that presmolt abundance and survival estimates have tracked closely with smolt production and marine survival.

## ESCAPEMENT ESTIMATES

Gross escapement estimates ranged from 1,552 in 1986 to 7,109 fish in 2002 (average 3,447), and trended higher over time with period averages of 2,207 fish in 1982–1989, 3,676 fish in 1990-1999, and 4,189 fish in 2000–2007.

Efforts to obtain a complete count of the coho salmon escapement to Ford Arm Creek met with mixed success (Table 2). Mark-recapture estimation was critical to a complete accounting of escapement in many years. Freshets topped the weir in both 1982 (Shaul et al. 1985) and 1983 (Shaul et al. 1986). In 1982, water remained near the top of the weir for 15 hours and, while it rose above the catwalk, the hand railing held and continued to support the wire extension above the pickets. However, the crew observed several coho salmon jumping over the railing to the upstream side and, after the waters receded, discovered a hole in the fencing near the bank through which fish could easily pass. A total of 101 adults were sampled during mark-recovery sampling in spawning streams to recover Floy anchor tagged fish. Of those, 58 were marked of which 48 had Floy anchor tags and 10 (17%) had holes in their backs that indicated a probable lost tag. The total adult escapement was estimated at 2,655 fish (95% C.I.: 2,300–3,254) of which 554 (20.9%) were estimated to have passed uncounted.

In 1983, a more serious flood occurred on 20 September while several hundred coho salmon were evident below the weir. Floodwaters poured about 0.7 m over the lowest section of catwalk and some vertical supports failed resulting in collapse of the railing. Eight catwalk boards were washed downstream and water flowed over the weir for about 7 hours. The total adult escapement was estimated at 1,931 fish (95% C.I.: 1,546–2,565) compared with a total count of only 923 adults, indicating that about half of the escapement passed uncounted. Of 49 marked fish in the recovery sample, 37 had Floy anchor tags and 12 (24%) had a partial dorsal clip indicating a lost tag.

There were no evident breaches of the weir during 1985–1987, so no mark-recovery sampling was conducted in those years (Tables 2 and 3). However, one unmarked adult washed up on the weir in 1986 and two washed up in 1987. Thereafter, mark-recapture sampling was conducted routinely every year, even in cases when the weir was thought to have remained fish-tight.

Based on results from those years, it became evident that a small number of fish had escaped uncounted in most years regardless of how well the weir was operated. It appears most likely that fish entered the lake before the weir was installed. This conclusion is supported by the absence of any unmarked fish in recovery samples in 1993, 2004, and 2007, years when few or no fish were evident near the weir for several days after it was installed. In contrast, 10% of the run was estimated uncounted in 1998, a year when the weir was operational on 11 August and appeared to remain tight throughout the season. However, in that year several adult coho salmon were noted in the outlet area and others were observed entering the lake when the weir was installed.

Fish thought to be coho salmon were observed rising in the lake and double-digit daily adult counts were recorded immediately following installation of the weir.

Table 1.–Annual number of Ford Arm Creek coho salmon presmolts tagged, total presmolt population estimates in 1980–2007, and estimated survival to adulthood 2 years later.

| Tagging Year | Number Marked (*M*) | Returns Sampled (*C*) | Adjusted Ad Clips (*R*)[a] | Estimate (*N*) | 95% C.I. Lower Bound | 95% C.I. Upper Bound | Total Adult Return | Survival (%) |
|---|---|---|---|---|---|---|---|---|
| 1980 | 6,369 | 1,749 | 140 | 79,059 | 67,886 | 94,636 | 4,590 | 5.8 |
| 1981 | 6,926 | 806 | 87 | 63,686 | 52,707 | 80,441 | 5,368 | 8.4 |
| 1982 | –[b] | – | – | – | – | – | – | – |
| 1983 | 3,882 | 1,804 | 181 | 38,509 | 33,632 | 45,040 | 4,806 | 12.5 |
| 1984 | 7,662 | 1,480 | 247 | 45,748 | 40,691 | 52,241 | 4,097 | 9.0 |
| 1985 | 7,626 | 1,597 | 172 | 70,322 | 61,226 | 82,592 | 3,233 | 4.6 |
| 1986 | 10,392 | 2,366 | 275 | 88,983 | 79,611 | 100,856 | 6,012 | 6.8 |
| 1987 | 11,054 | 1,856 | 396 | 51,658 | 47,036 | 57,286 | 6,160 | 11.9 |
| 1988 | 12,567 | 1,923 | 440 | 54,851 | 50,170 | 60,495 | 5,274 | 9.6 |
| 1989 | 11,300 | 2,275 | 456 | 56,284 | 51,559 | 61,961 | 6,018 | 10.7 |
| 1990 | 10,742 | 2,972 | 516 | 61,728 | 56,833 | 67,545 | 9,351 | 15.1 |
| 1991 | 9,506 | 3,336 | 552 | 57,401 | 52,985 | 62,618 | 12,562 | 21.9 |
| 1992 | 10,447 | 2,522 | 317 | 82,893 | 74,692 | 93,116 | 11,486 | 13.9 |
| 1993 | 10,552 | 1,051 | 81 | 134,640 | 110,837 | 171,463 | 6,787 | 5.0 |
| 1994 | 6,564 | 1,540 | 109 | 91,605 | 77,251 | 112,511 | 5,864 | 6.4 |
| 1995 | 10,993 | 3,176 | 522 | 66,772 | 61,504 | 73,026 | 9,771 | 14.6 |
| 1996 | 10,093 | 4,893 | 613 | 80,517 | 74,616 | 87,432 | 16,124 | 20.0 |
| 1997 | 12,050 | 2,806 | 254 | 132,655 | 118,172 | 151,182 | 10,195 | 7.7 |
| 1998 | 7,129 | 1,518 | 172 | 62,444 | 54,370 | 73,336 | 8,048 | 12.9 |
| 1999 | 8,095 | 1,045 | 82 | 102,610 | 84,476 | 130,658 | 8,624 | 8.4 |
| 2000 | 12,762 | 5,525 | 684 | 102,918 | 95,752 | 111,243 | 15,118 | 14.7 |
| 2001 | 10,547 | 3,900 | 533 | 77,081 | 71,057 | 84,222 | 13,218 | 17.1 |
| 2002 | 8,858 | 2,414 | 210 | 101,579 | 89,512 | 117,405 | 12,103 | 11.9 |
| 2003 | 6,483 | 2,399 | 128 | 120,632 | 102,928 | 145,689 | 10,124 | 8.4 |
| 2004 | 10,437 | 3,372 | 357 | 98,470 | 89,230 | 109,844 | 9,815 | 10.0 |
| 2005 | 10,213 | 1,784 | 216 | 84,017 | 74,166 | 96,887 | 8,665 | 10.3 |
| 2006 | 10,542 | 3,408 | 496 | 72,315 | 66,474 | 79,281 | 11,060 | 15.3 |
| 2007 | 10,498 | 1,128 | 122 | 96,180 | 81,785 | 116,724 | 7,126 | 7.4 |
| Average | 9,418 | 2,394 | 310 | 80,576 | 71,154 | 93,323 | 8,612 | 11.2 |

[a] Number of adipose clipped fish in escapement samples multiplied by the fraction of total observed tag recoveries in fisheries and escapement from presmolts tagged in the year shown.
[b] Coho presmolts were not coded-wire tagged in 1982.

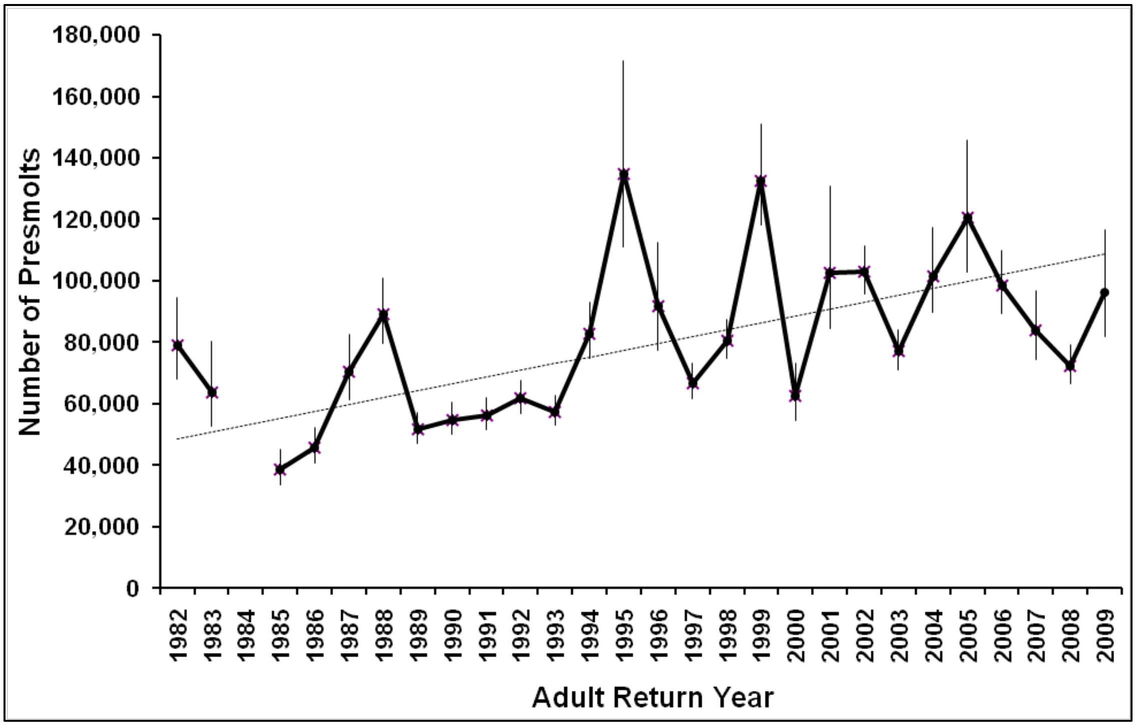


Figure 7.–Estimated coho salmon presmolt abundance in Ford Arm Lake, showing 95% confidence bounds and a robust linear trend (dashed line).

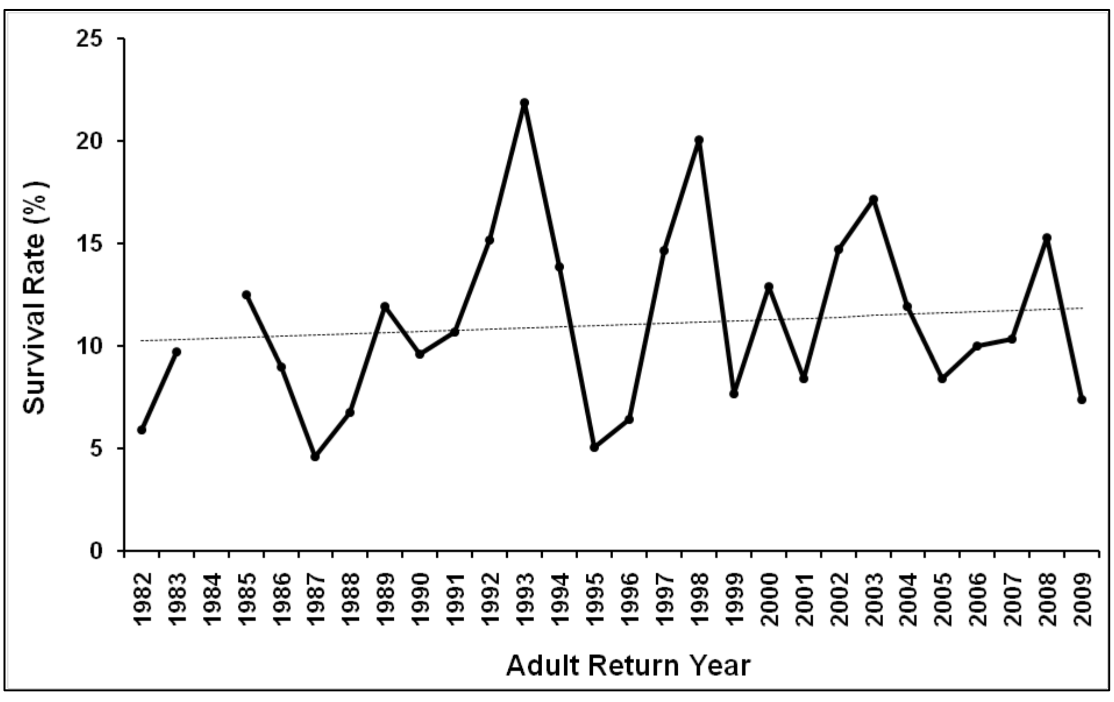


Figure 8.–Estimated survival rate to adulthood of coho salmon presmolts tagged in Ford Arm Lake showing a robust trend (dashed line).

Jacks accounted for 8% of the total coho salmon age-length-sex sample over all years, and fish identified as jacks by the weir crew represented an average of 9% of the total weir count of coho salmon. Fish identified as jacks from their scales averaged 380 mm in length (MEF) compared with 625 mm for adults. There was relatively little overlap in size between age .0 jacks and age .1 adults (Figure 9). Of the composite sample of fish determined to be jacks based on their scales across all years, 95% were 312−438 mm (MEF length) whereas 95% of adults were 490−720 mm.

The most accurate division point between jacks and adults based on the composite sample from all years appears to be about 430 mm, with all fish above that length classified at adults and fish at 430 mm and below classified as jacks. Although 5.3% of fish determined to be jacks measured more than 430 mm, only 0.4% of fish determined to be adults were under 431 mm. Use of that length to apportion the aggregate sample from all years to jacks and adults would have resulted in 99.2% correct classification. Although potential average error in correctly identifying adults is very low with that division point, the optimal point of separation has varied slightly from year-to-year, prompting minor inseason adjustments, particularly in years when the average dressed weight of troll caught coho salmon was well-below average.

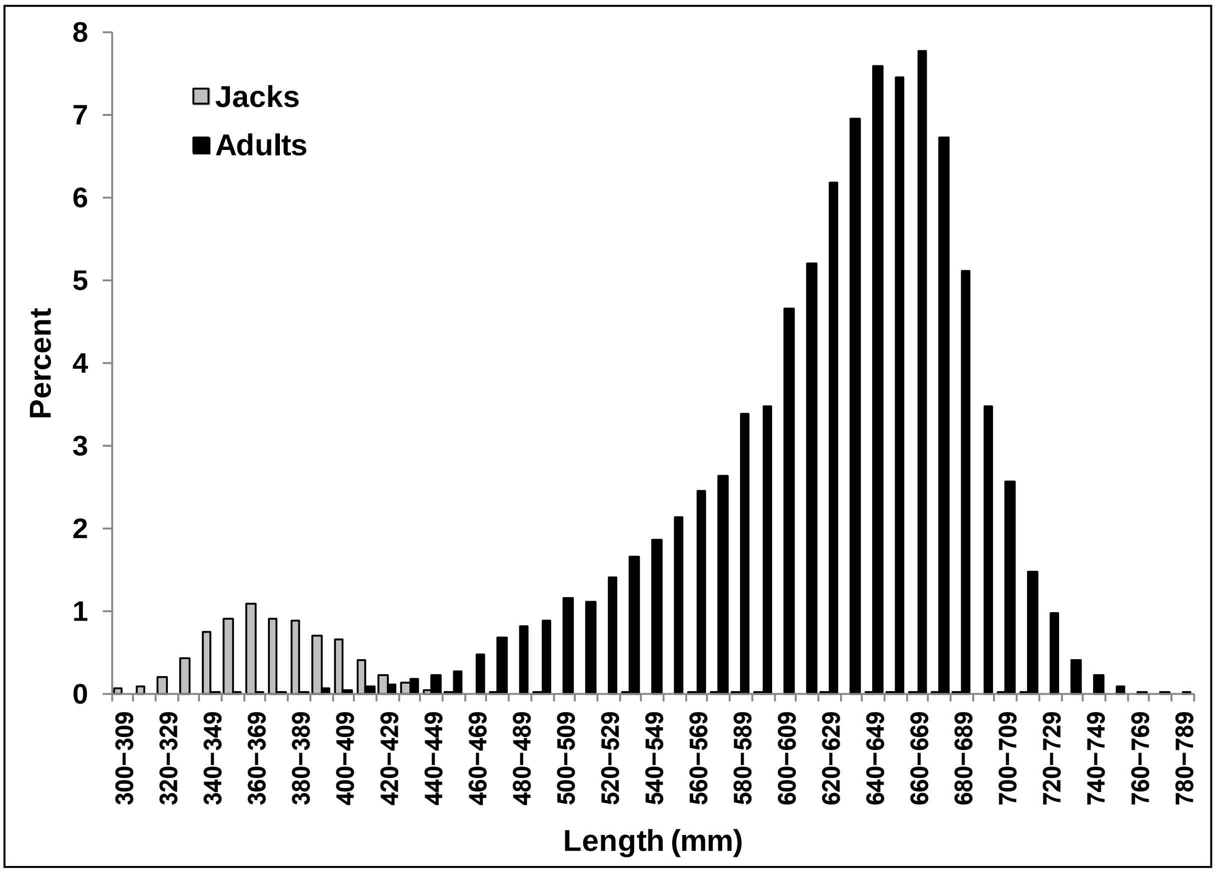


Figure 9.–Length-frequency distribution of all upstream-migrating Ford Arm Creek coho salmon classified as age .0 jacks and age .1 adults from scale samples, 1982−2009.

Fish identified as jacks by the weir crew represented an average 9% of the total weir count. Jacks were under-represented because some were able to pass between the weir pickets unexamined. Although recovery samples were generally insufficient to generate annual mark-recapture estimates for jacks, only 45% (153/339) of the jacks captured and examined in recapture samples during 1988−2009 had marks applied at the weir. Given an average weir count of 262 jacks during 1982−2009 (Appendix A4), it appears likely that the actual total return has averaged approximately 580 jacks (coded-wire tagged jacks were rare in fishery harvests). Given an average total adult return estimated at 8,612 fish, jacks have likely averaged about 6% of the total coho salmon return to Ford Arm Creek.

## PROPORTION MARKED

The estimated proportion of the adult escapement that was adipose clipped averaged 13.1%, and ranged from 5.3% in 2005 to 24.0% in 1989 (Figure 10; Appendix A1). The proportion of jacks that were clipped averaged lower at 8.3% (range 1.0–20.9%), suggesting potential capture bias against the very largest presmolts usually found in the lake, that are most likely to return as jacks (Lum 2003). The fraction of the adult escapement that contained coded-wire tags ($\hat{\theta}$) ranged from a low of 5.2% to a high of 22.3% (average 12.4%; Table 3). Tag retention estimates averaged 96.2% (range 90.6–98.7%) with the exception of 1989 when tag retention was estimated at only 75.7%. The low apparent retention rate in that year was likely due in part to the accidental release of about 250 large presmolts (80–100 mm) on 16 July 1987 that had been adipose clipped but not yet tagged.

## RUN RECONSTRUCTION ESTIMATES

The estimated annual gross escapement, harvest by fishery, and total run size are shown in Table 4 and Figure 11. More spatially detailed catch estimates by quadrant (troll), district (seine and gillnet), and port (sport) are presented in Appendix A4. During 1982–2009, the estimated total contribution of Ford Arm Creek coho salmon to all fisheries averaged 5,164 fish within a relatively broad range from 1,539 fish (1987) to 9,075 fish (1998).

The Alaska troll fishery was by far the single most important harvesting fishery in all years, accounting for an average of 4,494 (range 1,458–7,835) Ford Arm Creek coho salmon during 1982–2009. Alaska seiners harvested an average of 361 (range 0–1,260) Ford Arm coho Creek salmon. In most years, 100% of the purse seine catch of the stock occurred in local District 113, with most of it likely taken as incidental catch in the Khaz Bay seine fishery that operates primarily in Slocum Arm and Ford Arm. The harvest of all stocks of coho salmon in that fishery averaged 1,359 fish (range 77–5,643). Few tagged Ford Arm Creek coho were recovered from other purse seine fisheries over the 27-year period of this study: one tag each was recovered from the purse seine catch in Districts 102 and 103, one tag was recovered in 2 years in District 112, and a total of 10 tags were recovered during 8 years in the District 104 purse seine fishery (Appendix A2). Trace numbers of Ford Arm Creek coho salmon have been caught in drift gillnet fisheries in Southeast Alaska (Districts 106, 111 and 115) and Prince William Sound (District 212) as well as in the troll fishery in northern British Columbia.

Marine sport fisheries harvested an average 307 (range 0–1,770) Ford Arm Creek coho salmon. The first recorded sport harvest of the Ford Arm Creek stock occurred in 1993 but sampling effort in the Sitka marine sport fishery was minimal prior to that year. The marine sport catch and effort increased rapidly with development of the charter fishery in the 1990s. During 1993–2009, the estimated marine sport catch averaged 487 Ford Arm Creek coho salmon (range 0–1,770), of which over 90% was landed in Sitka, while smaller catches were landed in Elfin Cove, Gustavus, and Craig (Appendix A4).

Table 2.–Summary of observed problems during the Ford Arm Lake Weir operation and the estimated percent of the total adult escapement (based on a modified Petersen estimate) that was not included in the total count.

| Year | Weir Dates Start Date | Weir Dates End Date | Estimated Percent Uncounted | Observed Problem(s) |
|---|---|---|---|---|
| 1982 | 14-Aug | 17-Nov | 20.9 | Hole and water near top for 15 hours on 12 Oct. |
| 1983 | 12-Aug | 17-Nov | 52.2 | Weir topped for 7 hours on 20 Sept. |
| 1984 | – | – | – | Weir not operated in 1984. |
| 1985 | 16-Aug | 5-Nov | – | No evident breaches; no unmarked wash-ups; no M-R sample. |
| 1986 | 15-Aug | 27-Oct | – | No evident breaches; 1 unmarked wash-up; no M-R sample. |
| 1987 | 11-Aug | 31-Oct | – | No evident breaches; 2 unmarked wash-ups; no M-R sample. |
| 1988 | 13-Aug | 24-Oct | 11.2 | Fish passed immediately after installation; 18" hole in chicken wire during a freshet on 8 Oct. |
| 1989 | 11-Aug | 24-Oct | 1.4 | Small hole at high water for a few hours on 3 Oct. |
| 1990 | 11-Aug | 22-Oct | 2.0 | No evident breaches. |
| 1991 | 10-Aug | 23-Oct | 8.7 | No evident breaches. |
| 1992 | 12-Aug | 25-Oct | 2.0 | No evident breaches. |
| 1993 | 10-Aug | 24-Oct | 0.0 | No evident breaches; M-R estimate = count. |
| 1994 | 10-Aug | 23-Oct | 15.5 | First adult coho passed Aug. 21; opening between splayed pickets during a freshet allowed fish to pass 3–5 Oct. |
| 1995 | 12-Aug | 22-Oct | 14.6 | Fish passed immediately after installation; 822 adult coho dead in low oxygen events on 21 Aug. and 5–7 Sept.; weir opened to let fish pass. |
| 1996 | 11-Aug | 21-Oct | 21.5 | Hole from scouring on 11 Sept.; weir topped and railing collapsed on 25 Sept.; 416 dead unspawned adults downstream on 5 Sept. |
| 1997 | 14-Aug | 23-Oct | 3.8 | No evident breaches. |
| 1998 | 11-Aug | 22-Oct | 10.0 | No breaches but coho salmon visible in the outlet area before the weir was installed. M-R estimate = count. |
| 1999 | 11-Aug | 23-Oct | 1.8 | No breaches; 119 adults counted past unmarked during low oxygen events on 9 and 10 Sept. |
| 2000 | 11-Aug | 19-Oct | 0.6 | No evident breaches. |
| 2001 | 9-Aug | 21-Oct | 11.0 | Weir opened to pass coho during low oxygen event on 12 Sept.; 771 adult carcasses counted downstream. |
| 2002 | 13-Aug | 19-Oct | 9.9 | No breaches; 508 adults counted past weir unmarked during low oxygen events during 5 and 6 Sept. |
| 2003 | 10-Aug | 17-Oct | 5.5 | 1,025 adults counted past unmarked during low oxygen events during 23 and 24 Aug. and 7 Sept. |
| 2004 | 11-Aug | 19-Oct | -0.5 | No evident breaches; 16 adults passed unmarked. M-R est. < count. |
| 2005 | 10-Aug | 19-Oct | 7.2 | 813 fish passed unmarked; scouring under four tripods on 13 Sept. |
| 2006 | 12-Aug | 19-Oct | 3.6 | No evident breaches. |
| 2007 | 10-Aug | 19-Oct | 0.0 | No evident breaches; M-R estimate = count. |
| 2008 | 13-Aug | 18-Oct | 6.3 | No evident breaches; coho passed first day. |
| 2009 | 12-Aug | 20-Oct | 0.8 | No evident breaches; coho passed first day. |

Table 3.–Total weir count of adult coho salmon spawners at Ford Arm Lake, 1982–2009 with mark-recapture summary statistics and the estimated proportion marked with coded-wire tags ($\theta$).

| Year | Total Count[a] | Mark-Recapture Statistics: Number Marked | Number Sampled | # Marks Recovered | Modified Petersen Estimate | Additional Counted Adults[b] | Best Total Estimate | 95% C. I. Lower Bound | Upper Bound | Type 2 Morts[c] | Net Spawning Escapement | Prop. w/CWTs ($\theta$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1982 | 2,101 | 1,008 | 101 | 58 | 1,743 | 912 | 2,655 | 2,300 | 3,254 | 49 | 2,606 | 0.07604 |
| 1983 | 923 | 690 | 122 | 49 | 1,699 | 232 | 1,931 | 1,546 | 2,565 | 33 | 1,898 | 0.10224 |
| 1984 [d] | – | – | – | – | – | – | – | – | – | – | – | – |
| 1985 [e] | 2,324 | 1,742 | – | – | – | – | 2,324 | – | – | 62 | 2,262 | 0.09091 |
| 1986 [e] | 1,552 | 1,429 | – | – | – | – | 1,552 | – | – | 56 | 1,496 | 0.17703 |
| 1987 [e] | 1,694 | 1,563 | – | – | – | – | 1,694 | – | – | 32 | 1,662 | 0.13274 |
| 1988 | 2,769 | 2,324 | 114 | 99 | 2,673 | 446 | 3,119 | 2,679 | 3,773 | 37 | 3,082 | 0.13439 |
| 1989 | 2,146 | 1,819 | 61 | 60 | 1,849 | 327 | 2,176 | 1,803 | 2,802 | 32 | 2,144 | 0.18157 |
| 1990 | 2,148 | 1,855 | 42 | 41 | 1,899 | 293 | 2,192 | 1,747 | 3,029 | 48 | 2,144 | 0.22317 |
| 1991 | 2,520 | 1,980 | 119 | 106 | 2,221 | 540 | 2,761 | 2,406 | 3,282 | 33 | 2,728 | 0.21534 |
| 1992 | 3,789 | 2,851 | 74 | 72 | 2,929 | 937 | 3,866 | 3,317 | 4,746 | 71 | 3,795 | 0.16723 |
| 1993 | 4,202 | 3,193 | 54 | 54 | 3,193 | 1,009 | 4,202 | 3,530 | 5,363 | 50 | 4,152 | 0.16337 |
| 1994 | 2,727 | 2,404 | 92 | 76 | 2,904 | 323 | 3,227 | 2,695 | 4,067 | 27 | 3,200 | 0.12329 |
| 1995 | 2,089 | 942 | 94 | 68 | 1,297 | 1,149 | 2,446 | 2,198 | 2,849 | 836 | 1,610 | 0.07897 |
| 1996 | 1,963 | 1,351 | 96 | 68 | 1,900 | 600 | 2,500 | 2,136 | 3,089 | 432 | 2,068 | 0.07076 |
| 1997 | 4,537 | 2,899 | 101 | 95 | 3,080 | 1,638 | 4,718 | 4,203 | 5,493 | 33 | 4,685 | 0.16278 |
| 1998 | 6,341 | 4,674 | 123 | 107 | 5,367 | 1,682 | 7,049 | 6,195 | 8,301 | 34 | 7,015 | 0.12400 |
| 1999 | 3,731 | 2,587 | 103 | 96 | 2,774 | 1,026 | 3,800 | 3,338 | 4,493 | 28 | 3,772 | 0.08909 |
| 2000 | 2,289 | 1,465 | 101 | 100 | 1,480 | 824 | 2,304 | 2,061 | 2,664 | 22 | 2,282 | 0.11199 |
| 2001 | 1,965 | 947 | 101 | 80 | 1,193 | 1,016 | 2,209 | 1,995 | 2,543 | 787 | 1,422 | 0.07748 |
| 2002 | 6,403 | 5,474 | 104 | 92 | 6,180 | 929 | 7,109 | 6,062 | 8,694 | 112 | 6,997 | 0.11475 |
| 2003 | 6,414 | 3,837 | 100 | 73 | 5,237 | 1,552 | 6,789 | 5,815 | 8,341 | 86 | 6,703 | 0.13436 |
| 2004 | 3,539 | 2,379 | 67 | 67 | 2,379 | 1,144 | 3,539 | 3,063 | 4,272 | 22 | 3,517 | 0.08451 |
| 2005 | 3,952 | 2,302 | 100 | 67 | 3,420 | 837 | 4,257 | 3,599 | 5,327 | 176 | 4,081 | 0.05163 |
| 2006 | 4,568 | 3,252 | 100 | 95 | 3,421 | 1,316 | 4,737 | 4,165 | 5,598 | 18 | 4,719 | 0.10202 |
| 2007 | 2,567 | 1,575 | 49 | 49 | 1,575 | 992 | 2,567 | 2,222 | 3,180 | 7 | 2,560 | 0.11323 |
| 2008 | 4,849 | 3,310 | 100 | 91 | 3,634 | 1,539 | 5,173 | 4,554 | 6,111 | 36 | 5,137 | 0.13991 |
| 2009 | 2,164 | 942 | 54 | 53 | 959 | 1,222 | 2,181 | 1,978 | 2,535 | 10 | 2,171 | 0.10018 |

[a] The weir count combined with the sum of all other non-duplicated counts of adults in the system.
[b] The number of adults counted in the system that were not included in the mark-recapture estimate.
[c] Type 2 mortalities include a) all fish assumed to have died as a result of the project including fish sacrificed for samples, fish dead in the weir trap, unspawned marked wash-ups (assumed to be handling morts), bear kills of unspawned fish observed at the weir, and b) unspawned fish found dead during downstream counts usually as a result of low oxygen events.
[d] Coho salmon were not coded-wire tagged in 1982 and, subsequently, the adult weir project was not operated in 1984.
[e] Mark-recapture studies were not conducted in 1985, 1986, and 1987.

Escapement estimates during the period ranged from 1,552 adults in 1986 to 7,109 adults in 2002, with the average being 3,447 adults.

Total adult run size estimates ranged from 3,233 fish (1987) to 16,124 fish (1998) and averaged 8,612 fish. Average run sizes have doubled in recent years compared with the early years of the project, increasing from 5,026 fish in 1982–1989 to 9,343 fish in 1990–1999 and 10,390 fish in 2000–2009 (Figure 11). While the trend in survival of presmolts has shown no strong trend, the increase in adult returns since the early 1990s occurred concurrent with increased presmolt abundance (Figure 12), pointing to improved conditions for survival in the freshwater environment as the most probable cause of substantially larger average returns in the latter part of the study period.

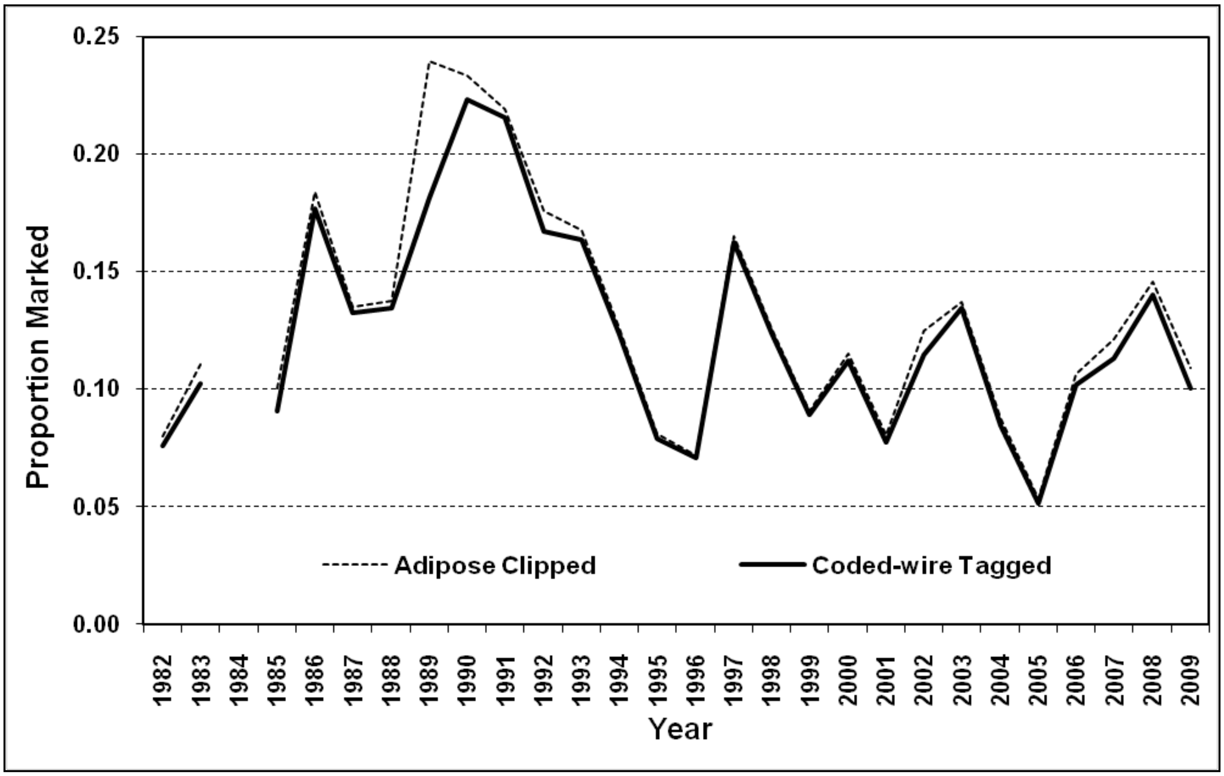


Figure 10.–Estimated proportion of adult coho salmon escapement to Ford Arm Creek that were adipose clipped and contained a coded-wire tag, 1982–2009.

## EXPLOITATION RATE ESTIMATES

Ford Arm Creek coho salmon are exploited primarily by ocean commercial troll and sport fisheries on the outer coast and by a local purse seine fishery directed at pink salmon stocks in Khaz Bay, Slocum Arm, and Ford Arm. Overall, harvest accounted for an average of 59.6% of the return (range 43.4–74.4%) and escapement accounted for 40.4% (range 25.6–56.6%; Table 5). More detailed exploitation rates by area are presented in Appendix A5.

Total exploitation estimates for the Ford Arm Creek stock during the early years of the assessment project (1982–1989) averaged 55.2% and increased to 60.2% during 1990–1999 and 62.1% during 2000–2009 (Table 5; Figure 13). The slight increase in the average exploitation rate on this stock after 1999 contrasts with the Hugh Smith Lake stock, where the average exploitation rate declined from 75.3% in 1990–1999 to 54.7% in 2000–2007 (Shaul et al. 2009). In comparison, the estimated average exploitation rate for the Ford Arm Creek stock during 2000–2007 was 62.3%.

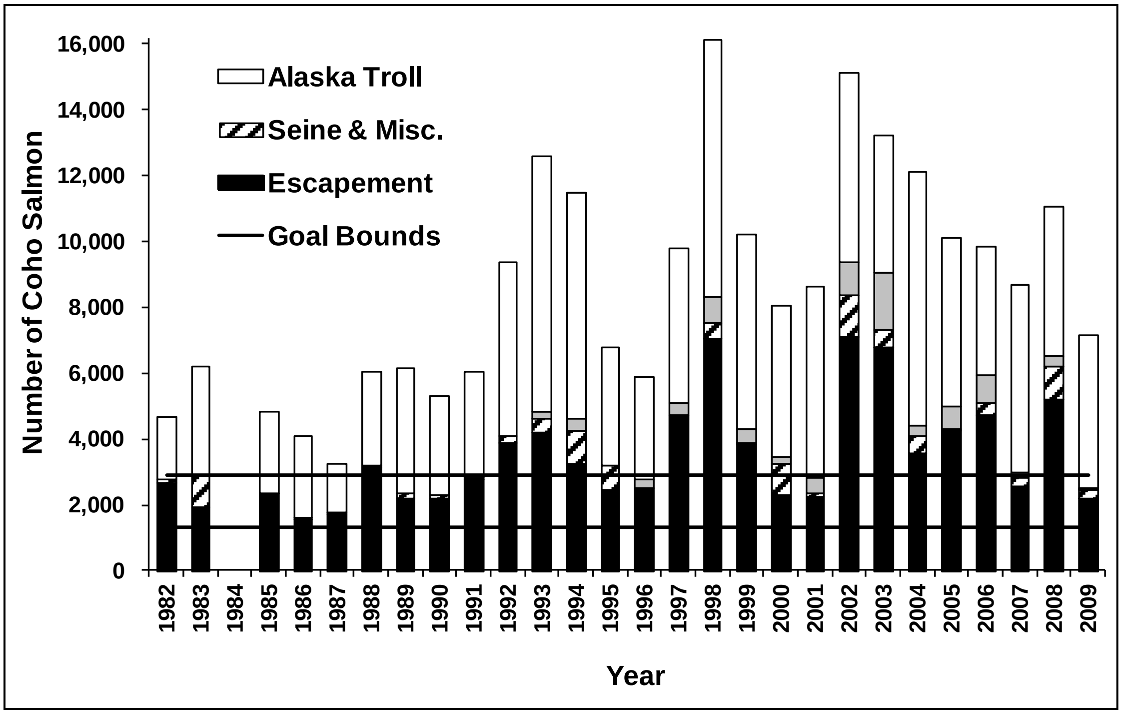


Figure 11.–Total run size, catch, escapement, and biological escapement goal range for Ford Arm Creek coho salmon, 1982–2009 (excluding 1984). The displayed escapement goal range of 1,300–2,900 spawners was in effect during 1994–2009.

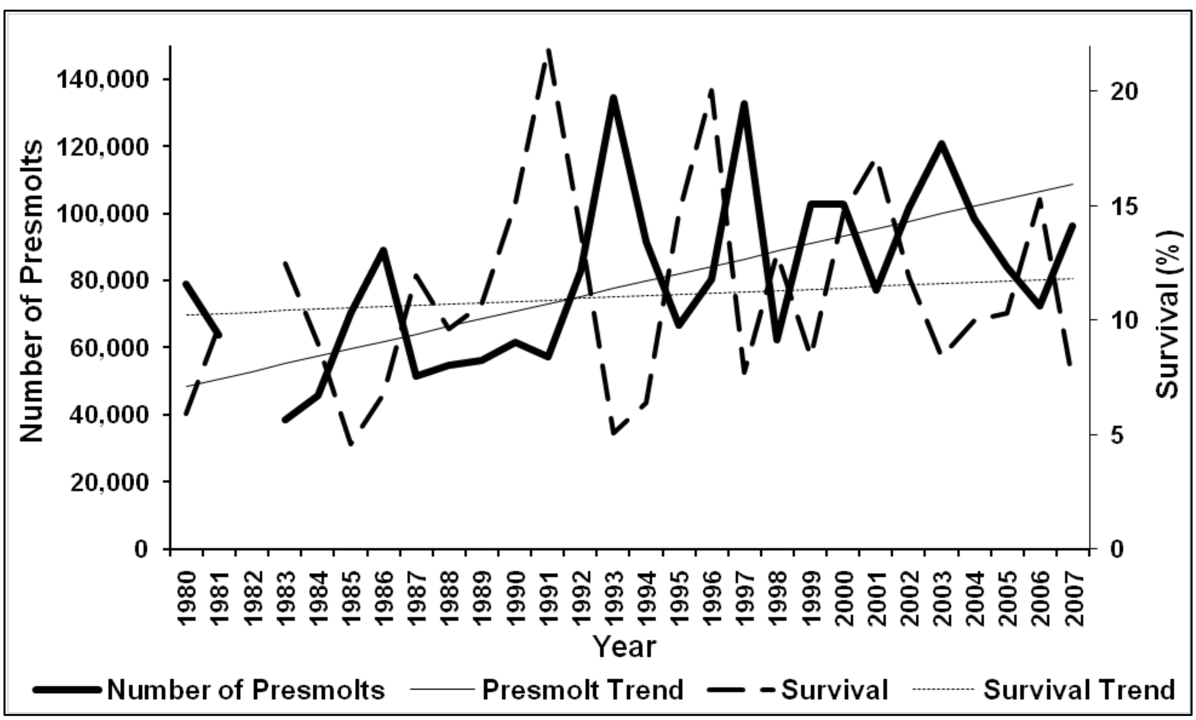


Figure 12.–Estimated number of coho salmon presmolts in the Ford Arm Lake system and their survival rate to adulthood, 1980–2007, showing robust trends.

The Ford Arm Creek stock is a less migratory “milling” stock located in the area of most intensive troll effort in the region on the outer coast between Sitka and Pelican. As a consequence, it has incurred a substantially higher average exploitation rate by the troll fishery compared with most other stocks that have been studied in the region. The trend in the troll fishery exploitation rate on the stock has been relatively stable around a long-term average of 52.9% (Table 5; Figures 14 and 15) and has ranged from 31.4% in 2003 to 67.5% in 2001. The troll exploitation rate has been substantially more variable since 2000 with the coefficient of variation increasing from 0.11 in 1982–1999 to 0.26 in 2000–2009. The record low troll exploitation rate in 2003 may have been attributed to a combination of low fishing effort related to low salmon prices and extended Chinook (*O. tshawytscha*) salmon fishing opportunity during periods when the troll fleet has normally targeted coho salmon.

The troll fishery exploitation rate on the Hugh Smith Lake stock, in southern Southeast Alaska, provides an interesting comparison with Ford Arm Creek. The Alaska troll exploitation rate on the Hugh Smith Lake Stock decreased markedly from an average of 41.2% in the 1990s to 30.8% in 2000–2007, a decrease of 10.4% (Shaul et al. 2009). In contrast, the average troll exploitation rate on the Ford Arm Creek stock remained substantially higher and more stable between these periods, decreasing by only 3.0% from a 1990s average of 54.7% to a 2000–2007 average of 51.7%. Even within the NW quadrant, where the majority of the troll catch of both stocks occurred, the average troll exploitation rate on the Hugh Smith Lake stock decreased by 6.0% from 24.8% to 16.8% while the average troll exploitation rate on the Ford Arm Creek stock decreased by only 3.1% from 54.5% to 51.4%. It appears likely that as troll effort has decreased since the 1990s, more migratory stocks like Hugh Smith Lake have been more affected compared with less migratory ones like Ford Arm Creek that have a longer residence time in the area of most intensive fishing and greater likelihood of multiple encounters with troll gear. It is also possible that Hugh Smith Lake fish have tended to approach the coast farther to the south in recent years following the post-1998 return to a colder North Pacific climate pattern.

The estimated average purse seine exploitation rate has been low (3.9%) and variable (range 0–11.4%). On average 3.7% of the run was taken in District 113, mostly in the Khaz Bay fishery, which is directed primarily at local stocks, while 0.2% was taken in the highly mixed stock District 104 purse seine fishery in southern Southeast (Appendix A5).

The marine sport harvest in the Sitka area was relatively small and poorly sampled for coded-wire tags prior to 1993. Since 1993, however, marine sport fisheries have harvested an estimated average of 4.4% of the Ford Arm Lake return (range 0–13.4%). Interestingly, the peak marine sport exploitation rate estimate of 13.4% occurred in 2003, the year when the commercial troll exploitation rate was lowest at 31.4% (Figure 15). In fact, marine sport exploitation rates have tended to be higher during periods when troll exploitation rates were low and vice versa, which has contributed to stability in the total exploitation rate. During 1993–2000, the marine sport exploitation rate averaged 3.1%, compared with 54.8% for the troll fishery, and increased to 7.2% during 2001–2006 as the average troll exploitation rate declined to 48.5%. During 2007–2009, the marine sport exploitation rate fell to an average of only 2.0% while the average troll exploitation rate increased to 57.1%. The recent downturn in the marine sport exploitation rate on the Ford Arm stock may partly reflect a reduction in charter effort that may have been affected by recent economic recession and recent bag limit restrictions on the non-resident harvest of other species, including Chinook salmon (Mike Jaenicke, ADF&G, Division of Sport Fish, personal communication).

Table 4.–Estimated harvest by gear type, escapement, and total run of coho salmon returning to Ford Arm Lake, 1982–2009.

| | | Number of Fish | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Fishery Sample Size | Alaska Troll | Seine | Drift Gillnet | Sport | Canadian Troll | Total Catch | Escapement | Total Return |
| 1982 | 38 | 1,927 | 106 | 0 | 0 | 0 | 2,033 | 2,655 | 4,688 |
| 1983 | 93 | 3,344 | 912 | 0 | 0 | 0 | 4,256 | 1,931 | 6,187 |
| 1984 | –[a] | – | – | – | – | – | – | – | – |
| 1985 | 49 | 2,482 | 0 | 0 | 0 | 0 | 2,482 | 2,324 | 4,806 |
| 1986 | 87 | 2,483 | 63 | 0 | 0 | 0 | 2,545 | 1,552 | 4,097 |
| 1987 | 71 | 1,458 | 81 | 0 | 0 | 0 | 1,539 | 1,694 | 3,233 |
| 1988 | 151 | 2,816 | 46 | 0 | 0 | 31 | 2,893 | 3,119 | 6,012 |
| 1989 | 218 | 3,799 | 185 | 0 | 0 | 0 | 3,984 | 2,176 | 6,160 |
| 1990 | 174 | 2,982 | 100 | 0 | 0 | 0 | 3,082 | 2,192 | 5,274 |
| 1991 | 193 | 3,203 | 44 | 10 | 0 | 0 | 3,257 | 2,761 | 6,018 |
| 1992 | 199 | 5,252 | 233 | 0 | 0 | 0 | 5,485 | 3,866 | 9,351 |
| 1993 | 349 | 7,749 | 434 | 0 | 176 | 0 | 8,360 | 4,202 | 12,562 |
| 1994 | 236 | 6,856 | 1,020 | 0 | 384 | 0 | 8,259 | 3,227 | 11,486 |
| 1995 | 82 | 3,582 | 759 | 0 | 0 | 0 | 4,341 | 2,446 | 6,787 |
| 1996 | 64 | 3,083 | 0 | 0 | 281 | 0 | 3,364 | 2,500 | 5,864 |
| 1997 | 242 | 4,702 | 0 | 0 | 351 | 0 | 5,053 | 4,718 | 9,771 |
| 1998 | 320 | 7,835 | 435 | 20 | 785 | 0 | 9,075 | 7,049 | 16,124 |
| 1999 | 146 | 5,893 | 66 | 0 | 436 | 0 | 6,395 | 3,800 | 10,195 |
| 2000 | 193 | 4,604 | 916 | 14 | 211 | 0 | 5,744 | 2,304 | 8,048 |
| 2001 | 131 | 5,821 | 115 | 0 | 480 | 0 | 6,415 | 2,209 | 8,624 |
| 2002 | 246 | 5,751 | 1,260 | 0 | 998 | 0 | 8,009 | 7,109 | 15,118 |
| 2003 | 225 | 4,154 | 504 | 0 | 1,770 | 0 | 6,429 | 6,789 | 13,218 |
| 2004 | 153 | 7,722 | 524 | 0 | 319 | 0 | 8,564 | 3,539 | 12,103 |
| 2005 | 81 | 5,134 | 60 | 0 | 672 | 0 | 5,867 | 4,257 | 10,124 |
| 2006 | 137 | 3,866 | 367 | 0 | 844 | 0 | 5,078 | 4,737 | 9,815 |
| 2007 | 188 | 5,673 | 217 | 7 | 202 | 0 | 6,098 | 2,567 | 8,665 |
| 2008 | 231 | 4,563 | 1,047 | 0 | 277 | 0 | 5,887 | 5,173 | 11,060 |
| 2009 | 156 | 4,604 | 248 | 0 | 93 | 0 | 4,945 | 2,181 | 7,126 |
| Average | | 4,494 | 361 | 2 | 307 | 1 | 5,164 | 3,447 | 8,612 |

[a] Coho salmon were not coded-wire tagged in 1982 and, subsequently, the adult weir project was not operated in 1984.

Table 5.–Estimated harvest by gear type, escapement, as a percent of the total run of coho salmon returning to Ford Arm Lake, 1982–2009.

| Year | Fishery Sample Size | Percent of Run | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Alaska Troll | Seine | Drift Gillnet | Sport | Canadian Troll | Total Catch | Escapement | Total Run |
| 1982 | 38 | 41.1 | 2.3 | 0.0 | 0.0 | 0.0 | 43.4 | 56.6 | 100.0 |
| 1983 | 93 | 54.0 | 14.7 | 0.0 | 0.0 | 0.0 | 68.8 | 31.2 | 100.0 |
| 1984 | –[a] | – | – | – | – | – | – | – | – |
| 1985 | 49 | 51.6 | 0.0 | 0.0 | 0.0 | 0.0 | 51.6 | 48.4 | 100.0 |
| 1986 | 87 | 60.6 | 1.5 | 0.0 | 0.0 | 0.0 | 62.1 | 37.9 | 100.0 |
| 1987 | 71 | 45.1 | 2.5 | 0.0 | 0.0 | 0.0 | 47.6 | 52.4 | 100.0 |
| 1988 | 151 | 46.8 | 0.8 | 0.0 | 0.0 | 0.5 | 48.1 | 51.9 | 100.0 |
| 1989 | 221 | 61.7 | 3.0 | 0.0 | 0.0 | 0.0 | 64.7 | 35.3 | 100.0 |
| 1990 | 174 | 56.5 | 1.9 | 0.0 | 0.0 | 0.0 | 58.4 | 41.6 | 100.0 |
| 1991 | 193 | 53.2 | 0.7 | 0.2 | 0.0 | 0.0 | 54.1 | 45.9 | 100.0 |
| 1992 | 199 | 56.2 | 2.5 | 0.0 | 0.0 | 0.0 | 58.7 | 41.3 | 100.0 |
| 1993 | 349 | 61.7 | 3.5 | 0.0 | 1.4 | 0.0 | 66.5 | 33.5 | 100.0 |
| 1994 | 236 | 59.7 | 8.9 | 0.0 | 3.3 | 0.0 | 71.9 | 28.1 | 100.0 |
| 1995 | 82 | 52.8 | 11.2 | 0.0 | 0.0 | 0.0 | 64.0 | 36.0 | 100.0 |
| 1996 | 64 | 52.6 | 0.0 | 0.0 | 4.8 | 0.0 | 57.4 | 42.6 | 100.0 |
| 1997 | 242 | 48.1 | 0.0 | 0.0 | 3.6 | 0.0 | 51.7 | 48.3 | 100.0 |
| 1998 | 320 | 48.6 | 2.7 | 0.1 | 4.9 | 0.0 | 56.3 | 43.7 | 100.0 |
| 1999 | 146 | 57.8 | 0.7 | 0.0 | 4.3 | 0.0 | 62.7 | 37.3 | 100.0 |
| 2000 | 193 | 57.2 | 11.4 | 0.2 | 2.6 | 0.0 | 71.4 | 28.6 | 100.0 |
| 2001 | 131 | 67.5 | 1.3 | 0.0 | 5.6 | 0.0 | 74.4 | 25.6 | 100.0 |
| 2002 | 246 | 38.0 | 8.3 | 0.0 | 6.6 | 0.0 | 53.0 | 47.0 | 100.0 |
| 2003 | 225 | 31.4 | 3.8 | 0.0 | 13.4 | 0.0 | 48.6 | 51.4 | 100.0 |
| 2004 | 153 | 63.8 | 4.3 | 0.0 | 2.6 | 0.0 | 70.8 | 29.2 | 100.0 |
| 2005 | 81 | 50.7 | 0.6 | 0.0 | 6.6 | 0.0 | 57.9 | 42.1 | 100.0 |
| 2006 | 137 | 39.4 | 3.7 | 0.0 | 8.6 | 0.0 | 51.7 | 48.3 | 100.0 |
| 2007 | 188 | 65.5 | 2.5 | 0.1 | 2.3 | 0.0 | 70.4 | 29.6 | 100.0 |
| 2008 | 231 | 41.3 | 9.5 | 0.0 | 2.5 | 0.0 | 53.2 | 46.8 | 100.0 |
| 2009 | 156 | 64.6 | 3.5 | 0.0 | 1.3 | 0.0 | 69.4 | 30.6 | 100.0 |
| Average | | 52.9 | 3.9 | 0.0 | 2.8 | 0.0 | 59.6 | 40.4 | 100.0 |

[a] Coho salmon were not coded-wire tagged in 1982 and, subsequently, the adult weir project was not operated in 1984.

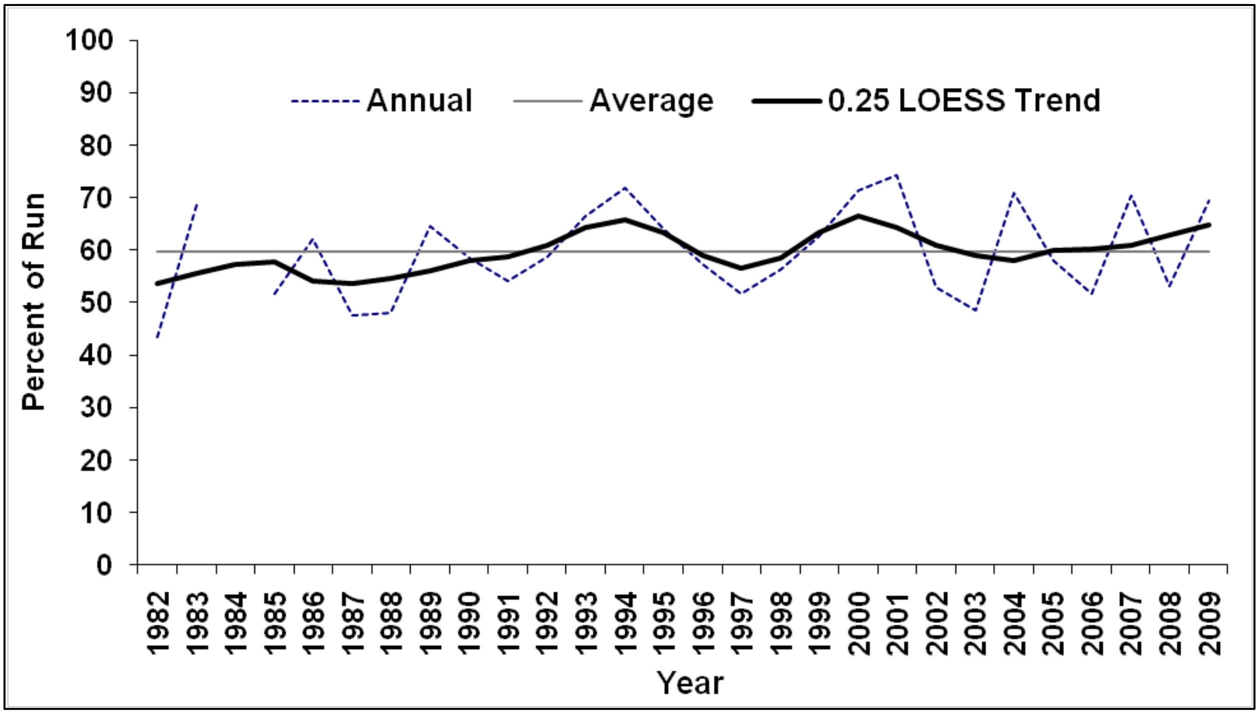


Figure 13.–Estimated total exploitation rate on returning adult Ford Arm Lake coho salmon by all fisheries, 1982-2009, showing the 0.25 LOESS Trend.

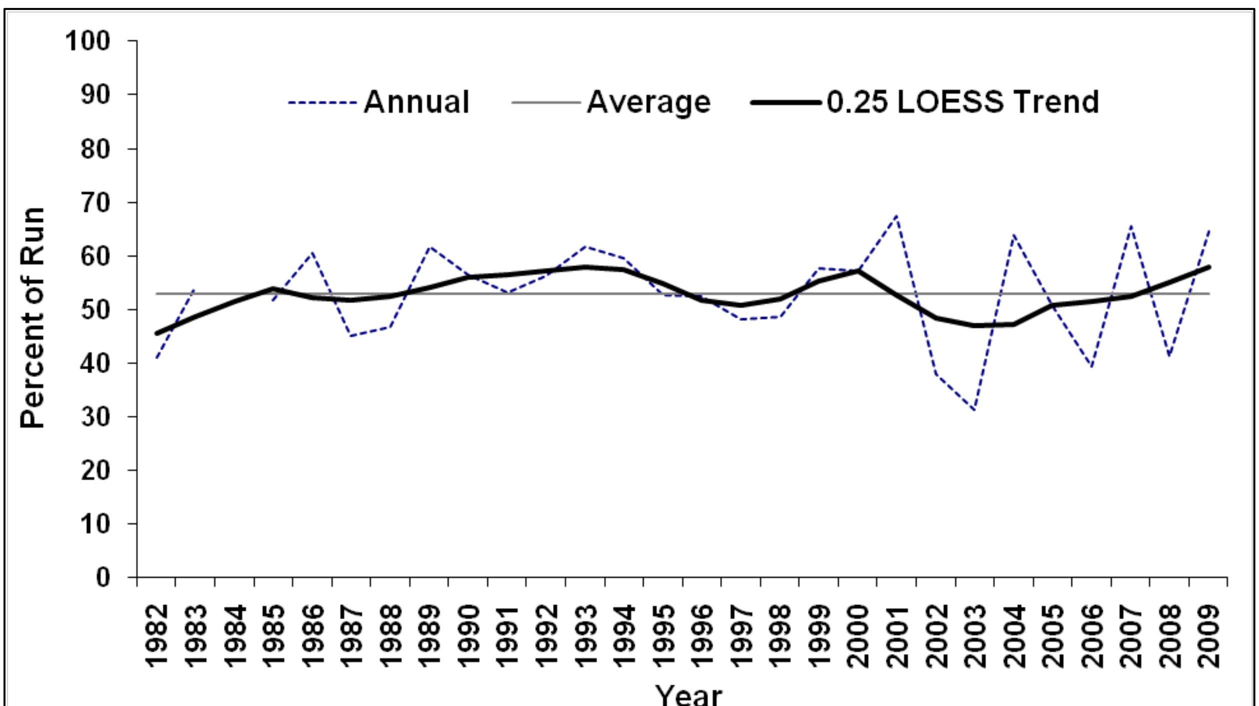


Figure 14.–Estimated exploitation rate on returning adult Ford Arm Lake coho salmon by the Alaska troll fishery, 1982–2009, showing the 0.25 LOESS Trend.

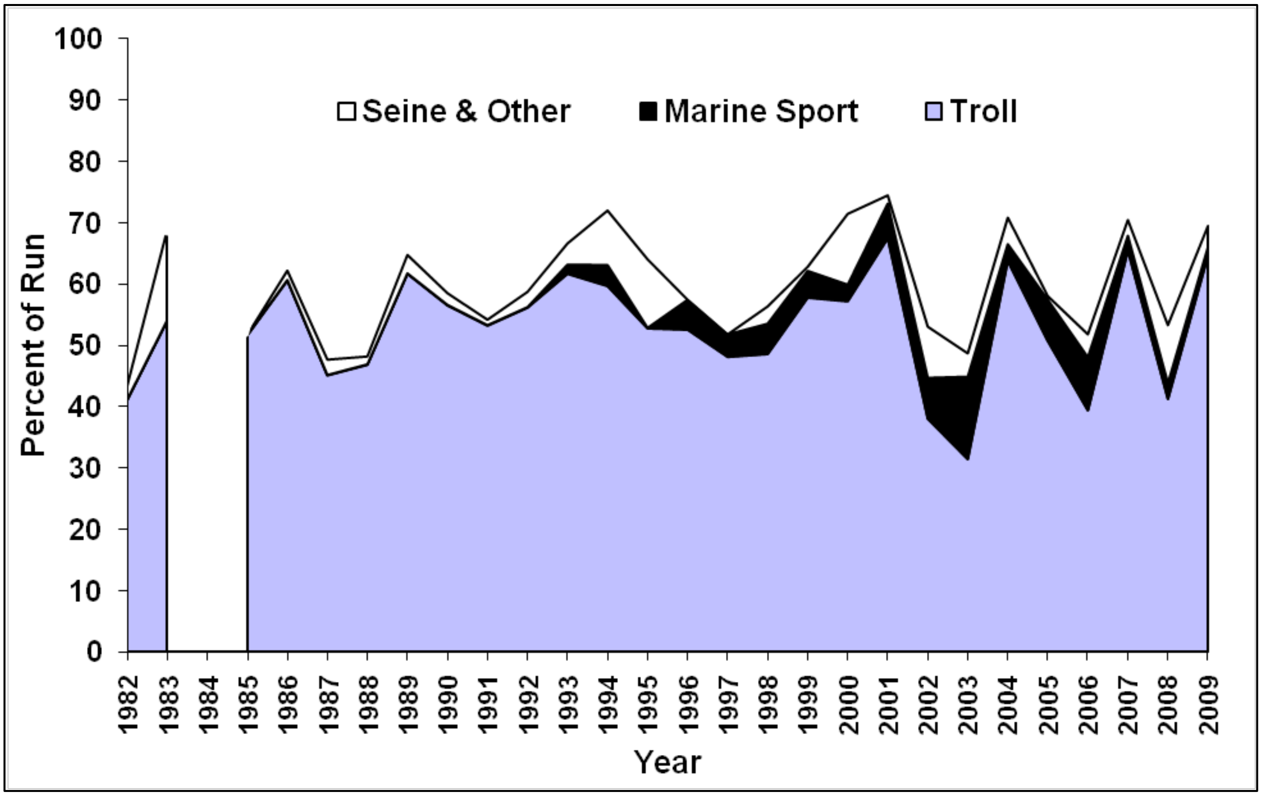


Figure 15.–Estimated exploitation rate on returning adult Ford Arm Lake coho salmon by major fishery, 1982–1983 and 1985–2009 (no estimates for 1984).

## Exploitation Rate per Unit of Troll Effort

The troll exploitation rate on the Ford Arm Creek stock has followed a relatively stable trend (Figure 14) as total troll effort in the NW quadrant (where an average of 99% of the harvest occurred) has declined from about 48,800 boat-days (power troll equivalents) in 1982 to an average of only 15,300 boat-days in 2000–2009, reaching a minimum of 12,200 boat-days in 2003 (Figure 16; effort estimates provided by John Carlile, ADF&G, Division of Commercial Fisheries, Juneau, personal communication). The exploitation rate per 1,000 boat-days increased at an exponential rate of about 6.5% from 1982 through 1999 before leveling off for the past 10 years. The average exploitation rate per effort increased by 171% from 1.23%/1,000 boat-days in 1982, 1983 and 1985 to 3.35%/1,000 boat-days in 1999–2009. At the same time, average total fishing effort was 163% higher in the earlier period, declining from 40,690 boat-days to 15,433 boat-days. Therefore, the protracted period of declining fishing effort (stabilizing after 1999) was slightly more than offset by an apparent increase in the effectiveness of a boat-day of effort.

Possible explanations for the dramatic change in apparent efficiency of a boat-day of fishing effort include (a) improved skill and equipment among fishery participants, (b) exit from the fishery of less effective participants, (c) gear saturation effects, and (d) increased cost and price pressure on participants that has raised the catch/boat-day threshold at which fishing can be profitably conducted. All of these factors have likely played a role, but we believe based on discussions with fishermen that the last factor (d) was probably most important.

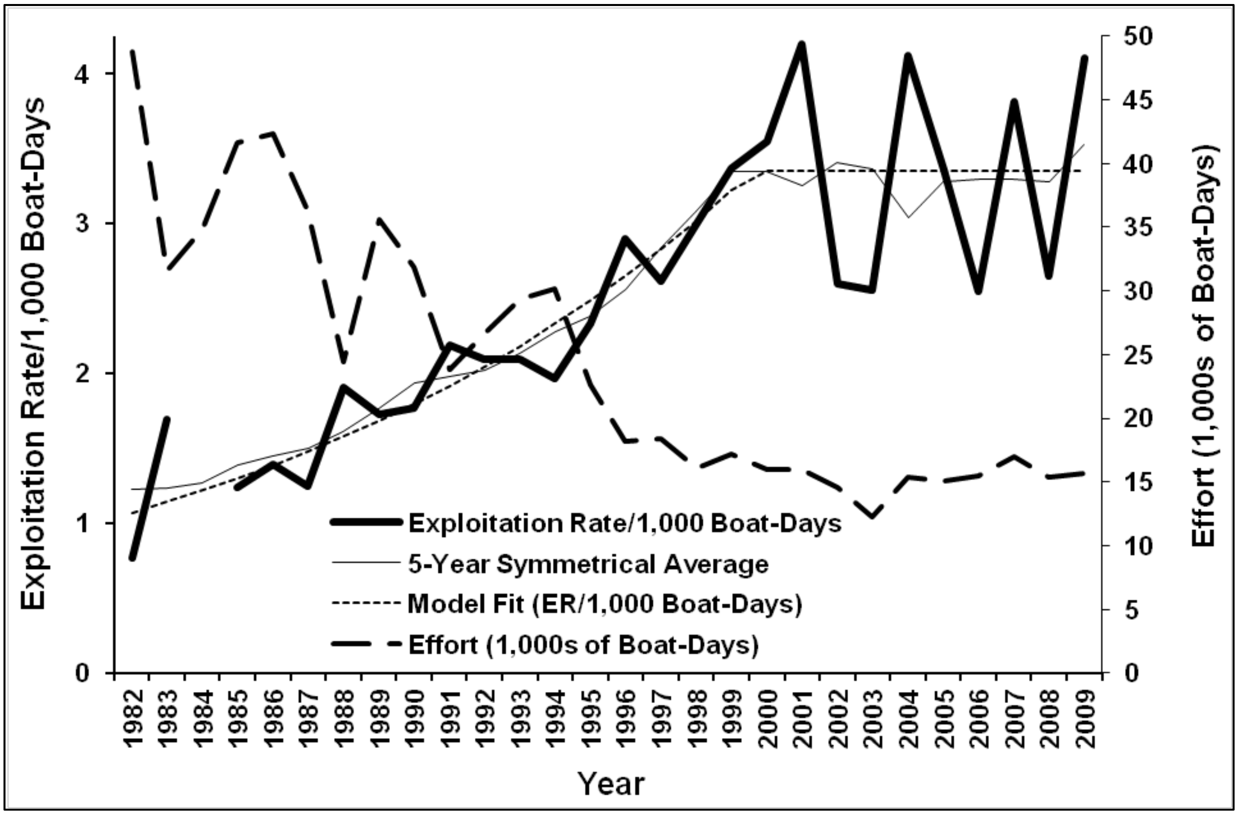


Figure 16.–Estimated exploitation rate/1,000 boat-days for the Ford Arm Lake coho salmon stock in the NW quadrant, showing a 5-year symmetrical average and a model fit transitioning from a 6.5% exponential annual rate of increase from 1982–1999 to a constant 2000–2009 average. Also shown is total troll effort in the NW quadrant in boat-days (combined power troll and hand troll converted to power troll equivalent boat-days).

## MIGRATORY TIMING

The Ford Arm Creek stock was available to the troll fishery along the nearby coast at some level throughout the normal summer season from 1 July to 20 September. While the stock contributed an average of only 4,460 fish (0.4%) to the 1982–2009 average troll catch in the Northwest Quadrant of 1.072 million coho salmon, its average proportionate contribution to the catch was greatest before the last week of August and decreased thereafter (Figure 17). The average mid-point of the troll catch of the Ford Arm Lake stock occurred on about 9 August (allowing for an average of 2 days between catch and tag recovery sampling), which was 34 days before the average 50% date for the weir count (12 September). The Ford Arm Lake stock could be classified as an "early-fall" coho salmon stock based on its migration past the weir, which typically peaks in the first half of September (Figure 18). The average mid-dates of catch in the marine sport and purse seine fisheries were 5 August and 12 August, respectively.

In addition to having migratory characteristics typical of a "milling" stock, its broad temporal distribution and relatively high exploitation rate in the troll fishery was likely affected by the central location of Ford Arm Creek in the outer coastal area most heavily fished by the Alaska troll fleet. A nearby stock in the Nakwasina River, located about 50 km south of Ford Arm, is far more migratory. Its catch in the troll fishery usually peaks around the second week of September (Brookover et al. 2001 and 2003; Tydingco 2003, 2005a, 2005b, 2006 and 2010; Tydingco and

Fowler 2010)—about a month later than the average peak catch of the Ford Arm Creek stock in the troll fishery and around the typical peak of migration through the Ford Arm Weir. As a consequence of later, more compressed timing, the Nakwasina River stock has been exploited at a far lower average rate by all marine fisheries (troll, seine, sport), with an average all-gear exploitation rate of 31% (range 19–50%) compared with 62% (range 49–74%) for the Ford Arm Creek stock during 2000–2007 (Shaul et al. 2008).

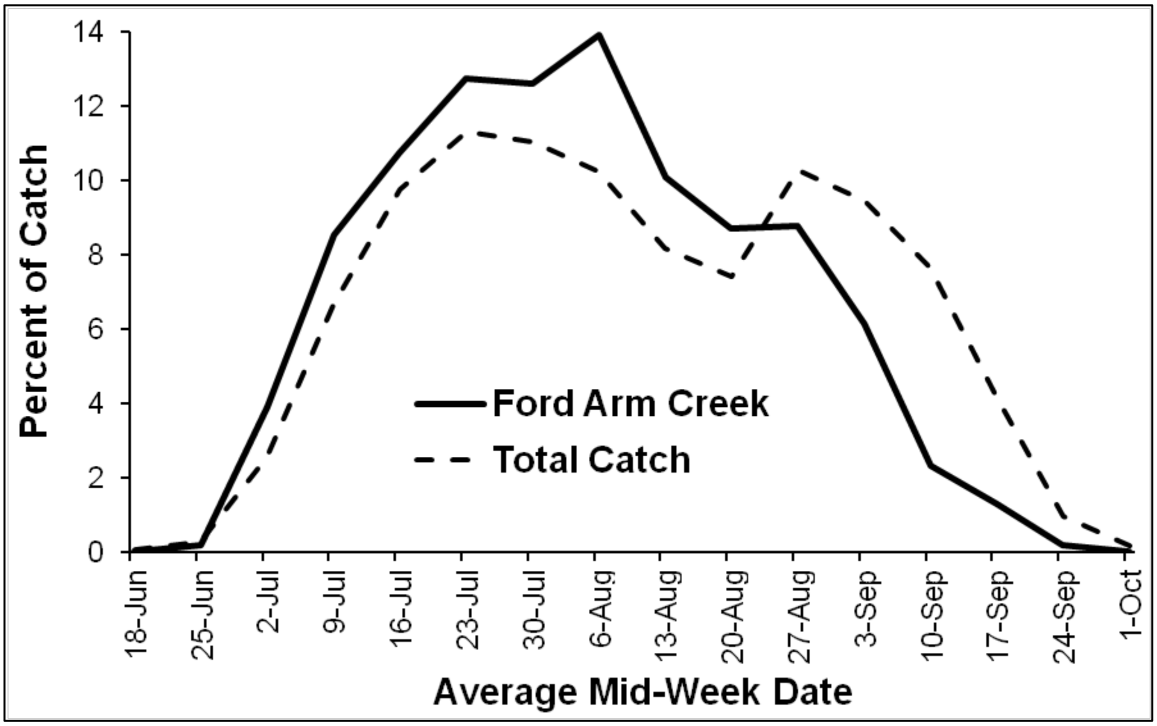


Figure 17.–Average weekly percent of the total troll catch of Ford Arm Creek coho salmon in the Northwest Quadrant compared with the average weekly percent of the total troll catch of all coho salmon in the same area, 1982–2009.

Passage of coho salmon through the Ford Arm Creek Weir usually slows greatly after 1 October, although many fish have typically remained below the weir when it was removed for the season (even as late as mid-November). A high proportion of the fish holding downstream from the weir at the end of the weir season likely remain and spawn there, but a substantial number may also move into the lake and spawn in the inlet streams in some years. During the first two years of operation, the weir was maintained until 17 November, with 515 adults (29% of upstream migrants) passed during 26 October–17 November in 1982 compared with only 16 adults passed during that period in 1983. In 1982, 351 adult spawners were counted below the weir when it was pulled, compared with 190 spawners in 1983.

The majority of coho salmon that enter the system move quickly up the outlet stream to a reach between the weir and the “first riffle” located around a bend downstream from the weir. This section has slow to moderate current, good spawning habitat, and enough depth in places to provide considerable security for holding fish.

The timing of spawning appears variable from year-to-year. Fish have occasionally been observed spawning in reaches below the weir as early as the last week of September, but spawning activity in the outlet stream usually becomes noticeable a week or two before the weir is pulled in the third week of October. The timing of the peak downstream survey count (minus the subsequent weir count, representing spawners that did not pass the weir) has been affected by rainfall and stream conditions as well as fish behavior. However, it has most often fallen within the first week of October, after all fish have entered fresh water and before substantial spawning and associated predation mortality has occurred.

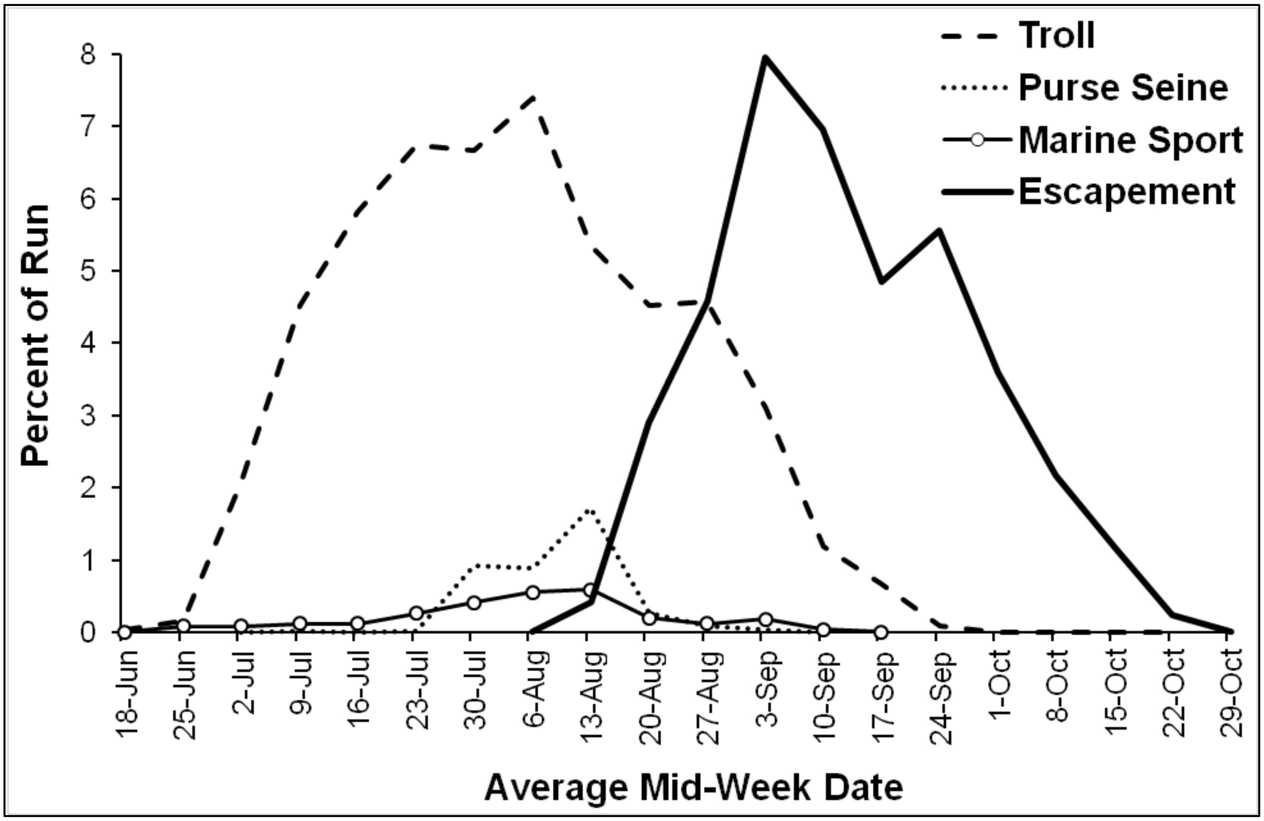


Figure 18.–Average weekly harvest by Alaska troll, seine and marine sport fisheries and escapement as a percent of the total coho salmon return to Ford Arm Creek, 1982–2009.

In 1982, heavy spawning activity was observed in the inlet streams beginning on 31 October through the end of mark-recovery sampling effort on 16 November. In 1983, however, very little spawning occurred in the inlet streams before mid-November and most mark-recovery sampling was conducted by rod-and-reel during 15–18 November on spawners holding in the lake. Earlier project ending dates after 1983 have restricted more recent observations of the timing and duration of spawning activity.

## AGE COMPOSITION AND BROOD YEAR RETURN

Adult coho salmon sampled from the Ford Arm Creek escapement were represented by three age classes (ages 1.1, 2.1, and 3.1) that corresponded with an early freshwater residency period (from egg to smolt) of approximately 18 months, 30 months, and 42 months, respectively. Sampled adults spent approximately 16 months in the ocean and most remained in fresh water for about 2 months before spawning. Therefore, the total age of adults used for assigning brood year production was 3 years (age class 1.1), 4 years (age class 2.1) and 5 years (age class 3.1).

Despite samples of 4 scales per fish, many samples (commonly about 20%) could not be aged because of regeneration. On average, 454 scales from adults were successfully aged (range 345–561). The entire collection was aged by the same scale reader (Molly Kemp). No aging validation studies have been conducted at Ford Arm Creek, but accuracy likely benefited from an extensive reference collection of known-age smolt scales from Hugh Smith and Auke lakes. The average age composition of adults over the entire period was 58.2% age 1.1, 41.0% age 2.1, and 0.8% age 3.1 (Table 6). Returns were adjusted to an average (1982–2009) presmolt–adult survival rate of 11.2% to arrive at estimates of survival-adjusted returns ranging from 4,304 to 15,048 adults.

Age .0 coho salmon jacks sampled at Ford Arm Creek were, on average, of substantially older freshwater age than were adults. Jacks were on average 7.1% age 1.0, 91.4% age 2.0 and 1.5% age 3.0 (Table 7).

## SPAWNER-RECRUIT ANALYSIS

Net spawning escapement estimates (total escapement minus Type 2 mortalities) were paired with estimates of survival-adjusted brood year returns (standardized to an average presmolt–adult survival rate of 11.2%). Standardization to average survival removed variability from adult return estimates that occurred largely in the marine environment and was assumed to be density independent. Net spawning escapement estimates ranged from 1,422–7,015 spawners, and survival-adjusted brood year returns ranged from 4,734–14,624 adults (Table 8).

### Conventional Spawner-Recruit Models

Paired estimates of net spawning escapement and survival-adjusted return, ranked by escapement level, indicate a generally positive relationship over the range of observations ($P = 0.022$; Figure 19, upper left graph). Larger escapements have, on average, produced larger returns. The average estimated return from escapements over 4,000 spawners ($n = 6$) was 10,174 adults compared with 9,982 adults produced from escapements from 3,000–4,000 spawners ($n = 5$), 8,189 adults from escapements from 2,000–3,000 spawners ($n = 7$) and 8,070 adults from escapements with fewer than 2,000 spawners ($n = 5$).

Of the three conventional spawner-recruit models tested, the Beverton-Holt model displayed the best fit based on the least sum of squared residuals, followed by the logistic hockey stick (LHS) model (Table 9). While the Ricker model produced the poorest statistical fit, it had an associated AIC value about equal with the LHS model.

Escapement ranges estimated to produce 90% or more of MSY for the Ford Arm Creek stock based on the individual models are as follows: Ricker 1,880–4,196 spawners, LHS 1,349–2,857 spawners, and Beverton-Holt 1,242–4,153 spawners. The range for the LHS model is remarkably close to the current goal range of 1,300–2,900 spawners, while the Beverton-Holt model suggests a lower bound similar to the current goal but with a higher upper bound of 4,100 or 4,200 spawners.

Table 6.–Age composition of the total adult coho salmon return to Ford Arm Lake, presmolt–adult survival rate, and adult return adjusted to an average survival rate of 11.2%, 1985–2009.

| Return Year | Ageable Scale Sample Adult Age (Samples) | | | | Percent by Age Adult Age (Percent) | | | | No. of Adults by Age Class Age Class (Number of Fish) | | | | Survival Rate (Percent) | Survival Adjusted Return No. of Adults by Age Class Age Class (Number of Fish) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3 | 4 | 5 | Total | 3 | 4 | 5 | Total | 3 | 4 | 5 | Total | | 3 | 4 | 5 | Total |
| 1985 | 203 | 192 | 10 | 405 | 50.1 | 47.4 | 2.5 | 100.0 | 2,409 | 2,278 | 119 | 4,806 | 12.5 | 2,157 | 2,040 | 106 | 4,304 |
| 1986 | 172 | 256 | 2 | 430 | 40.0 | 59.5 | 0.5 | 100.0 | 1,639 | 2,439 | 19 | 4,097 | 9.0 | 2,045 | 3,044 | 24 | 5,113 |
| 1987 | 257 | 230 | 0 | 487 | 52.8 | 47.2 | 0.0 | 100.0 | 1,706 | 1,527 | 0 | 3,233 | 4.6 | 4,148 | 3,712 | 0 | 7,859 |
| 1988 | 216 | 282 | 1 | 499 | 43.3 | 56.5 | 0.2 | 100.0 | 2,603 | 3,398 | 12 | 6,012 | 6.8 | 4,305 | 5,620 | 20 | 9,945 |
| 1989 | 281 | 131 | 4 | 416 | 67.5 | 31.5 | 1.0 | 100.0 | 4,161 | 1,940 | 59 | 6,160 | 11.9 | 3,900 | 1,818 | 56 | 5,773 |
| 1990 | 216 | 235 | 1 | 452 | 47.8 | 52.0 | 0.2 | 100.0 | 2,520 | 2,742 | 12 | 5,274 | 9.6 | 2,930 | 3,187 | 14 | 6,130 |
| 1991 | 310 | 121 | 2 | 433 | 71.6 | 27.9 | 0.5 | 100.0 | 4,308 | 1,682 | 28 | 6,018 | 10.7 | 4,504 | 1,758 | 29 | 6,290 |
| 1992 | 239 | 205 | 3 | 447 | 53.5 | 45.9 | 0.7 | 100.0 | 5,000 | 4,288 | 63 | 9,351 | 15.1 | 3,689 | 3,164 | 46 | 6,899 |
| 1993 | 201 | 232 | 19 | 452 | 44.5 | 51.3 | 4.2 | 100.0 | 5,586 | 6,448 | 528 | 12,562 | 21.9 | 2,853 | 3,293 | 270 | 6,415 |
| 1994 | 148 | 276 | 1 | 425 | 34.8 | 64.9 | 0.2 | 100.0 | 4,000 | 7,459 | 27 | 11,486 | 13.9 | 3,226 | 6,016 | 22 | 9,264 |
| 1995 | 209 | 154 | 3 | 366 | 57.1 | 42.1 | 0.8 | 100.0 | 3,875 | 2,856 | 56 | 6,787 | 5.0 | 8,593 | 6,332 | 123 | 15,048 |
| 1996 | 248 | 162 | 1 | 411 | 60.3 | 39.4 | 0.2 | 100.0 | 3,538 | 2,311 | 14 | 5,864 | 6.4 | 6,178 | 4,035 | 25 | 10,238 |
| 1997 | 294 | 154 | 7 | 455 | 64.6 | 33.8 | 1.5 | 100.0 | 6,314 | 3,307 | 150 | 9,771 | 14.6 | 4,822 | 2,526 | 115 | 7,463 |
| 1998 | 323 | 228 | 10 | 561 | 57.6 | 40.6 | 1.8 | 100.0 | 9,283 | 6,553 | 287 | 16,124 | 20.0 | 5,181 | 3,657 | 160 | 8,999 |
| 1999 | 256 | 216 | 2 | 474 | 54.0 | 45.6 | 0.4 | 100.0 | 5,506 | 4,646 | 43 | 10,195 | 7.7 | 8,007 | 6,756 | 63 | 14,826 |
| 2000 | 209 | 162 | 10 | 381 | 54.9 | 42.5 | 2.6 | 100.0 | 4,415 | 3,422 | 211 | 8,048 | 12.9 | 3,828 | 2,967 | 183 | 6,979 |
| 2001 | 209 | 131 | 5 | 345 | 60.6 | 38.0 | 1.4 | 100.0 | 5,224 | 3,275 | 125 | 8,624 | 8.4 | 6,947 | 4,355 | 166 | 11,468 |
| 2002 | 333 | 187 | 1 | 521 | 63.9 | 35.9 | 0.2 | 100.0 | 9,663 | 5,426 | 29 | 15,118 | 14.7 | 7,352 | 4,129 | 22 | 11,503 |
| 2003 | 318 | 145 | 0 | 463 | 68.7 | 31.3 | 0.0 | 100.0 | 9,078 | 4,139 | 0 | 13,218 | 17.1 | 5,917 | 2,698 | 0 | 8,615 |
| 2004 | 346 | 143 | 1 | 490 | 70.6 | 29.2 | 0.2 | 100.0 | 8,546 | 3,532 | 25 | 12,103 | 11.9 | 8,017 | 3,313 | 23 | 11,353 |
| 2005 | 366 | 87 | 1 | 454 | 80.6 | 19.2 | 0.2 | 100.0 | 8,161 | 1,940 | 22 | 10,124 | 8.4 | 10,86 | 2,584 | 30 | 13,482 |
| 2006 | 309 | 160 | 0 | 469 | 65.9 | 34.1 | 0.0 | 100.0 | 6,466 | 3,348 | 0 | 9,815 | 10.0 | 7,251 | 3,755 | 0 | 11,005 |
| 2007 | 373 | 130 | 0 | 503 | 74.2 | 25.8 | 0.0 | 100.0 | 6,426 | 2,239 | 0 | 8,665 | 10.3 | 6,963 | 2,427 | 0 | 9,390 |
| 2008 | 291 | 235 | 1 | 527 | 55.2 | 44.6 | 0.2 | 100.0 | 6,107 | 4,932 | 21 | 11,060 | 15.3 | 4,463 | 3,604 | 15 | 8,082 |
| 2009 | 302 | 186 | 2 | 490 | 61.6 | 38.0 | 0.4 | 100.0 | 4,392 | 2,705 | 29 | 7,126 | 7.4 | 6,625 | 4,080 | 44 | 10,749 |
| Average | 265 | 186 | 3 | 454 | 58.2 | 41.0 | 0.8 | 100.0 | 5,237 | 3,553 | 75 | 8,866 | 11.4 | 5,391 | 3,635 | 62 | 9,088 |

A similar order of fit among models was found for the Hugh Smith Lake stock (Shaul et al. 2009). A strong over-compensation mechanism is generally inconsistent with the life history and ecology of coho salmon, and therefore the Ricker model has typically produced an inferior statistical fit compared with hockey stick and Beverton-Holt models for populations from Oregon to central British Columbia (Bradford et al. 2000; Barrowman et al. 2003).

Table 7.–Age composition of coho salmon jacks counted at Ford Arm Weir, 1985–2009.

| Return | Ageable Scale Sample Age Class (Samples) | | | | Percent by Age Age Class (Percent) | | | | Jack Count by Age Class Age Class (Number of Fish) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 1.0 | 2.0 | 3.0 | Total | 1.0 | 2.0 | 3.0 | Total | 1.0 | 2.0 | 3.0 | Total |
| 1985 | 4 | 67 | 0 | 71 | 5.6 | 94.4 | 0.0 | 100.0 | 16 | 260 | 0 | 276 |
| 1986 | 0 | 65 | 5 | 70 | 0.0 | 92.9 | 7.1 | 100.0 | 0 | 204 | 16 | 220 |
| 1987 | 0 | 52 | 1 | 53 | 0.0 | 98.1 | 1.9 | 100.0 | 0 | 127 | 2 | 129 |
| 1988 | 2 | 68 | 1 | 71 | 2.8 | 95.8 | 1.4 | 100.0 | 9 | 297 | 4 | 310 |
| 1989 | 3 | 56 | 0 | 59 | 5.1 | 94.9 | 0.0 | 100.0 | 14 | 253 | 0 | 267 |
| 1990 | 2 | 40 | 0 | 42 | 4.8 | 95.2 | 0.0 | 100.0 | 12 | 241 | 0 | 253 |
| 1991 | 0 | 38 | 0 | 38 | 0.0 | 100.0 | 0.0 | 100.0 | 0 | 241 | 0 | 241 |
| 1992 | 0 | 20 | 1 | 21 | 0.0 | 95.2 | 4.8 | 100.0 | 0 | 279 | 14 | 293 |
| 1993 | 0 | 30 | 1 | 31 | 0.0 | 96.8 | 3.2 | 100.0 | 0 | 64 | 2 | 66 |
| 1994 | 7 | 28 | 1 | 36 | 19.4 | 77.8 | 2.8 | 100.0 | 42 | 170 | 6 | 218 |
| 1995 | 1 | 26 | 0 | 27 | 3.7 | 96.3 | 0.0 | 100.0 | 7 | 179 | 0 | 186 |
| 1996 | 5 | 51 | 4 | 60 | 8.3 | 85.0 | 6.7 | 100.0 | 20 | 202 | 16 | 238 |
| 1997 | 1 | 35 | 3 | 39 | 2.6 | 89.7 | 7.7 | 100.0 | 13 | 457 | 39 | 509 |
| 1998 | 0 | 8 | 0 | 8 | 0.0 | 100.0 | 0.0 | 100.0 | 0 | 315 | 0 | 315 |
| 1999 | 1 | 15 | 0 | 16 | 6.3 | 93.8 | 0.0 | 100.0 | 11 | 164 | 0 | 175 |
| 2000 | 2 | 36 | 0 | 38 | 5.3 | 94.7 | 0.0 | 100.0 | 19 | 338 | 0 | 357 |
| 2001 | 5 | 59 | 0 | 64 | 7.8 | 92.2 | 0.0 | 100.0 | 25 | 298 | 0 | 323 |
| 2002 | 2 | 5 | 0 | 7 | 28.6 | 71.4 | 0.0 | 100.0 | 102 | 254 | 0 | 356 |
| 2003 | 19 | 66 | 1 | 86 | 22.1 | 76.7 | 1.2 | 100.0 | 174 | 606 | 9 | 789 |
| 2004 | 9 | 18 | 0 | 27 | 33.3 | 66.7 | 0.0 | 100.0 | 112 | 223 | 0 | 335 |
| 2005 | 1 | 31 | 0 | 32 | 3.1 | 96.9 | 0.0 | 100.0 | 10 | 317 | 0 | 327 |
| 2006 | 0 | 17 | 0 | 17 | 0.0 | 100.0 | 0.0 | 100.0 | 0 | 314 | 0 | 314 |
| 2007 | 2 | 27 | 0 | 29 | 6.9 | 93.1 | 0.0 | 100.0 | 7 | 93 | 0 | 100 |
| 2008 | 0 | 4 | 0 | 4 | 0.0 | 100.0 | 0.0 | 100.0 | 0 | 165 | 0 | 165 |
| 2009 | 2 | 16 | 0 | 18 | 11.1 | 88.9 | 0.0 | 100.0 | 3 | 28 | 0 | 31 |
| Average | 3 | 35 | 1 | 39 | 7.1 | 91.4 | 1.5 | 100.0 | 24 | 244 | 4 | 272 |

Table 8.–Ford Arm Lake coho salmon net adult spawning escapement and total adult coho salmon return and total return adjusted to 1982–2009 average presmolt survival (11.2%), by brood year.

| Brood | Net Escapement[a] | Total Adult Return Age (Number of Fish) | | | | Return Adjusted to Average Survival Age (Number of Fish) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Number of Spawners | 3 | 4 | 5 | Total | 3 | 4 | 5 | Total |
| 1982 | 2,606 | 2,409 | 2,439 | 0 | 4,848 | 2,157 | 3,043 | 0 | 5,201 |
| 1983 | 1,898 | 1,639 | 1,527 | 12 | 3,178 | 2,045 | 3,712 | 20 | 5,777 |
| 1984 | –[b] | 1,706 | 3,398 | 59 | 5,163 | 4,147 | 5,621 | 55 | 9,823 |
| 1985 | 2,262 | 2,602 | 1,940 | 12 | 4,554 | 4,304 | 1,818 | 14 | 6,136 |
| 1986 | 1,496 | 4,161 | 2,742 | 28 | 6,931 | 3,900 | 3,187 | 29 | 7,116 |
| 1987 | 1,662 | 2,520 | 1,682 | 63 | 4,265 | 2,929 | 1,758 | 46 | 4,734 |
| 1988 | 3,082 | 4,308 | 4,288 | 528 | 9,124 | 4,503 | 3,164 | 270 | 7,937 |
| 1989 | 2,144 | 5,000 | 6,448 | 27 | 11,475 | 3,689 | 3,293 | 22 | 7,004 |
| 1990 | 2,144 | 5,586 | 7,459 | 56 | 13,101 | 2,853 | 6,016 | 124 | 8,993 |
| 1991 | 2,728 | 4,000 | 2,856 | 14 | 6,870 | 3,226 | 6,333 | 24 | 9,583 |
| 1992 | 3,795 | 3,876 | 2,311 | 150 | 6,337 | 8,594 | 4,035 | 115 | 12,744 |
| 1993 | 4,152 | 3,538 | 3,307 | 287 | 7,132 | 6,177 | 2,526 | 160 | 8,863 |
| 1994 | 3,200 | 6,314 | 6,553 | 43 | 12,910 | 4,822 | 3,657 | 63 | 8,542 |
| 1995 | 1,610 | 9,284 | 4,646 | 211 | 14,141 | 5,181 | 6,756 | 183 | 12,121 |
| 1996 | 2,068 | 5,506 | 3,422 | 125 | 9,053 | 8,007 | 2,968 | 166 | 11,141 |
| 1997 | 4,685 | 4,415 | 3,275 | 29 | 7,719 | 3,829 | 4,355 | 22 | 8,206 |
| 1998 | 7,015 | 5,224 | 5,426 | 0 | 10,650 | 6,947 | 4,128 | 0 | 11,075 |
| 1999 | 3,772 | 9,663 | 4,140 | 25 | 13,828 | 7,352 | 2,698 | 23 | 10,074 |
| 2000 | 2,282 | 9,078 | 3,532 | 22 | 12,632 | 5,917 | 3,313 | 29 | 9,259 |
| 2001 | 1,422 | 8,546 | 1,940 | 0 | 10,486 | 8,016 | 2,584 | 0 | 10,600 |
| 2002 | 6,997 | 8,162 | 3,348 | 0 | 11,510 | 10,870 | 3,754 | 0 | 14,624 |
| 2003 | 6,703 | 6,467 | 2,239 | 21 | 8,727 | 7,252 | 2,426 | 15 | 9,693 |
| 2004 | 3,517 | 6,426 | 4,932 | 29 | 11,387 | 6,964 | 3,604 | 44 | 10,612 |
| 2005 | 4,081 | 6,107 | 2,705 | ***82***[c] | 8,894 | 4,463 | 4,080 | ***59***[b] | 8,602 |
| Average | 3,275 | 5,272 | 3,607 | 76 | 8,955 | 5,339 | 3,701 | 62 | 9,102 |

[a] Net adult spawning escapement is calculated as the total accounted number of adults entering the system minus Type 2 mortalities, defined as estimated pre-spawning mortalities related to sampling, operation of the weir and depletion of oxygen in the system.

[b] Coho salmon were not coded-wire tagged in 1982 and, subsequently, the adult weir project was not operated in 1984.

[c] The age 5 return for the 2005 brood year (shown in bold italics) was extrapolated based on the average age 5 proportion of 1982–2004 brood year returns.

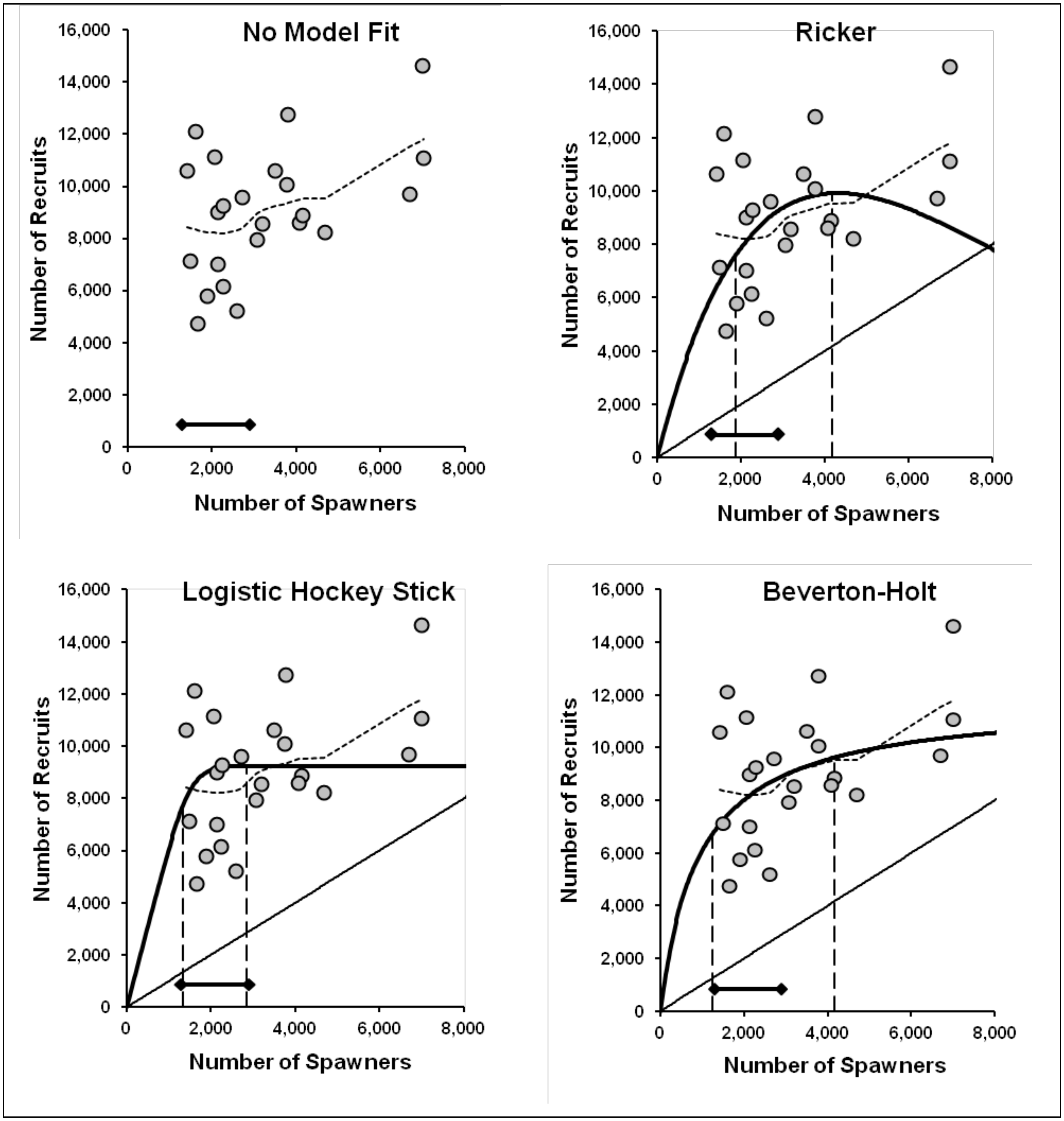


Figure 19.–Spawner-recruit relationship for Ford Arm Lake coho salmon fitted with three different stock-recruitment models showing escapement ranges estimated to produce 90% or more of MSY. Also shown is a 0.8 LOESS fit. The effect of presmolt–adult survival is removed by standardizing returns to the long-term survival rate of 11.2%. The current goal range is shown by a horizontal bar.

The residuals from the best-fitting Beverton-Holt model exhibit autocorrelation (Figure 20). We suspect that variation in the level of marine derived nutrients deposited in the system may have been a factor, based on an observed increase in pink salmon escapements (Figure 21) concurrent with an increase in coho salmon returns (Figure 11). In particular, brood years associated with the lowest levels of pink salmon escapement, with average peak counts <55,000 spawners in the common brood year and the following year, underperformed other brood years by a substantial margin (Figure 22). Therefore, we examined the spawner-recruit residual for coho salmon as a function of the peak pink salmon survey count in the same brood year, in the following year, and the average for both years (Figure 23). The positive relationships associated with low to moderate pink salmon escapements also featured inflection and saturation points that appeared best described by a logistic hockey stick (LHS) model (Barrowman and Myers 2000), with the addition of a variable Y-intercept. Statistical fits were about the same for pink salmon escapement in the common brood year and the following year, and were closest for the average of peak counts in both years.

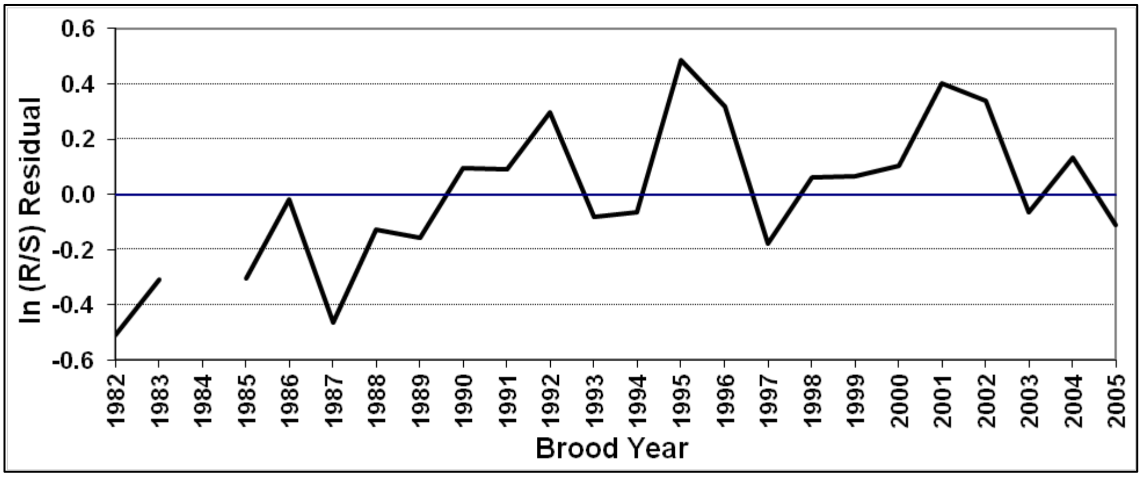


Figure 20.–Residuals (ln (R/S) - fitted ln (R/S)) from the Beverton-Holt spawner–recruit relationship for Ford Arm Lake coho salmon, 1982–1983 and 1985–2005.

Based on these results, we tested a combined Coho-Pink model based on (a) the Beverton-Holt spawner-recruit relationship between coho spawners and recruits and (b) a LHS model fit of the 2-year average pink salmon escapement against residuals from the Beverton-Holt relationship. Excel Solver was used to arrive at the combination of parameter values resulting in the best least-sum-of-squares fit for the combined model. This model produced substantial improvement in describing the spawner-recruit relationship for the coho salmon population but produced a statistically inferior fit to a Pink-Coho population involving a different combination of models (described below).

## Pink Only Model

We fitted a LHS model to the relationship between the 2-year average peak pink salmon count and the survival-adjusted brood year return of coho salmon. Best-fit LHS model parameter estimates were: inflection point ($\mu$) = 78,800; $\theta$ = 0.19667; $\alpha$ = 0.07972; intercept = 4,325. This model will henceforth be referred to as a Pink Only model (Figure 24). A plot of the residuals suggests a positive overall relationship between coho escapement and survival-adjusted brood-year return after accounting for the effect of variable pink salmon escapement (Figure 25). The resulting linear relationship with a positive slope is not well-described by established spawner-recruit models, although it appears consistent with the absence of over-compensation apparent in most spawner-recruit relationships for coho salmon (Bradford et al. 2000, Barrowman et al. 2003, Shaul et al. 2009).

Table 9.–Spawner-recruit parameter estimates and statistics for the Ford Arm Lake coho salmon population based on the Logistic Hockey Stick (LHS), Beverton-Holt, and Ricker spawner-recruit models, as well as a combined Pink-Coho model incorporating average pink salmon escapement and a slanted hockey stick (BHS) spawner-recruit model for coho salmon.

| | Model | | | | Current |
|---|---|---|---|---|---|
| Parameter | Ricker | LHS | Beverton-Holt | Pink-Coho BHS | Goal |
| Slope at Origin (α) | 6.248 | 6.263 | 12.501 | 6.781 | |
| LHS (θ) | | 0.1678 | | | |
| LHS (μ) | | 1,473 | | | |
| Beverton-Holt (A) | | | 11,803 | | |
| Beverton-Holt (B) | | | 944 | | |
| Ricker (β) | 0.00023178 | | | | |
| Combined Pink-Coho Model | | | | | |
| Pink-Coho Intercept ($m_p$) | | | | 4,243 | |
| Pink-Coho (μ) | | | | 68,092 | |
| Pink-Coho (θ) | | | | 0.1611 | |
| Pink-Coho (α) | | | | 0.091967 | |
| Log Residual Slope ($m_c$) | | | | 0.00002909 | |
| Log Residual Intercept ($b_p$) | | | | -0.1042 | |
| Combined Pink-Coho BHS Model with Stationary Pink Salmon Escapement | | | | | |
| Pink-Coho BHS Slope ($m_{SHS}$) | | | | 0.3091 | |
| Pink-Coho BHS (Intercept $b_{SHS}$) | | | | 9,210 | |
| Standard Pink Peak Count ($P_s$) | | | | 81,948 | |
| Maximum Sustained Yield (MSY) | | | | | |
| Escapement at MSY ($E_{MSY}$) | 2,987 | 1,885 | 2,394 | 1,422 | 2,050 |
| Lower Esc. Bound (90% of MSY) | 1,880 | 1,349 | 1,242 | 1,280 | 1,300 |
| Upper Esc. Bound (90% of MSY) | 4,196 | 2,857 | 4,153 | 2,572 | 2,900 |
| Point Estimate of MSY | 6,353 | 7,096 | 6,071 | 8,220 | |
| Return at MSY | 9,339 | 8,981 | 8,465 | 9,642 | |
| Exploitation Rate at MSY | 68.0% | 79.0% | 71.7% | 85.3% | |
| Maximum Return ($R_{max}$) | | | | | |
| Point Estimate of $R_{max}$ | 9,917 | 9,250 | 10,859 | 13,836 | |
| Escapement at $R_{max}$ | 4,314 | 3,475 | 10,859 | 13,836 | |
| Exploitation Rate at $R_{max}$ | 56.50% | 62.43% | 0.00% | 0.00% | |
| Carrying Capacity ($K$) | | | | | |
| Point Estimate of $K$ | 7,905 | 9,250 | 10,859 | 13,836 | |
| Best Model Fit | | | | | |
| Sum of Squared Residuals | 146,106,927 | 132,017,010 | 113,366,596 | 50,106,835 | |
| AIC Value | 364.5 | 364.6 | 358.6 | 351.4 | |

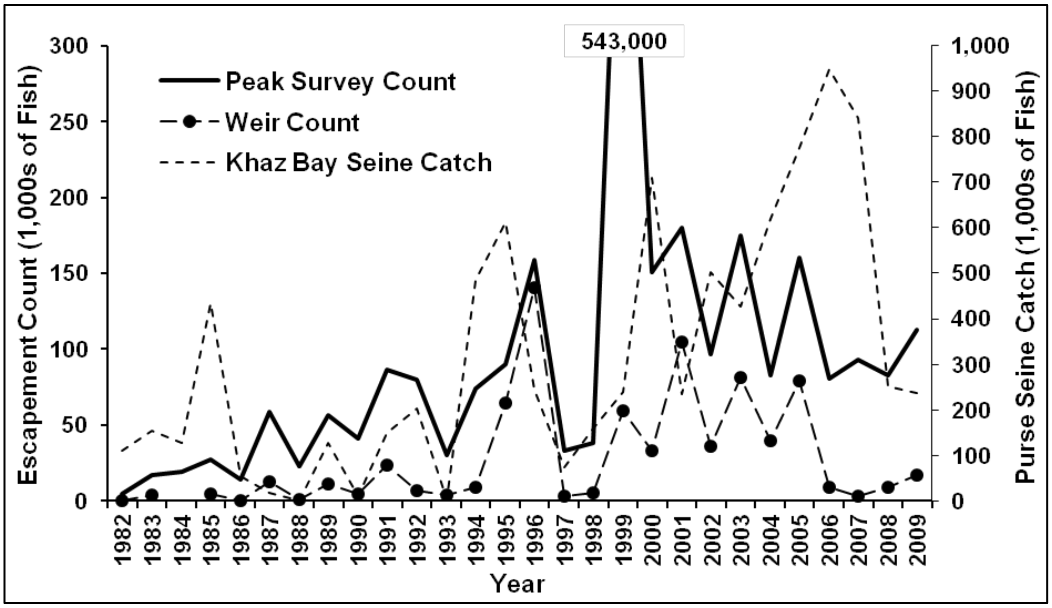


Figure 21.–Pink salmon peak survey count in Ford Arm Creek, number of pink salmon counted through the Ford Arm weir, and number harvested in the Khaz Bay purse seine fishery, 1982–2009.

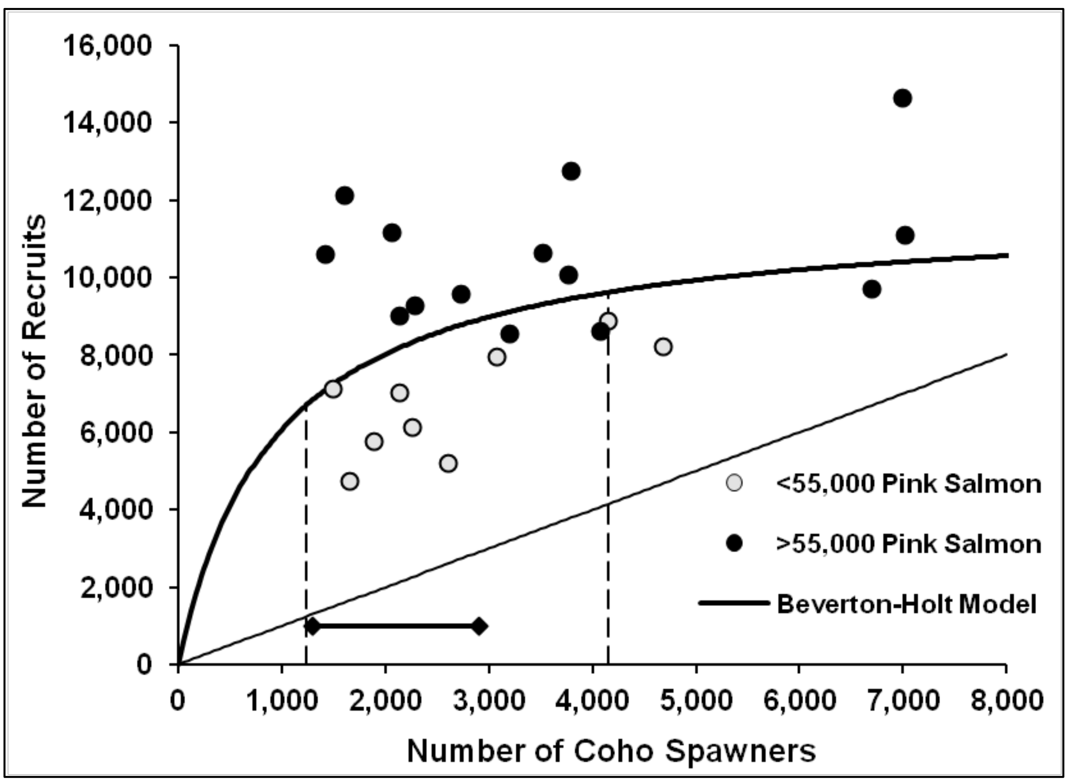


Figure 22.–Beverton-Holt spawner-recruit relationship for Ford Arm Creek coho salmon, with adult returns adjusted to a long-term average presmolt–adult survival rate of 11.2%, showing returns associated with 2-year average peak pink salmon escapements above and below a peak count of 55,000 spawners.

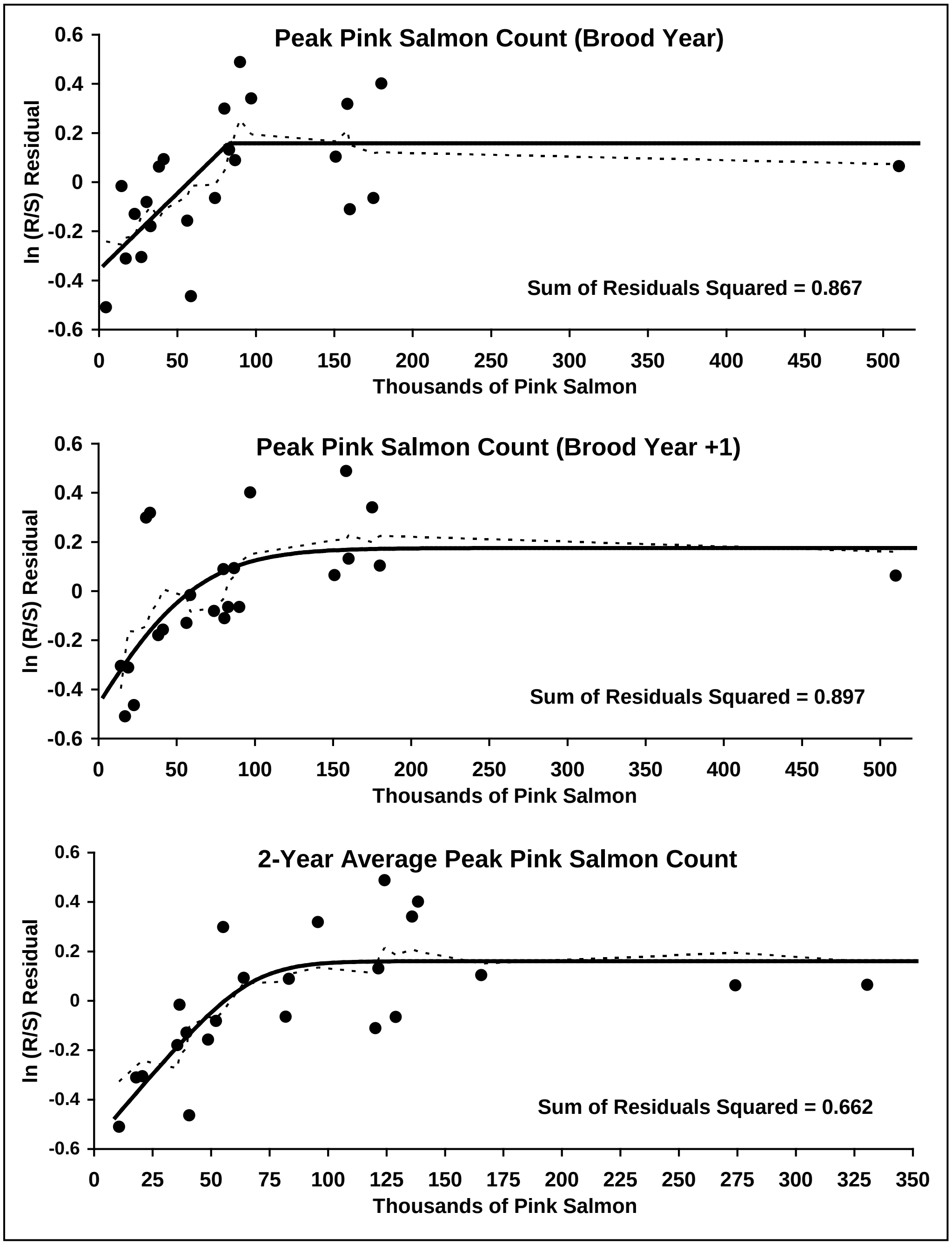


Figure 23.–Relationship between the peak survey count of pink salmon in Ford Arm Creek and the residuals (ln (R/S) - fitted ln (R/S)) from the Beverton-Holt spawner–recruit relationship for coho salmon, 1982–1983 and 1985–2005. The solid line is an LHS model fit and the dashed line is the 7-year symmetrical average. The independent variable in the top graph is the peak pink salmon count in the common brood year with coho salmon, the middle graph is based on the peak count in the following brood year, and the bottom graph includes the average peak pink salmon count in both years.

The positive linear relationship between coho escapement and residuals from the Pink Only model appears consistent with observations of successful rearing of coho juveniles to smolt size outside of the confines of the stream, including in estuaries (Koski 2009) and even in marine waters (Shaul et al. 2013). We suspect that the contribution to smolt production by these nomads, though relatively low compared with stream-reared fish, is relatively non-compensatory and, therefore, consistent with higher average survival-adjusted returns from more abundant brood year escapements. A positive linear relationship with escapement is not unexpected, given a relatively non-compensatory component (attributed to production from nomads surplus to stream capacity) combined with a highly compensatory component driven by territoriality and the limitations of the stream environment as per the hockey stick model.

## Pink-Coho Model

These observations led to construction of a Pink-Coho model. We combined the Pink Only model with a linear sub-model and regressed the net coho salmon escapement against the residuals from the pink-coho relationship. The combined model was fit simultaneously using Excel Solver. The Pink-Coho model produced an 18% better statistical fit compared with the Coho-Pink model described above and accounted for 62.1% of the variation in observed survival-adjusted returns (Figure 26), of which 57.5% is attributed to variation in pink salmon escapement and only 4.6% is attributed to variation in brood year coho salmon escapement.

To arrive at an escapement range approximating 90% or more of MSY, we adapted the plain hockey stick model (Barrowman and Myers 2000) to allow for a positive slope above the inflection point (μ) by setting the pink salmon escapement parameter in the Pink-Coho model at the 1982–2009 median peak count of 82,000 fish. The best statistical fit was achieved when μ was set at the lowest observed escapement of 1,422 spawners. The resulting bent hockey stick (BHS) model (Shaul et al. 2013), described conceptually below, has an associated α parameter of 6.781 (Figure 27; Table 9), which is likely conservative because it presumes a linear relationship between the origin and μ and because there are no observations from escapements below the estimate of μ.

The combined Pink-Coho BHS model indicates an escapement range at 90% or more of $E_{MSY}$ of 1,280–2,572 spawners, relatively close to the current goal range of 1,300–2,900 spawners. At a long-term average coho salmon escapement of 3,275 spawners, the Pink-Coho model predicts an inflection point (μ) in the coho salmon return at a slightly lower peak count of 78,200 pink salmon spawners compared with 78,800 spawners for the Pink Only model. However, the range associated with 90–99% of maximum coho production (at unlimited salmon nutrient biomass) is lower for the Pink-Coho model at 63,600–82,000 pink salmon spawners compared with 74,200–116,300 spawners for the Pink Only model (Table 10).

## Bent Hockey Stick Model

None of the three primary models (Ricker, Beverton-Holt, Hockey Stick) provided a satisfactory best-fit for the coho salmon spawner-recruit data series after adjustment for pink salmon escapement (Figure 25). The Ricker model, with its over-compensation feature, is typically inconsistent with a data series for coho salmon. The Beverton-Holt model produced a substantially inferior statistical fit compared with a simple linear model and resulted in an improbably high α estimate of 12.501 (Table 9). A standard hockey stick or LHS model produced the best statistical fit to the data but assumed a constant return above $E_{MSY}$ when there appeared to be a slight upward linear trend. As described above, there appears to be some biological rationale for a consistently positive response above μ, based on nomads that rear in marine and estuarine waters outside the system and are unlikely to be governed by the same rigid compensatory constraints as stream-rearing fish (Shaul et al. 2013). These fish face a more treacherous but less density-constraining environment that may produce survival rates to smolthood that are low but relatively independent of abundance. In the Ford Arm system in the fall, we have observed and sampled large, silver, smolt-sized fish that were sensitive to handling mortality, likely due to osmoregulatory stress, and exhibited explosive growth in the presmolt scale zone (Shaul et al. 1986).

Based on these considerations, Shaul et al. (2013) modified the simple hockey stick model to produce a "bent" hockey stick (BHS) model that allows for positive slope above $E_{MSY}$ with a constant increase in returns at larger escapements, as is consistent with the trend in spawner-recruit data, not only in this system but also for Hugh Smith Lake. We fitted the BHS model in a similar fashion to that described for the simple hockey stick model by Barrowman and Myers (2000), but employed a simple linear regression fit instead of a constant average return for escapements above μ. Coho salmon return estimates adjusted for a constant 1982–2009 median peak escapement count of 82,000 pink salmon (Figure 27) show an overall positive slope throughout their range. With no escapement estimates below μ, α is conservatively estimated at 6.781 based on a straight line from the origin, with an $E_{MSY}$ of 1,422 spawners predicted to produce an adult return of 9,642 fish for a yield of 8,220 fish at an exploitation rate of 85%. The range of escapements predicted to produce 90% or more of MSY is 1,280–2,572 spawners, compared 1,242–4,153 spawners indicated by the Beverton-Holt model and the current goal of 1,300–2,900 spawners. Despite inclusion of more parameters (6 total), the Pink-Coho BHS model has a lower associated AIC value compared with the conventional spawner-recruit models that include either two parameters (Beverton-Holt and Ricker models) or three parameters (LHS model; Table 9).

## Reference Points for Response to Pink Salmon Escapement

The Pink Only model based on the average of both brood years was selected as the best model for determining potential pink salmon escapement reference points, based on the lowest associated AIC value (Akaike 1974; Table 10). Nominal saturation (defined as 99% of maximum coho salmon production) corresponds to a peak count of 116,300 pink salmon spawners and 90% of saturation corresponds with a count of 74,200 pink salmon spawners (Figure 24). The apparent effect of pink salmon escapement on the survival-adjusted coho salmon return is substantial over a limited range, with a doubling of the coho salmon return predicted between a low peak count of 10,000 pink salmon spawners and a moderately high peak count of 93,000 pink salmon spawners. Predicted returns increase from 4,318 adult coho salmon at zero pink salmon escapement, to 5,172 coho salmon at the lowest recently observed 2-year average peak count of 10,750 pink salmon spawners, and 10,547 coho salmon at nominal saturation (116,300 pink spawners).

The peak aerial escapement count of pink salmon at Ford Arm Creek (Appendix C) is currently combined with peak counts at 6 other streams in the vicinity, for a management target for Slocum Arm of 160,000–520,000 spawners (Heinl et al. 2008). The peak survey count at Ford Arm Creek (including both aerial and foot surveys) during 1982–2009 averaged 30.0% of the aggregate index used for the Slocum Arm management target. Therefore, the portion of the index goal represented by Ford Arm Creek totals about 48,000–156,000 spawners. Establishing a pink salmon index escapement threshold at 90% of maximum coho abundance based on the Pink Only Model would increase the lower goal bound from 48,000 to about 74,000 pink salmon spawners, whereas nominal saturation (116,300 spawners) falls 14% above the mid-point of the current goal (102,000).

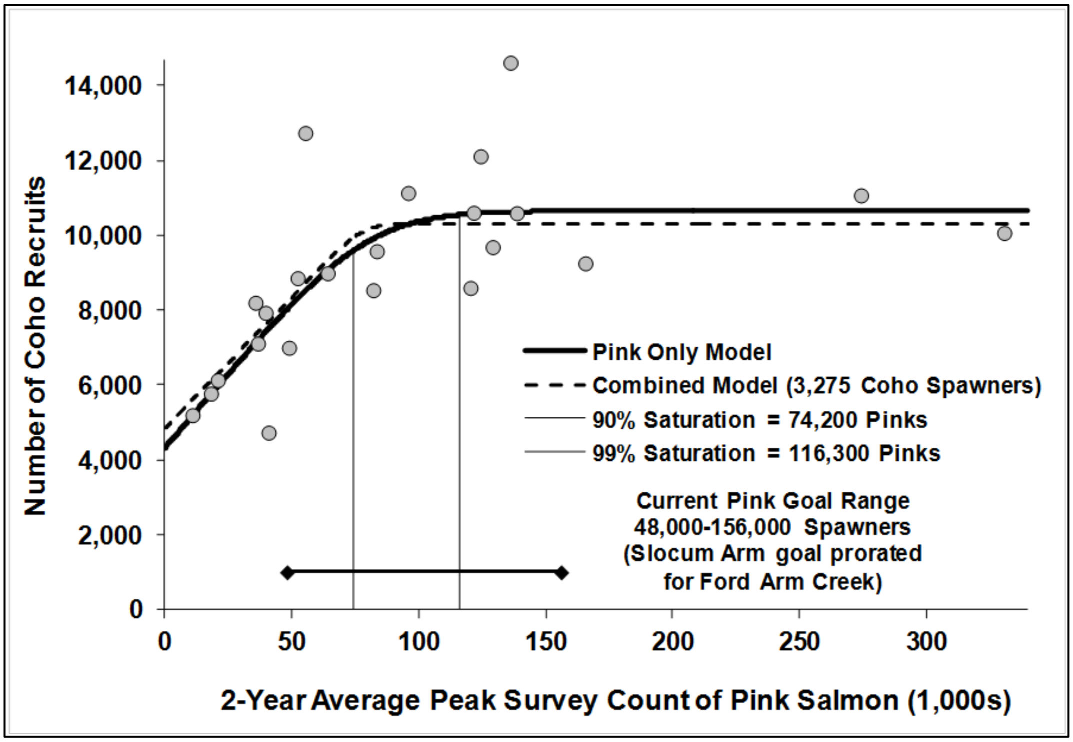


Figure 24.–LHS model fit of the relationship between the 2-year average peak pink salmon count and the number of coho salmon recruits, adjusted to a constant 11.2% presmolt–adult survival rate (dashed line). The inflection point (μ) and nominal saturation point are shown based on the model fit at a constant 1982–2005 average net coho salmon escapement of 3,275 spawners (solid line). Also shown is the current Slocum Arm pink salmon escapement index goal prorated for Ford Arm Creek.

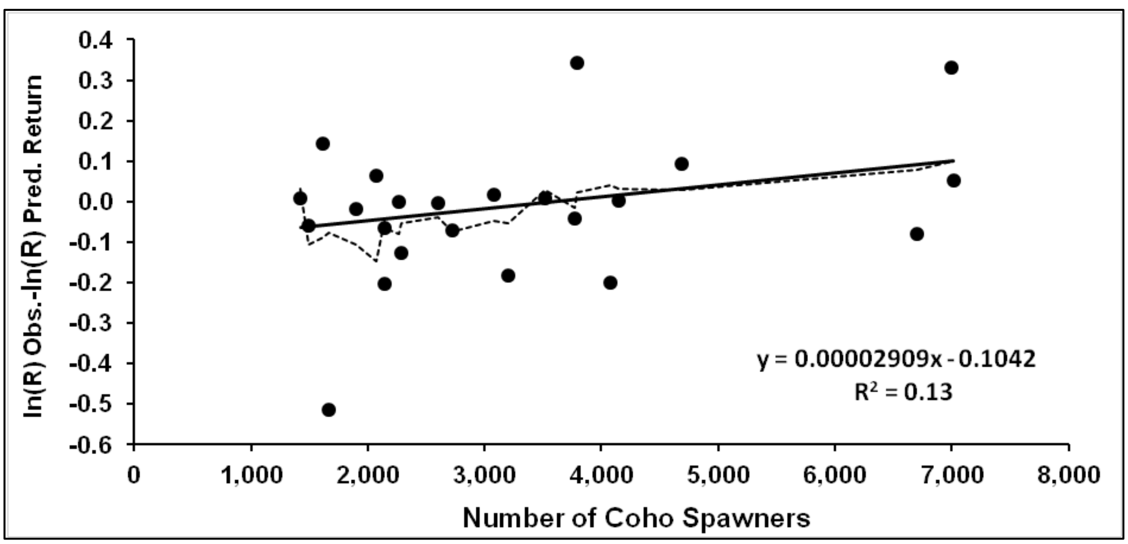


Figure 25.–Relationship between the number of coho salmon spawners and the residual (ln (R) - fitted ln (R)) from the LHS model fit of the relationship between the 2-year average peak pink salmon count and the number of survival-adjusted coho salmon recruits. The dashed line is a 5-year symmetrical average.

Table 10.–A comparison of models that predict coho salmon brood year recruitment (adjusted to constant presmolt–adult survival) based on pink salmon escapement (Pink Only) and both pink and coho salmon escapement (Pink-Coho).

| Model | Pink Brood Year (s)[a] | AIC Value[b] | Pink Salmon % Saturation (Spawners)[c] 0.90 | 0.99 | Coho Production Saturation/ Zero Pinks[d] |
|---|---|---|---|---|---|
| Pink Only | Common | 2.7 | 63,400 | 131,200 | 2.07 |
| | Common + 1 | -0.5 | 103,700 | 214,100 | 2.27 |
| | Average | -8.0 | 74,200 | 116,300 | 2.47 |
| Pink-Coho | Common | 3.5 | 71,400 | 158,100 | 1.82 |
| | Common + 1 | 3.7 | 92,100 | 117,600 | 1.75 |
| | Average | -5.1 | 63,600 | 82,000 | 2.13 |

[a] Includes pink salmon escapement in the coho brood year (common), the year following the coho brood year (common + 1) and the average for both years.
[b] Akaike information criterion (Akaike 1974).
[c] Pink salmon peak survey count. Saturation represents the maximum predicted coho salmon return that can be achieved at unlimited salmon nutrient biomass.
[d] Ratio of predicted maximum effect of pink salmon escapement on coho salmon production to predicted production without pink salmon .

Expansion of the peak pink salmon survey count by a factor of 2.5 (to approximate total escapement) results in reference points of 186,000 total pink salmon spawners at 90% of maximum coho production and 291,000 spawners at nominal saturation. When divided by total stream and lakeshore area of 175,721 $m^2$, estimated pink salmon carcass densities associated with the two parameters are 1.1 carcasses/$m^2$ and 1.7 carcasses/$m^2$, respectively. These values are consistent with the growth response by juvenile coho salmon to addition of pink salmon carcasses in an artificial stream channel observed by Wipfli et al. (2003), who found a substantial response in increased mass and length between 0 and 1 carcass/$m^2$ with incremental increases sharply diminishing at higher densities up to 4 carcasses/$m^2$. However, accounting for the contribution by carcasses of all species in Ford Arm Creek, the densities of total pink salmon equivalents (Table 11) associated with the 90% of maximum coho production and nominal saturation are approximately 1.3 carcasses/$m^2$ and 1.9 carcasses/$m^2$, respectively (Figure 28, bottom graph).

## MARINE DERIVED NUTRIENT LOADING AND EFFECTS

The average estimated biomass of salmon in the system increased nearly 3-fold during the study period, from 155,619 kg in 1982–1989 to 509,646 kg in 1990–1999 and 610,630 kg in 2000–2009 (Table 12). Pink Salmon comprised 84% of estimated average spawner biomass during the overall period (Table 13), with the remainder comprised of chum salmon (11%), coho salmon (3%) and sockeye salmon (2%). Average biomass of spawners of all species increased after the 1980s and all species except sockeye salmon increased again from the 1990s to the 2000s. The average contribution by pink salmon to total spawner biomass increased from 67% in 1982–1989 to 84% in 2000–2009. Average annual spawner biomass per km calculated over the total of 13.2 km of stream and lake length accessible to salmon was estimated at 11,789 kg/km in 1982–1989, 38,610 kg/km in 1990–1999 and 46,260 kg/km in 2000–2009 (Table 12).

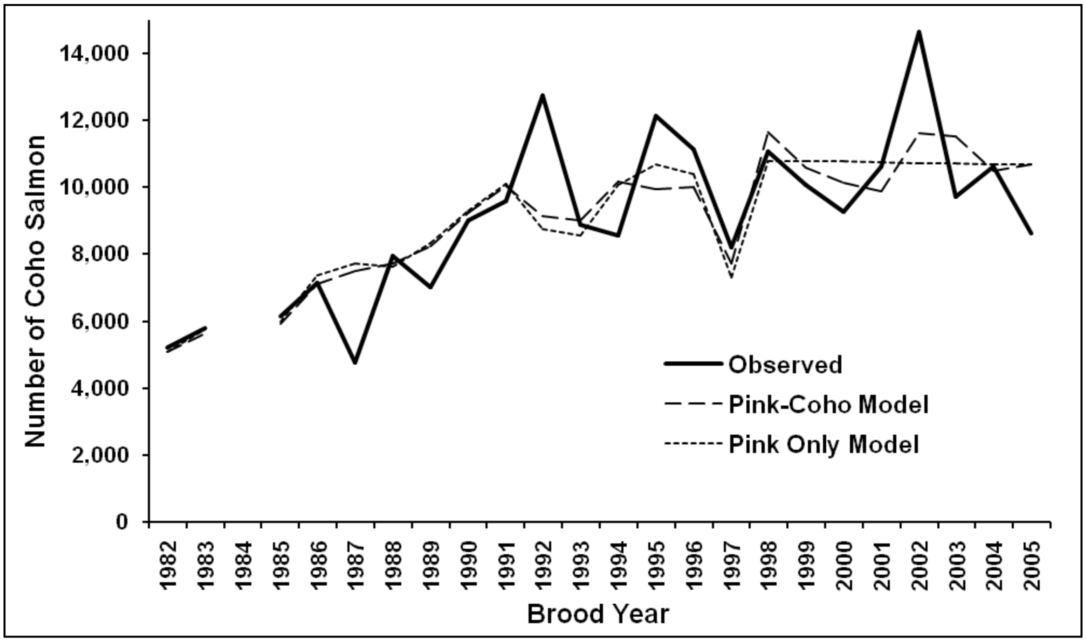


Figure 26.–Estimated coho salmon return by brood year (adjusted to a constant 11.2% presmolt–adult survival rate) compared with returns predicted by the Pink-Coho and Pink Only models.

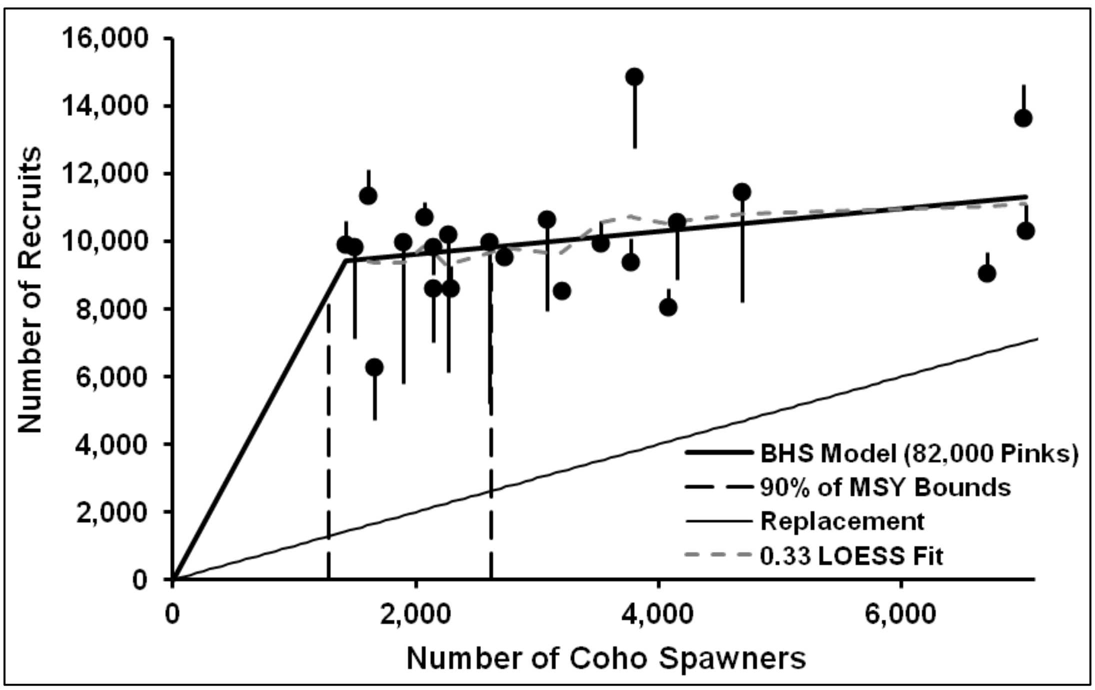


Figure 27.–Ford Arm Lake coho salmon BHS spawner-recruit relationship based on the combined Pink-Coho model at a constant 1982–2009 median pink salmon escapement and a long-term average coho salmon presmolt–adult survival rate of 11.2%. The tails on the data points indicate predicted movement from their original locations based on a constant peak survey count of 82,000 pink salmon.

Table 11.–Estimated number of Ford Arm Lake pink salmon spawners and spawners of all four main species (converted to pink salmon equivalents) and spawner density calculations based on four methods of calculating habitat area.

| Year | Number of Fish: Pink Salmon | Number of Fish: Total Pink Equivalents[a] | Percent Pink Salmon | Area Calculation (Pink Salmon Equivalent Carcasses/$m^2$): Total Surface[b] 538,180 $m^2$ | Lakeshore & Stream[c] 175,721 $m^2$ | Stream Only[d] 126,980 $m^2$ | Outlet Only[e] 61,975 $m^2$ |
|---|---|---|---|---|---|---|---|
| 1982 | 11,250 | 26,476 | 42.5 | 0.05 | 0.15 | 0.21 | 0.43 |
| 1983 | 42,500 | 62,674 | 67.8 | 0.12 | 0.36 | 0.49 | 1.01 |
| 1984 | 47,500 | 62,502 | 76.0 | 0.12 | 0.36 | 0.49 | 1.01 |
| 1985 | 67,750 | 84,272 | 80.4 | 0.16 | 0.48 | 0.66 | 1.36 |
| 1986 | 35,825 | 43,929 | 81.6 | 0.08 | 0.25 | 0.35 | 0.71 |
| 1987 | 146,750 | 157,385 | 93.2 | 0.29 | 0.90 | 1.24 | 2.54 |
| 1988 | 56,855 | 75,261 | 75.5 | 0.14 | 0.43 | 0.59 | 1.21 |
| 1989 | 140,750 | 159,238 | 88.4 | 0.30 | 0.91 | 1.25 | 2.57 |
| 1990 | 103,115 | 132,083 | 78.1 | 0.25 | 0.75 | 1.04 | 2.13 |
| 1991 | 216,750 | 245,838 | 88.2 | 0.46 | 1.40 | 1.94 | 3.97 |
| 1992 | 199,933 | 224,667 | 89.0 | 0.42 | 1.28 | 1.77 | 3.63 |
| 1993 | 76,000 | 107,149 | 70.9 | 0.20 | 0.61 | 0.84 | 1.73 |
| 1994 | 184,738 | 216,647 | 85.3 | 0.40 | 1.23 | 1.71 | 3.50 |
| 1995 | 225,000 | 254,467 | 88.4 | 0.47 | 1.45 | 2.00 | 4.11 |
| 1996 | 396,113 | 415,107 | 95.4 | 0.77 | 2.36 | 3.27 | 6.70 |
| 1997 | 82,355 | 117,313 | 70.2 | 0.22 | 0.67 | 0.92 | 1.89 |
| 1998 | 95,433 | 144,795 | 65.9 | 0.27 | 0.82 | 1.14 | 2.34 |
| 1999 | 1,275,000 | 1,313,840 | 97.0 | 2.44 | 7.48 | 10.35 | 21.20 |
| 2000 | 377,500 | 400,594 | 94.2 | 0.74 | 2.28 | 3.15 | 6.46 |
| 2001 | 450,000 | 494,135 | 91.1 | 0.92 | 2.81 | 3.89 | 7.97 |
| 2002 | 242,500 | 278,486 | 87.1 | 0.52 | 1.58 | 2.19 | 4.49 |
| 2003 | 437,500 | 466,980 | 93.7 | 0.87 | 2.66 | 3.68 | 7.53 |
| 2004 | 207,500 | 225,715 | 91.9 | 0.42 | 1.28 | 1.78 | 3.64 |
| 2005 | 400,000 | 416,046 | 96.1 | 0.77 | 2.37 | 3.28 | 6.71 |
| 2006 | 201,250 | 240,247 | 83.8 | 0.45 | 1.37 | 1.89 | 3.88 |
| 2007 | 232,500 | 249,338 | 93.2 | 0.46 | 1.42 | 1.96 | 4.02 |
| 2008 | 207,500 | 274,274 | 75.7 | 0.51 | 1.56 | 2.16 | 4.43 |
| 2009 | 282,750 | 297,536 | 95.0 | 0.55 | 1.69 | 2.34 | 4.80 |
| Average | | | | | | | |
| 1982-1989 | 68,648 | 83,967 | 75.7 | 0.16 | 0.48 | 0.66 | 1.35 |
| 1990-1999 | 285,444 | 317,191 | 82.8 | 0.59 | 1.81 | 2.50 | 5.12 |
| 2000-2009 | 303,900 | 334,335 | 90.2 | 0.62 | 1.90 | 2.63 | 5.39 |
| All Years | 230,093 | 256,678 | 83.4 | 0.48 | 1.46 | 2.02 | 4.14 |

[a] Combined mass estimate for all species divided by the average weight for pink salmon.
[b] Based on the total lake and stream surface area accessible to anadromous fish.
[c] Based on total anadromous stream surface area and a 10 m perimeter zone around the lake and pond.
[d] Based only on the area of the outlet stream (Ford Arm Creek).

The four primary salmon species likely differ substantially in the areas, pathways, and efficiency in which marine derived nutrients (MDN) from their carcasses are delivered, utilized and retained in the system. Pink and chum salmon, which spawn mostly in the outlet stream, benefit the food web used by rearing fish below the lake. A few thousand pink salmon and some chum salmon usually spawn in inlet streams where their carcasses decompose, or are removed by bears and eagles or drift into the lake. Nearly all sockeye salmon spawn in beach areas around the shoreline and the outlet area immediately below the lake. The 70–75% of sockeye carcasses, on average, that do not drift onto the weir likely benefit coho salmon and other rearing species in the lake and immediate outlet area. The majority of coho salmon spawning occurs in the four inlet streams, although a significant amount also occurs in the outlet stream both below and above the weir. Coho spawners, being relatively few in number and somewhat isolated in time from other species, are heavily targeted by predators and scavengers. Therefore, nutrients from their carcasses are likely deposited mostly in riparian and upland areas rather than directly in streams.

Eggs deposited by spawning salmon but not retained in the substrate are likely directly available to juvenile coho salmon in all salmon spawning areas. Eggs available directly as food might be expected to increase proportionately more than the increase in spawner biomass due to scouring and superimposition of reds and attempts by spawners to deposit eggs in less suitable habitat.

An LHS model was fitted to estimates of total MDN loading density in the common brood year with coho salmon, the following brood year, and the average for both years combined against the survival-adjusted coho salmon return (Figure 28). The average for both years produced the best statistical fit with the lowest AIC value, and indicated that the benefit to coho salmon is maximized as escapement approaches 2 pink salmon equivalents per square meter, based on average salmon carcass biomass in the common brood year with coho salmon and the prior year. Associated density over stream and lakeshore habitat at 99% of maximum coho production is 1.57 fish/m$^2$ for Year X, 3.59 fish/m$^2$ for Year X+1 and 1.93 fish/m$^2$ for both. Predicted coho salmon returns at nominal MDN saturation are greater than returns predicted without MDN by 108% for Year X, 186% for Year X+1 and 189% for both.

In addition to their importance to rearing and resident fish, salmon derived nutrients can provide a large benefit to both aquatic and terrestrial communities (Gende et al. 2002), with one of the most evident benefiting species being the brown bear (Levi et al. 2012; Van Daele et al. 2013). In the Ford Arm Creek drainage the estimated average salmon biomass of 441,561 kg (Table 12) distributed across a total drainage area of 25.4 km$^2$ corresponds to an average salmon biomass density of 17,384 kg/km$^2$. Salmon spawner biomass loading at the drainage level increased nearly three-fold during the period of the study from an estimated 6,127 kg/km$^2$ in 1982–1989 to 24,041 kg/km$^2$ in 2000–2009. On average, the salmon biomass density in the Ford Arm Creek drainage has averaged approximately two orders of magnitude above estimated averages for four drainages presented by Levi et al. (2012) ranging from 43 kg/km$^2$ in the Quesnel River drainage in the Fraser River system to 229 kg/km$^2$ in the Egegik River system in Bristol Bay (overall average 149 kg/km$^2$).

Approximately 2,300 adult and sub-adult brown bears on Kodiak Island are estimated to annually consume about 3.77 million kg of salmon, or about 1,639 kg/bear, accounting for about 29% of salmon escapement (Van Daele et al. 2013). Assuming the same rate of salmon usage, the Ford Arm Creek drainage would support approximately 78 brown bears, or about 3 bears/km$^2$. The density estimate (including all bears) used for purposes of managing bear hunting in the west Chichagof Island unit that includes the Ford Arm Creek drainage is nearly an order of magnitude less at 0.32 bears/km$^2$ (Anthony Crupi, Bear Research Project Assistant, Alaska Department of Fish and Game, Douglas). The large difference suggests that the brown bear population may be limited by other factors to a density below what could be supported by salmon. That conclusion is supported by our anecdotal observations suggesting there may be substantial mortality from predation and population strife, evidenced by crews finding remains of bears (including a large male that washed up on the weir with severe head injuries apparently inflicted by another bear) and distinctive sows that frequented the weir with young-of-the-year cubs but returned without offspring the following year.

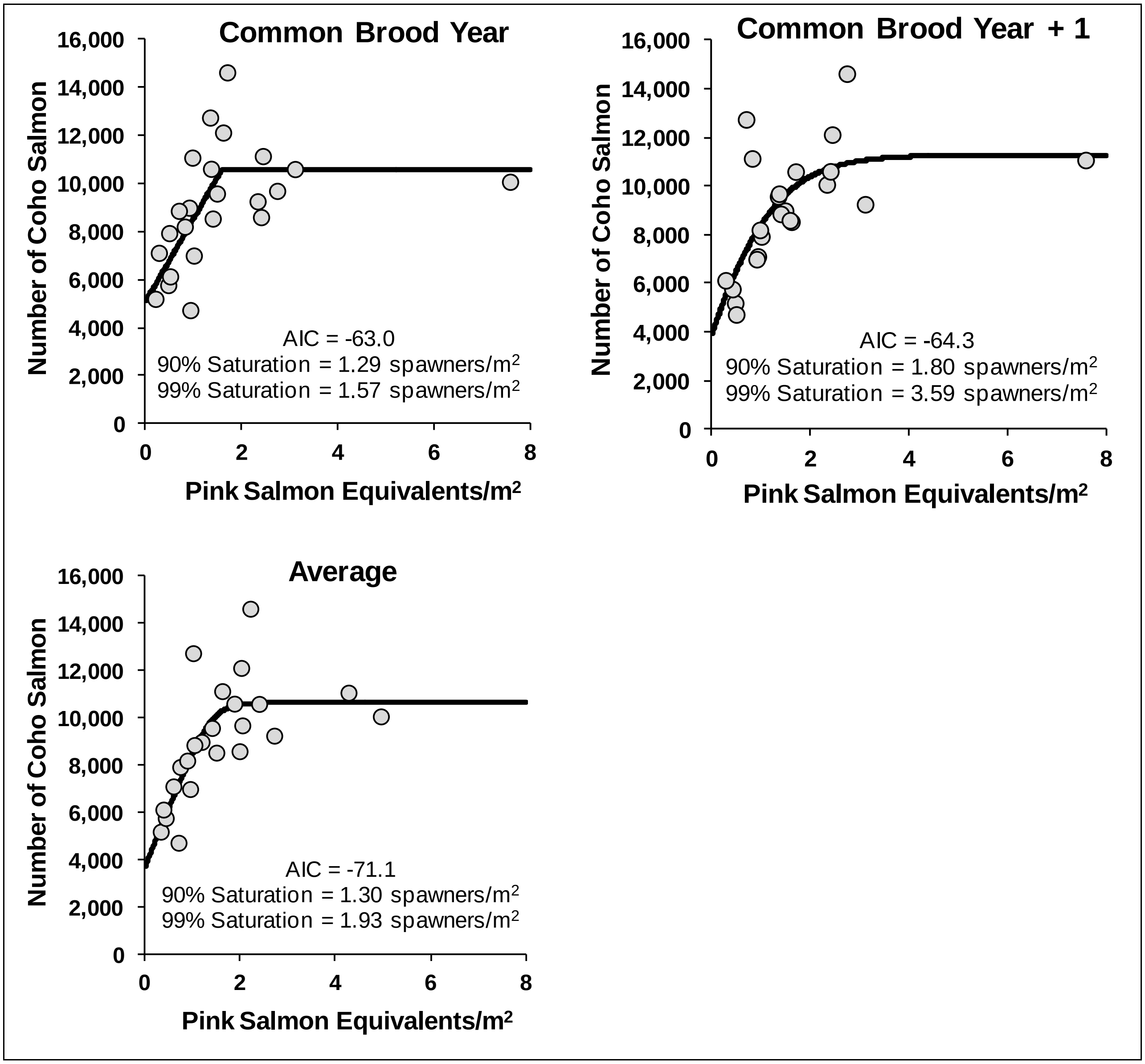


Figure 28.–Logistic Hockey Stick relationship between estimated total MDN loading density (pink salmon equivalents/$m^2$) in Ford Arm Creek and the survival-adjusted coho salmon return by brood year, 1982–1983 and 1985–2005. The independent variable in the top left graph is the MDN density in the common brood year with coho salmon, while the upper right graph is based on MDN loading in the following brood year. The bottom graph includes the average MDN loading density in both years.

Table 12.–Estimates of marine derived (MDN) nutrient loading, total and by habitat area in the Ford Arm Creek system, 1982−2009.

| | Species (Number of Fish) [a] | | | | Species (kg) | | | | | Area Calculation (kg of spawners/m²) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Total Surface Area[b] | Lakeshore & Stream[c] | Stream Only[d] | Outlet Only[e] |
| Year | Pink | Chum | Sockeye | Coho | Pink | Chum | Sockeye | Coho | Total | 538,180 $m^2$ | 175,721 $m^2$ | 126,980 $m^2$ | 61,975 $m^2$ |
| 1982 | 11,250 | ***5,581*** | ***1,694*** | 2,655 | 20,196 | 26,112 | 5,297 | 11,508 | 63,112 | 0.12 | 0.36 | 0.50 | 1.02 |
| 1983 | 42,500 | 12,400 | 1,095 | 1,931 | 68,019 | 51,861 | 3,069 | 8,306 | 131,256 | 0.24 | 0.75 | 1.03 | 2.12 |
| 1984 | 47,500 | 6,200 | ***1,694*** | ***2,031*** | 80,923 | 27,422 | 4,893 | 9,609 | 122,847 | 0.23 | 0.70 | 0.97 | 1.98 |
| 1985 | 67,750 | 2,790 | 3,363 | 2,324 | 105,218 | 11,893 | 9,828 | 11,036 | 137,975 | 0.26 | 0.79 | 1.09 | 2.23 |
| 1986 | 35,825 | 2,480 | 712 | 1,552 | 58,210 | 10,298 | 2,141 | 6,875 | 77,524 | 0.14 | 0.44 | 0.61 | 1.25 |
| 1987 | 146,750 | 4,036 | 1,847 | 1,694 | 262,940 | 15,920 | 5,675 | 6,962 | 291,496 | 0.54 | 1.66 | 2.30 | 4.70 |
| 1988 | 56,855 | 6,405 | 1,454 | 3,119 | 87,802 | 26,588 | 4,288 | 13,416 | 132,094 | 0.25 | 0.75 | 1.04 | 2.13 |
| 1989 | 140,750 | 9,982 | 1,330 | 2,176 | 231,647 | 44,529 | 3,916 | 8,556 | 288,648 | 0.54 | 1.64 | 2.27 | 4.66 |
| 1990 | 103,115 | 15,500 | 2,941 | 2,192 | 159,570 | 68,330 | 8,036 | 9,239 | 245,175 | 0.46 | 1.40 | 1.93 | 3.96 |
| 1991 | 216,750 | 9,027 | 5,852 | 2,761 | 306,498 | 33,365 | 16,467 | 11,212 | 367,542 | 0.68 | 2.09 | 2.89 | 5.93 |
| 1992 | 199,933 | 7,068 | 3,773 | 3,866 | 307,123 | 26,596 | 10,572 | 16,700 | 360,990 | 0.67 | 2.05 | 2.84 | 5.82 |
| 1993 | 76,000 | 9,666 | 6,362 | 4,202 | 109,338 | 33,099 | 17,091 | 14,375 | 173,903 | 0.32 | 0.99 | 1.37 | 2.81 |
| 1994 | 184,738 | 18,600 | 1,635 | 3,227 | 260,725 | 65,915 | 4,499 | 13,957 | 345,096 | 0.64 | 1.96 | 2.72 | 5.57 |
| 1995 | 225,000 | 18,600 | 1,986 | 2,446 | 344,313 | 71,908 | 5,318 | 10,779 | 432,319 | 0.80 | 2.46 | 3.40 | 6.98 |
| 1996 | 396,113 | 7,880 | 1,964 | 2,500 | 598,619 | 32,096 | 5,724 | 10,039 | 646,479 | 1.20 | 3.68 | 5.09 | 10.43 |
| 1997 | 82,355 | 18,321 | 3,847 | 4,718 | 141,389 | 72,338 | 10,345 | 20,502 | 244,575 | 0.45 | 1.39 | 1.93 | 3.95 |
| 1998 | 95,433 | 16,312 | 6,555 | 7,049 | 144,977 | 64,104 | 17,751 | 31,390 | 258,222 | 0.48 | 1.47 | 2.03 | 4.17 |
| 1999 | 1,275,000 | 10,521 | 10,255 | 3,800 | 1,936,687 | 44,362 | 27,387 | 13,722 | 2,022,159 | 3.76 | 11.51 | 15.93 | 32.63 |
| 2000 | 377,500 | 5,233 | 6,984 | 2,304 | 627,562 | 22,033 | 19,951 | 9,556 | 679,103 | 1.26 | 3.86 | 5.35 | 10.96 |
| 2001 | 450,000 | 36,580 | 2,723 | 2,209 | 767,437 | 145,739 | 7,731 | 8,773 | 929,679 | 1.73 | 5.29 | 7.32 | 15.00 |
| 2002 | 242,500 | 11,947 | 2,701 | 7,109 | 377,025 | 49,330 | 7,627 | 28,430 | 462,413 | 0.86 | 2.63 | 3.64 | 7.46 |
| 2003 | 437,500 | 10,974 | 3,093 | 6,789 | 757,713 | 37,764 | 8,689 | 27,140 | 831,306 | 1.54 | 4.73 | 6.55 | 13.41 |
| 2004 | 207,500 | 9,672 | 1,039 | 3,539 | 359,316 | 36,792 | 2,908 | 13,799 | 412,815 | 0.77 | 2.35 | 3.25 | 6.66 |
| 2005 | 400,000 | 3,348 | 2,208 | 4,257 | 677,251 | 14,507 | 5,965 | 15,353 | 713,076 | 1.32 | 4.06 | 5.62 | 11.51 |
| 2006 | 201,250 | 25,141 | 2,041 | 4,737 | 355,459 | 108,784 | 5,421 | 19,592 | 489,256 | 0.91 | 2.78 | 3.85 | 7.89 |
| 2007 | 232,500 | 7,936 | 3,096 | 2,567 | 430,535 | 31,645 | 8,966 | 9,453 | 480,599 | 0.89 | 2.74 | 3.78 | 7.75 |
| 2008 | 207,500 | 52,545 | 1,663 | 5,173 | 355,952 | 214,971 | 4,691 | 23,174 | 598,788 | 1.11 | 3.41 | 4.72 | 9.66 |
| 2009 | 282,750 | 5,084 | 3,039 | 2,164 | 472,981 | 19,361 | 8,349 | 8,578 | 509,269 | 0.95 | 2.90 | 4.01 | 8.22 |
| Average | | | | | | | | | | | | | |
| 1982-1989 | 68,648 | 6,234 | 1,649 | 2,185 | 114,369 | 26,828 | 4,888 | 9,533 | 155,619 | 0.29 | 0.89 | 1.23 | 2.51 |
| 1990-1999 | 285,444 | 13,150 | 4,517 | 3,676 | 430,924 | 51,211 | 12,319 | 15,192 | 509,646 | 0.95 | 2.90 | 4.01 | 8.22 |
| 2000-2009 | 303,900 | 16,846 | 2,859 | 4,085 | 518,123 | 68,093 | 8,030 | 16,385 | 610,630 | 1.13 | 3.47 | 4.81 | 9.85 |
| All Years | 230,093 | 12,494 | 3,105 | 3,396 | 371,622 | 50,274 | 8,664 | 14,001 | 444,561 | 0.83 | 2.53 | 3.50 | 7.17 |

[a] Pink and chum salmon estimates are peak counts multiplied by 2.5 and 6.2 respectively; figures in bold italics are based on closed 5-year averages.

[b] Based on the total lake and stream surface area accessible to anadromous fish.

[c] Based on total anadromous stream surface area and a 10 m perimeter zone around the lake and pond.

[d] Based only on the area of the outlet stream (Ford Arm Creek).

Table 13.–Estimates of average mass and mass-density of marine derived nutrients from salmon entering salmon habitat in the Ford Arm Creek system by species (in kilograms and pink salmon equivalent spawners), 1982–2009.

| Species | Method | Expansion [a] | Average Number | Average Weight (kg) [b] | Average Total Weight (kg) | Pink Salmon Equivalents (No.) | No./$m^2$ [c] | % of Total |
|---|---|---|---|---|---|---|---|---|
| Pink | Peak Count | 2.5 | 230,100 | 1.62 | 371,600 | 230,100 | 1.31 | 84 |
| Chum | Peak Count | 6.2 | 12,500 | 4.04 | 50,300 | 31,100 | 0.18 | 11 |
| Sockeye | MR | 1.0 | 3,100 | 2.83 | 8,700 | 5,400 | 0.03 | 2 |
| Coho | Weir/MR | 1.0 | 3,400 | 4.14 | 14,000 | 8,700 | 0.05 | 3 |
| Total | | | 249,100 | | 444,600 | 275,300 | 1.57 | 100 |

[a] Pink and chum salmon estimates are peak counts multiplied by 2.5 and 6.2 respectively.
[b] Mean-average weekly weight of salmon caught by common property commercial seine, drift gillnet and set gillnet fisheries in Southeast Alaska.
[c] Based on total anadromous stream surface area and a 10 m perimeter zone around the lake and pond.

Table 14.–LHS model parameters and estimates for the relationship between total mass of salmon spawners and production of adult coho salmon from Ford Arm Creek, based on residuals from the Beverton-Holt spawner-recruit model fit and assuming constant average presmolt−adult survival of 11.2%.

| Parameter | Units | Brood Year (X) | Year X +1 | Both |
|---|---|---|---|---|
| Inflection Point ($\mu$) | Spawner Mass (1,000s of kg) | 392.9 | 28.9 | 348.3 |
| | Pink Salmon Equivalents (No. of Fish) | 241,832 | 17,773 | 214,407 |
| | Spawner Mass Density (kg/$m^2$) | 2.24 | 0.16 | 1.98 |
| | Pink Salmon Equivalents/$m^2$ | 1.38 | 0.10 | 1.22 |
| | Beverton-Holt Residual | 0.150881 | -0.526955 | 0.090161 |
| | Number of Adult Coho Salmon | 10,654 | 5,409 | 10,026 |
| Nominal Saturation Point | Spawner Mass (1,000s of kg) | 393.4 | 877.6 | 508.7 |
| | Pink Salmon Equivalents (No. of Fish) | 242,200 | 540,200 | 313,100 |
| | Spawner Mass Density (kg/$m^2$) | 2.24 | 4.99 | 2.89 |
| | Pink Salmon Equivalents/$m^2$ | 1.38 | 3.07 | 1.78 |
| | Beverton-Holt Residual | 0.150881 | 0.170118 | 0.167573 |
| | Number of Adult Coho Salmon | 10,654 | 10,860 | 10,833 |
| Absolute Saturation Point | Beverton-Holt Residual | 0.151639 | 0.174066 | 0.172581 |
| | Number of Adult Coho Salmon | 10,662 | 10,903 | 10,887 |
| Y-Intercept | Spawner Mass (1,000s of kg) | 0.0 | 0.0 | 0.0 |
| | Beverton-Holt Residual | -0.435228 | -0.615025 | -0.639632 |
| | Number of Adult Coho Salmon | 5,929 | 4,953 | 4,833 |
| Theta ($\Theta$) | | 0.002702 | 5.121161 | 0.146332 |
| Alpha ($\alpha$) | | 0.001494 | 0.002507 | 0.002329 |

We have noticed that subdominant bears appear to have greater access to salmon in years when salmon are more abundant, probably because dominant bears are more quickly satiated, consistent with Gende and Quinn (2004). In addition, larger pink salmon escapements saturate the predator and scavenger community, likely resulting in a greater number of decomposing pink salmon carcasses remaining in the stream bed (often buried in sediment during freshets), that are excavated and eaten by bears later in the fall. However, despite these immediate nutritional benefits, is not clear that salmon abundance has been a limiting factor or that an increase salmon biomass (within historical levels observed in Ford Arm Creek) would by itself increase the density of brown bears.

# INSEASON ABUNDANCE ESTIMATION

In this section we will describe efforts to forecast the total return and spawning escapement for the Ford Arm Creek stock. A summary of the sources of information and recent methods used to forecast abundance and escapement will be presented without systematic statistical evaluation of the overall accuracy and precision of predictive models.

Despite the management challenges posed by highly mixed stock fisheries that occur far in advance of entry into freshwater, methods have been developed to assess abundance and predict escapement specifically for Ford Arm Creek and other indicator stocks in the region, including the Hugh Smith Lake stock (Shaul et al. 2009). The success of these methods depends upon intensive marking of smolts or pre-smolts, combined with a comprehensive catch sampling program and rapid sample and data processing by the ADF&G Mark, Tag and Age Laboratory. These programs provide essential elements needed to estimate abundance and forecast escapement.

The Ford Arm Creek return is poorly correlated with an index of aggregate wild coho salmon abundance in the region ($R^2$ = 0.11) as well as with average wild coho salmon power troll CPUE ($R^2$ = 0.30) (Figure 29). The index of aggregate wild abundance was calculated by subtracting the estimated hatchery contribution to the troll catch from the total troll catch and dividing the result by an index of the troll exploitation rate based on the Auke Creek, Ford Arm Creek, and Hugh Smith Lake stocks. Auke Creek and Hugh Smith Lake were each given a 40% weighting while Ford Arm Creek was given only a 20% weighting because it, like Auke Creek is also located in northern Southeast, and because it has had a substantially higher average troll exploitation rate compared with most stocks that have been studied in the region.

The relatively low correlation with indicators of region-wide wild coho salmon abundance is consistent with evidence that marine survival and other indicators of abundance for outer coastal stocks has been poorly correlated with inside stocks, not only in Southeast Alaska but in more southern areas including southern British Columbia and Washington state (Shaul et al. 2007), while the abundance of inside area indicator stocks in Southeast Alaska has tracked fairly closely with the index of aggregate regional wild coho salmon abundance shown in Figure 29. Therefore, efforts to forecast the Ford Arm Creek return during the fishing season have been constructed around stock-specific parameters of presmolt abundance and survival, rather than predications based on fishery performance indicators of aggregate abundance.

An inseason forecast of total adult abundance ($N_A$) is the product of real-time estimates for two parameters: the number of pre-smolts ($N_S$) and their survival rate to returning adult ($\mu$):

$$\hat{N}_A = \hat{N}_S \hat{\mu}\,. \tag{11}$$

The resulting forecast of $N_A$ is combined with a prediction for the all-gear exploitation rate ($U$) to predict the number of adults that will escape to Ford Arm Creek to spawn ($E$):

$$\hat{E} = \hat{N}_A(1-\hat{U})\,. \tag{12}$$

In the following sections, we will describe recent methods used to obtain estimates for the three key parameters ($N_S$, $\mu$, and $U$) used to assess abundance and predict escapement.

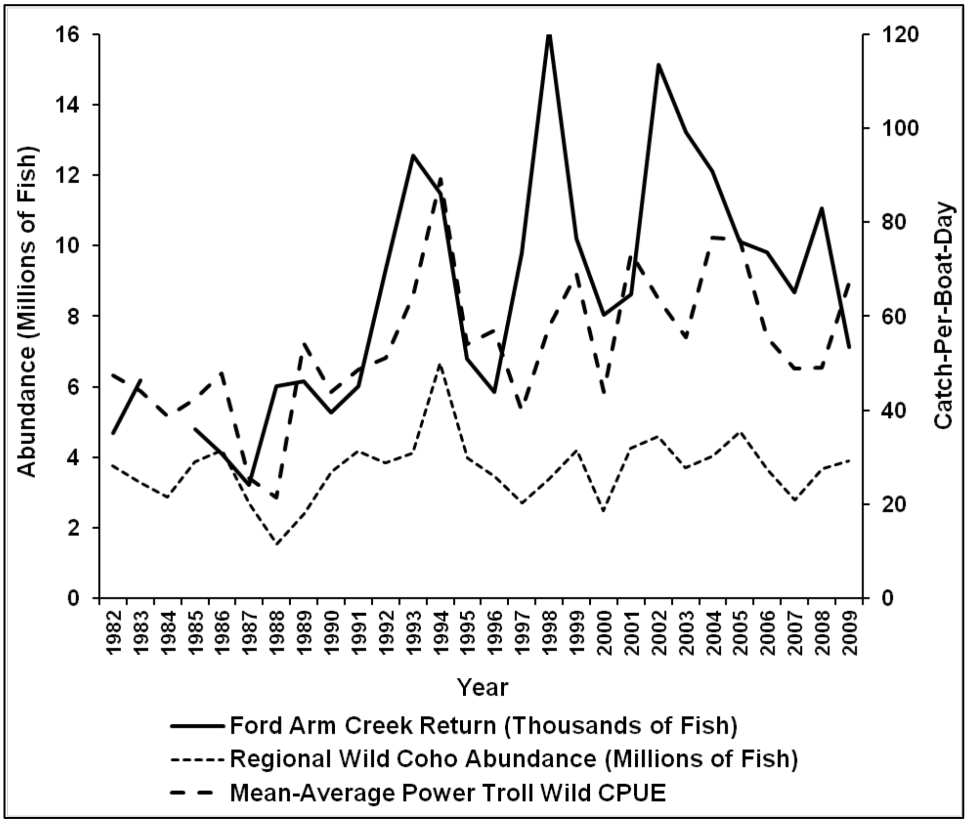


Figure 29.–Estimated total coho salmon return to Ford Arm Creek compared to the mean–average catch-per-boat-day of wild coho salmon by the Alaska troll fishery in statistical weeks 28–38 and an index of total regional coho salmon abundance.

## INSEASON PRESMOLT ESTIMATES

Final estimates of pre-smolt production are dependent upon sampling of returning spawners for adipose clips and coded-wire tags and are, therefore, of limited availability for inseason management. For the Hugh Smith Lake stock, a preliminary working estimate can be made by generating a preliminary modified Petersen estimate based on a sample of jack returns (Shaul et al. 2009). Unfortunately, while jacks are typically abundant at Ford Arm Lake, the marked fraction ($\theta$) is poorly correlated between jacks and adults from the same tagging year (Figure 30). Also, $\theta$ has been relatively variable (Table 3; Figure 10) ranging from 5.2% in 2005 to 22.3% in 1990, around an average of 12.5%.

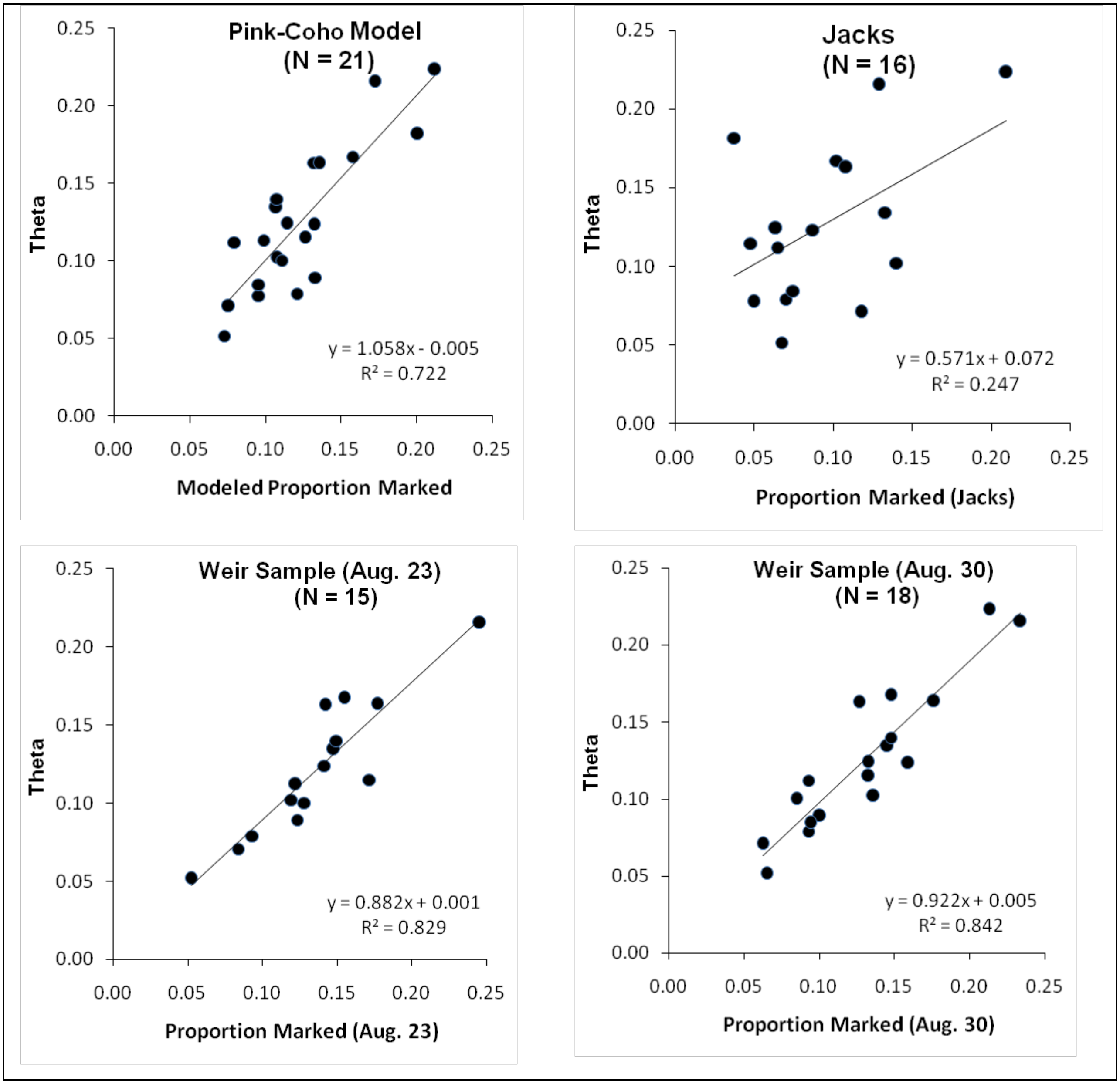


Figure 30.–Linear relationships used to predict the proportion tagged ($\theta$) for adult coho salmon returning to Ford Arm Creek based on (a) the pink-coho model, (b) the proportion marked of jacks returning in the prior year and (c and d, respectively) the proportion marked of adults sampled at the weir through 23 August and 30 August.

Therefore, inseason estimates of $\theta$ have been based primarily on the marked proportion of early adult migrants at the weir. The marked rate of adults at the weir through 23 August and 30 August is more closely correlated with $\theta$ than is the proportion marked for jacks in the prior year (Figure 30; upper right graph). However, a sufficient sample is usually unavailable before late-August after most of the troll harvest has already occurred. Jack and early adult indicators of $\theta$ both suffer from insufficient sample size in some years. During the most recent 21-year period from 1989–2009, recovery of 10 or more adipose clips occurred in only 16 years for jacks, 15 years for adults sampled through 23 August, and 18 years for adults sampled through 30 August. Samples in the other 14–28% of years were too limited to be reliable.

The Pink-Coho model (described above) appears to have potential as an alternative method to generate improved estimates of $\theta$ on a preseason basis. Since the number of presmolts marked ($M$) 2 years prior to the adult return is known, the task assigned to the model is to predict the abundance of coho salmon presmolts ($N_S$) in advance of the adult return based on (a) 2-year average peak pink salmon escapement counts and (b) parent coho salmon escapement estimates associated with the presmolt population. Coho and pink salmon escapement values used in the Pink-Coho model are weighted values associated with 3 brood years based on the historical average survival-adjusted freshwater age composition of brood year adult returns (57.6% age 1, 41.7% age 2, 0.7% age 3). The resultant prediction of the survival-adjusted adult return is then divided by the long-term average presmolt–adult survival rate ($\mu$) to predict $N_S$. The number of presmolts marked ($M$) is then divided by the Pink-Coho model prediction of $N_S$ to predict $\theta$. Model estimates of $\theta$ based on information available preseason have tracked relatively closely with post-season estimates based on sampling of returning adults since 1989 ($R^2 = 0.72$; Figure 31) and, therefore, should be considered as a tool for predicting $\theta$ in the future, particularly before late-August and in years when there is an insufficient early mark-recovery sample at the weir.

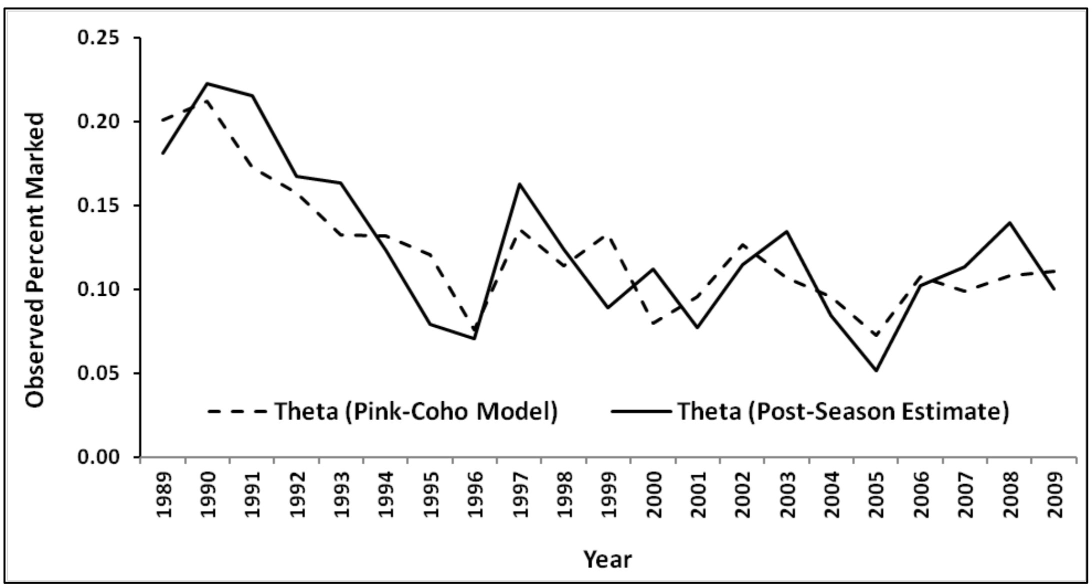


Figure 31.–Estimates of the proportion tagged ($\theta$) for returning Ford Arm Lake coho salmon compared with estimates from the Pink-Coho model, based on pink and coho salmon escapement information and the number of tagged coho salmon presmolts.

## INSEASON SURVIVAL FORECAST

Inseason forecasting of adult abundance depends on the ability to estimate survival from the pre-smolt stage to the returning adult stage.

The traditional summer Alaska troll fishery operates relatively continuously over a broad area and range of depths beginning in early July. That feature gives it the potential to act as a useful test fishery for the run strength of returning coho salmon. However, because of its highly mixed stock nature, the utility of the troll fishery as an indicator of run strength for individual indicator stocks depends upon a timely method of identifying specific stocks in the catch. Fortunately, coded-wire tagging and fishery sampling programs provide timely information on the harvest of marked fish. We have used the linear relationships depicted in Figure 32 to estimate survival based on the estimated cumulative harvest rate of tags released 2 years prior for the most recent week for which it can be reliably estimated. Estimates of presmolt–adult survival, when combined with preliminary presmolt estimates described above, can then be used to estimate the total adult return.

We excluded outlying points in the years 2002 and 2003 from the linear relationships shown in Figure 32, because troll fishery exploitation rates on the Ford Arm Creek stock were very low during that period (average 35%; range 31–38%) compared with an average of 54% (range 39–67%) for the other 25 years in study. Underlying reasons for the very low exploitation rates in those years appear to include a very low average price for coho salmon combined with high abundance of Chinook salmon and extended fishing opportunities for that species during mid- to late-summer periods when the troll fleet would normally be targeting coho salmon.

The recovery rate of tags in the troll fishery becomes a useful predictor of survival by early to mid-August. A linear relationship between marine survival and cumulative expanded recoveries in the traditional Alaska troll fishery (as a percentage of tagged presmolts released) reaches an $R^2$ value of 0.53 by the end of statistical week 30, which has an average ending date of 26 July. There is a lag of 1 to 2 weeks between the end of a statistical week and the point at which the harvest of tagged fish can be calculated with reasonable confidence. Therefore, a preliminary estimate through week 30 is available at the point when a decision is usually made about a mid-season troll closure beginning in mid-August. The predictive value of troll fishery tag recoveries in estimating marine survival improves until statistical week 38 in late September ($R^2 = 0.87$).

We have also examined relationships predicting survival based on the cumulative catch-per-unit-of-effort (CPUE) of tags. This method has an advantage in accounting for variable effort and is slightly more timely. Weekly power troll coho salmon CPUE estimates are obtained for six major fishing areas from dockside interviews by the Fishery Performance Data (FPD) program and are quickly entered into an accessible database. These estimates of total coho salmon CPUE can then be multiplied by the appropriate weekly estimate of the concentration of the tag codes of interest in the catch based on coded-wire tag samples received and decoded at the ADF&G Mark, Tag and Age Laboratory. Entry of both fishery performance and coded-wire tag sample information often precedes availability of reliable total catch estimates, which depend to some extent on mailing or delivery of fish tickets to the department by processors (in addition to data entry).

Despite the apparent advantages of using CPUE of tags rather than catch, we have found CPUE to be an inferior predictor of survival. The reasons for this are probably the same as those noted above for the inconsistent relationship between power troll CPUE and total regional wild abundance (Figure 29). However, we recommend that the usefulness of CPUE be re-examined in the future if the efficiency of a boat-day of power troll effort stabilizes.

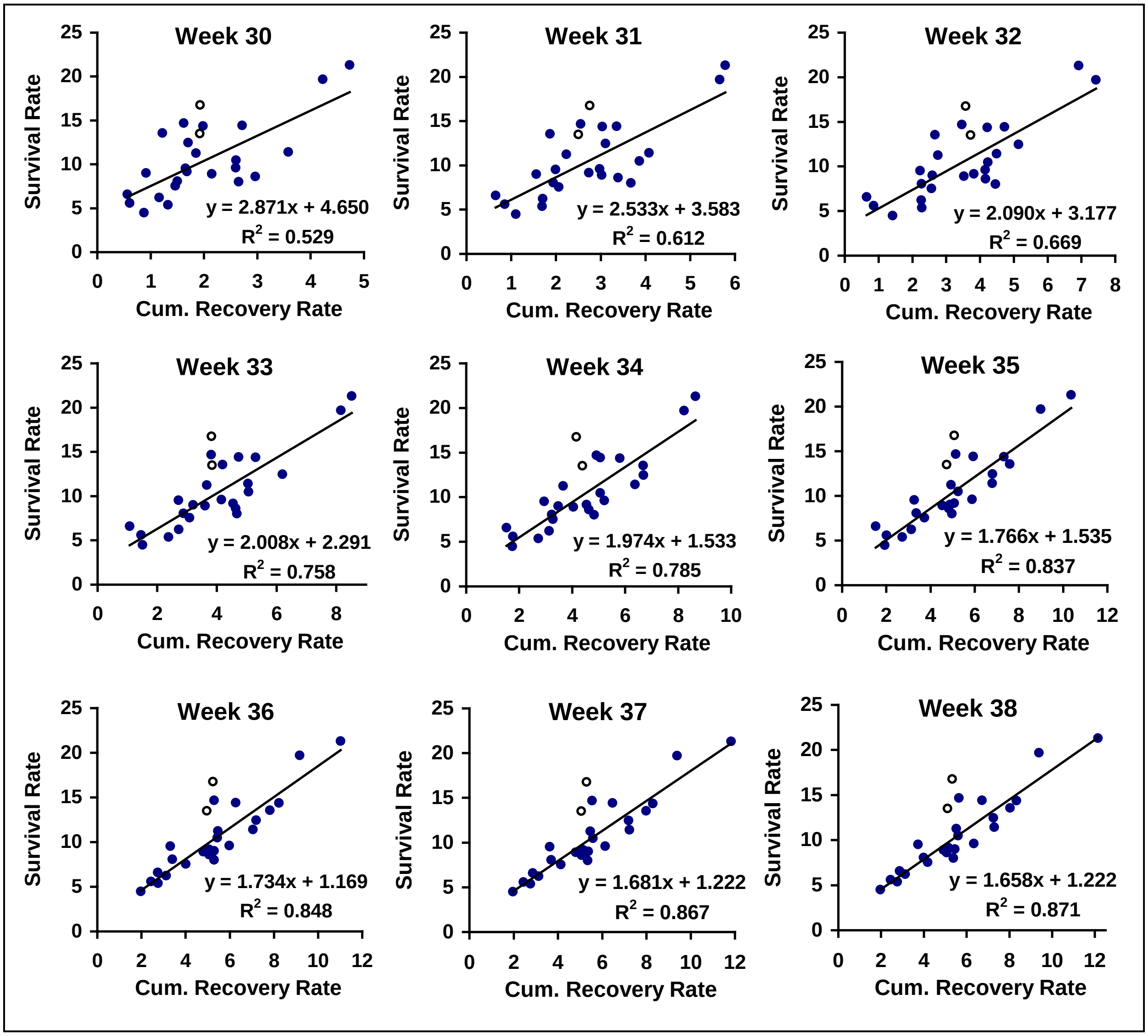


Figure 32.–Weekly linear relationships between the estimated cumulative harvest of coded-wire tagged Ford Arm Creek coho salmon in the traditional Alaska troll fishery by statistical week as a percent of tagged pre-smolts released and the survival rate for the stock to adulthood, 1982–2008. The years 2002–2003 (open circles) were excluded from the regression calculations because of exceptionally low troll fishery exploitation rates compared with other years in the data series.

## INSEASON ESCAPEMENT FORECAST

The total adult return ($N_A$) is estimated during the fishing season by multiplying the best available estimate of the number of presmolts ($N_s$) by the best available estimate of the survival rate ($\mu$). However, while an estimate of the total abundance of returning adults is useful, the primary objective of the fishery manager is to achieve a number of spawners ($E$) within a biological goal range around $E_{MSY}$, regardless of total returning abundance. Spawning escapement can be predicted in two ways.

Early in the season, the most useful method is to apply a best estimate of the all-gear exploitation rate ($U$) to the predicted adult return. Based on no other available information, $U$ might be most reliably predicted based on the most recent 2- or 3-year average. However, fishing patterns and intensity can vary substantially from year-to-year depending on fish prices, abundance of other target species, etc. Therefore, it is often useful to incorporate information on current fishing patterns compared with past years in judging the most likely overall exploitation rate during the current season. Many factors may play into such an estimate including: the number of trollers observed during over-flight surveys, the number of troll and sport-charter fishing-days restricted by poor weather, the amount of purse seining occurring in Khaz Bay, etc. All of these parameters invite experienced judgments that tend to provide more effective management than can be achieved by strict adherence to model results. Typically, a range of probable exploitation rates is applied to the best run size estimate to provide a range of probable escapements.

Although the all-gear exploitation rate on the Ford Arm Creek stock has followed a relatively level trend since the early 1980s (Figure 13), the coefficient of variation increased substantially from 0.19 in the 1980s and 1990s to 0.26 in 2000–2009. This increased variability has eroded the utility of inseason run size estimates as an indicator of likely escapement.

The second method of forecasting escapement is to extrapolate the inseason weir count based on historical average escapement timing. The weir count is an imprecise predictor of escapement until after nearly all of the harvest has been taken. Nevertheless, very strong early counts in some years provide a useful indication that the escapement goal range will be achieved. Typically, both the weir count and the CWT-based prediction are weighed in predicting escapement, depending on the point in the season. The weir count provides a valuable direct observation of escapement that supplements the CWT-based prediction.

# CONCLUSIONS

Despite some physical limitations, including small geographic size and limited solar exposure, Ford Arm Creek demonstrates the potential for highly concentrated anadromous fish production from a pristine watershed receiving a large annual influx of marine derived nutrients. The system receives only limited direct sunlight due to its close proximity to steep surrounding mountains and large timber, as well as a high percentage of days when the sun is obscured by clouds and fog. This limitation appears largely off-set by complex, pristine habitat and immense nutrient loading.

An estimated average of 80,576 presmolts and 8,470 adult coho salmon has been produced from the 13.2 km of total stream and lake length, with average density estimates of 6,104 presmolts/km and 642 adults/km of anadromous habitat, respectively. These are very high production densities for the species. The relationship between mean coho salmon smolt abundance and stream length estimated by Bradford et al. (1997) for 83 streams and rivers from Alaska to California predicts average production from Ford Arm Creek at 12,122 smolts, or about 1,455 adults, at an assumed average marine survival rate of 12%. Therefore, average adult production from Ford Arm Creek was nearly 6 times the predicted value based on its length and the relationship between length and production for the broad coast-wide group of 83 systems. In addition, the average peak adult steelhead density of 179 fish/km counted during snorkel surveys was by far the highest average observed density in Southeast Alaska, and over 8 times the mean-average count in other index streams (22 fish/km; Harding 2012; Appendix C).

Returns of both coho salmon and steelhead increased along with an increase in pink and chum salmon escapements and total MDN loading in the system. Both of the former species have been shown to benefit from the addition of, or increase in, spawning salmon and carcasses in streams

(Michael 1995; Bilby et al. 1998; Wipfli et al. 2003; Nelson and Reynolds 2014). Sockeye salmon returns, however, did not display a similar upward trend consistent with a response to increased MDN loading (Appendix B.4). Sockeye returns also did not show an expected relationship with brood year escapement (Appendix B.9). Consequently, the causes of the highly variable, cyclical return pattern in the sockeye salmon population remain a mystery.

Auto-correlation in both data series (spawning salmon biomass and coho salmon abundance) complicates analysis of cause and effect and apportionment of effect between escapement years. However, the indicated strong initial response to increasing spawner biomass by freshwater coho salmon production, followed by saturation effect as spawner biomass increased above a density of 1–2 pink salmon equivalents per $m^2$, is consistent with the growth response observed in juvenile coho salmon in a controlled experiment in Southeast Alaska (Wipfli et al. 2003). Other studies have suggested that stream ecosystems can become saturated with salmon-derived material and do not respond to further increases in spawner density beyond a saturation threshold (Bilby et al. 2001; Chaloner et al. 2002).

The best predictive model for freshwater production of coho salmon from Ford Arm Creek indicates that spawner density is approximately equally important in both of the two years preceding migration of smolts to sea, whereas studies in Puget Sound rivers (Michael 1995; Zimmerman 2011) have shown a concentrated response to spawning pink salmon in the year following the common brood year, which for age 1 coho salmon smolts is also the year prior to smolt migration. However, our findings are consistent with studies indicating persistence of a nutrient legacy into the next growing season in periphyton (Verspoor et al. 2010), generalist macro invertebrates and Dolly Varden (Rinella et al. 2013), and density of juvenile coho salmon (Nelson and Reynolds 2014). In addition to being retained in biota, nutrients may be stored in the stream-bed and resuspended (Rex and Petticrew 2008) or re-enter the main channel following deposition on the floodplain (Fellman et al. 2008). Reisinger et al. (2013) found evidence at two trophic levels (epilithon and juvenile coho salmon) that the size of the salmon run in one year can influence the isotopic signature of stream-resident biota prior to the salmon run in the following year.

In keeping with the practice we have employed of setting coho escapement goals at the range estimated to achieve 90% or more of MSY, we suggest that the lower pink salmon goal bound for Ford Arm Creek be increased from 48 thousand to 74 thousand spawners (corresponding with 90% of maximum potential coho salmon production at MDN saturation), with the upper bound remaining at 156 thousand. For the overall Slocum Arm complex, this would equate to 247–520 thousand spawners, with a point goal remaining at 340 thousand spawners (Heinl et al. 2008). Although substantial pre-spawn mortality has been associated with peak pink salmon counts as low as 90 thousand spawners in Ford Arm Creek, the pro-rated mid-point goal of 102 thousand spawners in Ford Arm Creek appears to have low enough associated oxygen demand to avoid major pre-spawn mortality events in all but the driest years, and is estimated to produce 98% of maximum potential coho salmon abundance. Therefore, the best estimate of $E_{MSY}$ to maximize fishery benefits from the pink salmon population also appears to produce near-maximum benefits to coho salmon production, while coinciding approximately with the point beyond which there is increasing risk of pre-spawning mortality from oxygen depletion.

Selection of a 90% of MSY escapement goal for coho salmon rests primarily on the results for the best-fitting established model (Beverton-Holt) and the Pink-Coho BHS model (Table 9). After considering these results, we recommend that the current escapement goal of 1,300–2,900 spawners developed by Clark et al. (1994) be retained. The best-fitting conventional Beverton-Holt model suggests a broader goal range of 1,242–4,153 spawners, based on 90% or more of MSY. However, accounting for the apparent effect of pink salmon escapements on coho returns substantially alters the spawner-recruit relationship. The bent hockey stick (BHS) relationship based on the Pink-Coho model suggests a goal range of 1,280–2,572 spawners, which would round to 1,300–2,600 spawners. We believe that, given evidence of increasing production from increasing escapements at both Ford Arm Creek, and at other locations, such as Hugh Smith Lake, it is desirable to continue with a relatively broad goal range, with an upper bound more than double the lower bound. Therefore, we recommend that the current goal range of 1,300–2,900 spawners be retained. Oddly, this conclusion, based on 23 data points suggests no change from the current goal established in 1994 that was based on only 7 paired estimates of brood year escapement clustered in a narrow range of 1,546–3,028 spawners (and survival-adjusted returns assigned on the basis of substantially less informed aging method). The current goal is based on the Ricker model and was developed when average freshwater production was lower. The fact that the Ricker model, which is inconsistent with coho salmon life history and ecology, produced similar results from a period of lower apparent habitat capability actually supports the Ricker model as a conservative and relatively safe tool for establishment of goals in an environment with low data contrast and substantial process and statistical error.

## MANAGEMENT EFFECTIVENESS

The Beverton-Holt and Pink-Coho BHS model results provide different perspectives on the effectiveness of recent management toward achieving MSY. A comparison of average estimated catch with estimated potential yield at constant $E_{MSY}$ based on the Beverton-Holt model suggests that recent management has been very effective for this stock. Based on the Beverton-Holt fit for the 1982–1983 and 1985–2005 brood years, the average yield from escapement held constant at $E_{MSY}$ of 2,394 spawners is predicted at 6,071 fish, which is reduced to 5,960 fish after subtracting from potential yield associated with an average Type 2 mortality rate of 4.4% of gross escapement. For comparison, the average realized harvest from those brood years was estimated at 5,625 fish, or 94% of estimated MSY. The estimate would be only slightly lower (93%) without subtracting Type 2 mortalities from potential yield.

Management effectiveness is somewhat more difficult to evaluate using the Pink-Coho SHS model. The BHS relationship based on the Pink-Coho model predicts $E_{MSY}$ at the lowest observed net escapement of 1,422 spawners. Under steady-state conditions with escapement held to exactly the estimated $E_{MSY}$ of 1,422 coho salmon spawners and a constant peak pink salmon count of 82,000 spawners, the model predicts potential yield of 8,220 coho salmon, which would be reduced to 8,154 fish after subtracting average Type 2 mortalities from yield. That potential yield suggests management effectiveness of about 69%. However, estimated potential average yield decreases substantially when observed annual pink salmon peak counts are incorporated, rather than an assumed constant average. The expected average yield after Type 2 mortalities is reduced to 7,112 fish, indicating 79% management effectiveness in achieving MSY.

These estimates are approximations, as more detailed modeling incorporating variable freshwater production and marine survival may provide more accurate estimates of management effectiveness. Nevertheless, indications of high management effectiveness toward achieving potential yield from this stock are consistent with an estimate that 95% of MSY has been achieved from the Hugh Smith Lake stock based on Beverton-Holt analysis (Shaul et al. 2009).

There are some similarities between the Ford Arm Creek and Hugh Smith Lake (Shaul et al. 2009). Both stocks were exploited at average rates 12 percentage points below the estimated equilibrium optimum exploitation rate estimated from the Beverton-Holt model (65% versus 77% for Hugh Smith Lake and 60% versus 72% for Ford Arm Creek). A large fraction of the harvest of both stocks has been taken by relatively passively managed fisheries. Therefore, while exploitation rates have been substantial, on average, they have not varied greatly and have resulted in escapements at or above $E_{MSY}$ in most years. In these studies, escapements were within the range estimated to produce 90% or more of MSY (based on Beverton-Holt model estimates) 69−70% of the time and over that range 30−31% of the time but never under the range for either stock. Average escapements exceeded estimated $E_{MSY}$ by 44% for Ford Arm Creek and 53% for Hugh Smith Lake but were 17% below the upper 90% of MSY bound for both systems. The trend in both spawner-recruit datasets suggests a positive relationship between escapement and survival-adjusted return across the overall range of observations. This aspect, which is best captured by the Beverton-Holt and BHS models, broadens the range of escapements that produce potential yields within 10% of MSY and reduces the long-term yield penalty for substantially exceeding $E_{MSY}$, in comparison with species best characterized by the Ricker Model with its strong over-compensation feature.

To the extent that the Ford Arm Creek and Hugh Smith Lake stocks are indicative of the thousands of coho salmon stocks in the region, we can conclude that recent over-all levels of fishing effort and methods of management, although somewhat conservative, have been quite effective in achieving near-optimal yield to the fisheries. Coho salmon as a species appear relatively well-suited to intensive mixed stock fishing because of their resilience, productivity, and relative flexibility in sustaining high average yield. Indeed, a management system that includes a substantial fraction of the harvest in highly mixed stock fisheries may be essential in order to achieve high yields because of the diffuse, broadly distributed nature of coho salmon production in the region.

Shaul et al. (2009) described some potential off-setting benefits of escapements above estimated $E_{MSY}$. Larger escapements increase MDN loading in natal streams that likely benefits future coho salmon returns and other ecosystem values through various pathways. Also, managing the aggregate conservatively for indicator stocks helps insure that more of the total aggregate of contributing stocks, including "weaker" stocks, contribute near their biological potential.

In addition, larger average returns produced by larger escapements likely have some direct economic benefits to passively managed fisheries through improved economic efficiency. The Beverton-Holt analysis for Hugh Smith Lake indicated that while the average escapement to the system substantially exceeded $E_{MSY}$, the resulting adult population averaged 5–6% larger than predicted had the stock been held to a constant $E_{MSY}$ goal (Shaul et al. 2009). For Ford Arm Creek, the Beverton-Holt analysis indicates that returns averaged 8–9% larger than under constant $E_{MSY}$ while an analysis based on the Pink-Coho BHS model suggests that returns were about 6% larger than predicted under constant $E_{MSY}$. Larger average run sizes likely benefit most types of fisheries where the cost of fishing is relatively fixed (and independent of catch) by improving economic efficiency; i.e., the number of fish that can be caught at a given level of effort and cost. The relationship between fishing effort and catch is not linear, with increasing rates of exploitation requiring a disproportionate increase in fishing effort. This is an important consideration because the total benefit to the fisherman is landed value minus cost.

Finally, managing at a higher level of average smolt production may provide some buffer against the sudden shock of very poor marine survival. This, in turn may help mitigate the need for fishery restrictions when survival decreases sharply in subsequent return years.

The hockey stick model with its assumption of a fixed level of smolt production above a saturation level may be over-simplistic in its representation of coho salmon life history in some systems. The presumption behind the hockey stick model is that stream habitat strictly limits the number of juveniles that can rear to smolthood based on limited available territories. Although territoriality also appears to be important in regulating smolt production from lakes and ponds, it may impose a less stringent limitation in those environments. In addition, recent evidence for marine rearing of juveniles (Shaul et al. 2013) suggests that estuaries and inside waters of Southeast Alaska may act as an overflow area for fry in excess of the capacity of the freshwater rearing habitat. Density dependence may be less important in regulating populations in those environments. Finally, an increase in nutrient delivery in stream systems in the form of more carcasses potentially increases habitat capability by increasing food available to progeny of a more abundant spawning population (Wipfli et al. 1999 and 2003; Bilby et al. 1998; Cederholm et a1. 1999; and others).

In addition to biological factors, practical economic and fishery management considerations also favor a broad escapement goal range. The broad temporal and spatial distribution of the harvest of the stock in mixed stock and mixed-species fisheries involving different management jurisdictions limits the range within which fishery managers can easily control escapement. Opportunities for active inseason management of outer coastal coho salmon stocks like Ford Arm Creek are very limited because of the manner in which they intermingle in traditional fishing areas with a broad mixture of coho stocks (troll and marine sport fisheries) and more abundant target species (e.g., the Khaz Bay pink salmon purse seine fishery). In practice, while the Ford Arm Creek coho salmon stock is likely one of the most intensely exploited in the region by mixed stock hook and line fisheries, fishing patterns and exploitation rates have remained relatively stable.

Although the coho salmon return to Ford Arm Creek is not strongly correlated with coho salmon indicator stocks located on inside waters, inseason forecasts for the system provide useful context for overall troll fishery management. For example, in 1997 inseason information indicating a strong return to Ford Arm Creek led fishery managers to draw a late August emergency closure boundary near Yakobi Island farther north than they otherwise would have to conserve an exceptionally weak coho salmon return to the Taku River where the drift gillnet fishery was closed. This management action achieved a substantial reduction in harvest of northern inside coho salmon, resulting in increased escapement to the Taku River, while maintaining a substantial troll exploitation rate (48%) on Ford Arm Creek coho salmon where the escapement of 4,718 adult spawners exceeded the goal of 1,300−2,900 spawners.

We recommend that inseason forecasts continue to be generated, first using $\theta$ estimates based on the number of presmolts tagged 2 years prior and (a) the pink-coho model estimate of freshwater production prior to 23 August and (b) the proportion of adipose-clipped fish among early adult migrants after that date. Cumulative inseason CWT recoveries in the troll fishery as a percent of CWTs released provides reliable estimates of marine survival beginning in early August, prior to the usual mid-season closure decision point.

The average density of salmon production in the area encompassed by the Ford Arm Creek drainage is about two orders of magnitude higher than in drainages included in a study showing a positive relationship between salmon biomass density and percent salmon in brown bear diets (Levi et al. 2012). Our ancillary observations of bear mortality, combined with the fact that findings by Van Daele et al (2013) suggest that average salmon biomass at Ford Arm Creek would support a bear density nearly an order of magnitude above the current best estimate, leads us to conclude that bear density is likely not sensitive to salmon biomass density within the range of salmon returns to Ford Arm Creek during this study.

Ford Arm Creek demonstrates the potential for a small, pristine, structurally complex system to produce remarkable sustained value in diverse fishery benefits while functioning near its full ecological potential.

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# APPENDIX A:
# COHO SALMON DATA

Appendix A1.–Escapement samples for adipose clips and coded-wire tags from jack and adult coho salmon and the number of Ford Arm Creek coho tags by tagging year recovered from marine fisheries, 1982−2009.

| | Jacks | | | Adults | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Observed Fishery Recoveries | | | | |
| Year | Sampled for Ad Clip | Ad Clips | Prop. Clipped | Sampled for Ad Clip | Ad Clips | Prop. Clipped | Ad Clips Sampled for Tag | Tags Recovered | Prop. Tagged $\theta$ | Percent of Clips w/Tags | Year X-1 | Year X-2 | Year X-3 | Total | Percent from Year X-2 |
| 1982 | 37 | 2 | 0.0541 | 1,749 | 140 | 0.0800 | 20 | 19 | 0.0760 | 95.0 | 0 | 58 | 0 | 58 | 100.0 |
| 1983 | 97 | 1 | 0.0103 | 806 | 89 | 0.1104 | 27 | 25 | 0.1022 | 92.6 | 0 | 117 | 3 | 120 | 97.5 |
| 1984 | –[a] | – | – | – | – | – | – | – | – | – | 0 | 0 | 1 | 1 | – |
| 1985 | 276 | 19 | 0.0688 | 1,804 | 181 | 0.1003 | 181 | 174 | 0.0965 | 96.1 | 0 | 76 | 0 | 76 | 100.0 |
| 1986 | 220 | 15 | 0.0682 | 1,480 | 272 | 0.1838 | 272 | 262 | 0.1770 | 96.3 | 0 | 109 | 11 | 120 | 90.8 |
| 1987 | 129 | 14 | 0.1085 | 1,597 | 216 | 0.1353 | 215 | 211 | 0.1327 | 98.1 | 0 | 71 | 18 | 89 | 79.8 |
| 1988 | 310 | 39 | 0.1258 | 2,366 | 325 | 0.1374 | 323 | 316 | 0.1344 | 97.8 | 0 | 139 | 25 | 164 | 84.8 |
| 1989 | 267 | 10 | 0.0375 | 1,856 | 445 | 0.2398 | 445 | 337 | 0.1816 | 75.7 | 0 | 261 | 32 | 293 | 89.1 |
| 1990 | 253 | 53 | 0.2095 | 1,923 | 449 | 0.2335 | 430 | 411 | 0.2232 | 95.6 | 0 | 240 | 5 | 245 | 98.0 |
| 1991 | 241 | 31 | 0.1286 | 2,275 | 499 | 0.2193 | 494 | 485 | 0.2153 | 98.2 | 0 | 212 | 20 | 232 | 91.4 |
| 1992 | 293 | 30 | 0.1024 | 2,972 | 523 | 0.1760 | 523 | 497 | 0.1672 | 95.0 | 0 | 235 | 3 | 238 | 98.7 |
| 1993 | 66 | 7 | 0.1061 | 3,336 | 559 | 0.1676 | 559 | 545 | 0.1634 | 97.5 | 0 | 377 | 5 | 382 | 98.7 |
| 1994 | 218 | 19 | 0.0872 | 2,522 | 317 | 0.1257 | 314 | 308 | 0.1233 | 98.1 | 0 | 251 | 0 | 251 | 100.0 |
| 1995 | 186 | 13 | 0.0699 | 1,051 | 85 | 0.0809 | 85 | 83 | 0.0790 | 97.6 | 0 | 96 | 3 | 99 | 97.0 |
| 1996 | 238 | 28 | 0.1176 | 1,540 | 111 | 0.0721 | 109 | 107 | 0.0708 | 98.2 | 0 | 70 | 1 | 71 | 98.6 |
| 1997 | 509 | 55 | 0.1081 | 3,176 | 524 | 0.1650 | 524 | 517 | 0.1628 | 98.7 | 0 | 273 | 1 | 274 | 99.6 |
| 1998 | 315 | 20 | 0.0635 | 4,893 | 616 | 0.1259 | 531 | 523 | 0.1240 | 98.5 | 0 | 353 | 2 | 355 | 99.4 |
| 1999 | 175 | 6 | 0.0343 | 2,806 | 254 | 0.0905 | 253 | 249 | 0.0891 | 98.4 | 0 | 160 | 0 | 160 | 100.0 |
| 2000 | 357 | 23 | 0.0644 | 1,518 | 175 | 0.1153 | 175 | 170 | 0.1120 | 97.1 | 1 | 202 | 2 | 205 | 98.5 |
| 2001 | 323 | 16 | 0.0495 | 1,045 | 84 | 0.0804 | 83 | 80 | 0.0775 | 96.4 | 0 | 132 | 4 | 136 | 97.1 |
| 2002 | 356 | 17 | 0.0478 | 5,525 | 689 | 0.1247 | 689 | 634 | 0.1148 | 92.0 | 0 | 290 | 2 | 292 | 99.3 |
| 2003 | 789 | 105 | 0.1331 | 3,900 | 535 | 0.1372 | 535 | 524 | 0.1344 | 97.9 | 0 | 244 | 1 | 245 | 99.6 |
| 2004 | 335 | 25 | 0.0746 | 2,414 | 212 | 0.0878 | 212 | 204 | 0.0845 | 96.2 | 0 | 176 | 2 | 178 | 98.9 |
| 2005 | 327 | 22 | 0.0673 | 2,399 | 128 | 0.0534 | 124 | 120 | 0.0516 | 96.8 | 0 | 91 | 0 | 91 | 100.0 |
| 2006 | 314 | 44 | 0.1401 | 3,372 | 359 | 0.1065 | 359 | 344 | 0.1020 | 95.8 | 0 | 145 | 1 | 146 | 99.3 |
| 2007 | 100 | 7 | 0.0700 | 1,784 | 216 | 0.1211 | 216 | 202 | 0.1132 | 93.5 | 0 | 193 | 0 | 193 | 100.0 |
| 2008 | 165 | 6 | 0.0364 | 3,408 | 496 | 0.1455 | 491 | 472 | 0.1399 | 96.1 | 0 | 243 | 0 | 243 | 100.0 |
| 2009 | 31 | 2 | 0.0645 | 1,128 | 123 | 0.1090 | 123 | 113 | 0.1002 | 91.9 | 0 | 161 | 1 | 162 | 99.4 |
| Average | 257 | 23 | 0.0833 | 2,394 | 319 | 0.1305 | 308 | 294 | 0.1240 | 95.6 | 0 | 184 | 5 | 189 | 96.9 |

[a] Coho salmon were not coded-wire tagged in 1982 and, subsequently, the adult weir project was not operated in 1984.

Appendix A2.–Number of observed recoveries of tagged Ford Arm Creek coho salmon from random fishery samples, 1982−2009 (excluding 1984).

| Fishery | Area | 1982 | 1983 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska Troll | NW | 35 | 82 | 49 | 81 | 65 | 147 | 205 | 156 | 186 | 187 | 336 | 186 | 74 | 63 |
| | NE | 0 | 0 | 0 | 3 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 2 | 0 | 0 |
| | SW | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 1 | 1 | 0 | 0 | 0 |
| | SE | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 37 | 83 | 49 | 85 | 65 | 148 | 206 | 156 | 191 | 189 | 337 | 188 | 74 | 63 |
| Alaska Seine | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 103 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 104 | 1 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 |
| | 112 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 113 | 0 | 10 | 0 | 1 | 6 | 0 | 12 | 17 | 1 | 9 | 7 | 47 | 8 | 0 |
| | Subtotal | 1 | 10 | 0 | 2 | 6 | 2 | 12 | 18 | 1 | 10 | 9 | 47 | 8 | 0 |
| Alaska Gillnet | 106 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 111 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 115 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 212 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Alaska Sport | Gustavus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Elfin Cove | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sitka | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 1 |
| | Craig | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 1 |
| Alaska Total | | 38 | 93 | 49 | 87 | 71 | 150 | 218 | 174 | 193 | 199 | 349 | 236 | 82 | 64 |
| B.C. Troll | | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Catch | | 38 | 93 | 49 | 87 | 71 | 151 | 218 | 174 | 193 | 199 | 349 | 236 | 82 | 64 |
| Escapement | | 19 | 25 | 164 | 262 | 211 | 316 | 337 | 411 | 485 | 497 | 545 | 308 | 83 | 107 |
| Total | | 57 | 118 | 213 | 349 | 282 | 467 | 555 | 585 | 678 | 696 | 894 | 544 | 165 | 171 |

- Continued -

Appendix A2.–continued (page 2 of 2).

| Fishery | Area | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska Troll | NW | 239 | 285 | 135 | 155 | 115 | 205 | 157 | 138 | 72 | 102 | 165 | 174 | 147 | 146 |
| | NE | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| | SW | 1 | 3 | 0 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 1 |
| | SE | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 240 | 290 | 135 | 158 | 117 | 207 | 158 | 139 | 72 | 102 | 167 | 177 | 148 | 147 |
| Alaska Seine | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | 103 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 104 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | 112 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 113 | 0 | 4 | 1 | 26 | 1 | 1 | 8 | 7 | 1 | 4 | 4 | 37 | 3 | 8 |
| | Subtotal | 0 | 5 | 1 | 27 | 2 | 2 | 8 | 7 | 1 | 4 | 4 | 39 | 3 | 8 |
| Alaska Gillnet | 106 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 111 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 115 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 212 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Alaska Sport | Gustavus | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 1 | 0 | 0 |
| | Elfin Cove | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 4 | 4 | 4 | 6 | 5 | 2 | 1 |
| | Sitka | 2 | 24 | 10 | 7 | 12 | 35 | 59 | 3 | 4 | 27 | 6 | 9 | 2 | 8 |
| | Craig | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | Subtotal | 2 | 24 | 10 | 7 | 12 | 37 | 59 | 7 | 8 | 31 | 16 | 15 | 5 | 9 |
| Alaska Total | | 242 | 320 | 146 | 193 | 131 | 246 | 225 | 153 | 81 | 137 | 188 | 231 | 156 | 165 |
| B.C. Troll | NBC | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Catch | | 242 | 320 | 146 | 193 | 131 | 246 | 225 | 153 | 81 | 137 | 188 | 231 | 156 | 165 |
| Escapement | | 517 | 523 | 249 | 170 | 80 | 634 | 524 | 204 | 120 | 344 | 202 | 472 | 113 | 293 |
| Total | | 759 | 843 | 395 | 363 | 211 | 880 | 749 | 357 | 201 | 481 | 390 | 703 | 269 | 458 |

Appendix A3.–Number of expanded recoveries of tagged Ford Arm Creek coho salmon from random fishery samples, 1982−2009 (excluding 1984).

| Fishery | Area | 1982 | 1983 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska Troll | NW | 134 | 338 | 226 | 427 | 194 | 376 | 687 | 665 | 676 | 872 | 1,263 | 840 | 283 | 218 |
| | NE | 0 | 0 | 0 | 8 | 0 | 2 | 3 | 0 | 3 | 3 | 0 | 5 | 0 | 0 |
| | SW | 9 | 4 | 0 | 5 | 0 | 0 | 0 | 0 | 11 | 2 | 3 | 0 | 0 | 0 |
| | SE | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 147 | 342 | 226 | 440 | 194 | 378 | 690 | 665 | 690 | 878 | 1,266 | 845 | 283 | 218 |
| Alaska Seine | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 103 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 104 | 8 | 0 | 0 | 8 | 0 | 6 | 0 | 0 | 0 | 4 | 10 | 0 | 0 | 0 |
| | 112 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 113 | 0 | 93 | 0 | 3 | 11 | 0 | 34 | 21 | 9 | 35 | 61 | 126 | 110 | 0 |
| | Subtotal | 8 | 93 | 0 | 11 | 11 | 6 | 34 | 22 | 9 | 39 | 71 | 126 | 110 | 0 |
| Alaska Gillnet | 106 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 111 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 115 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 212 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| Alaska Sport | Gustavus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Elfin Cove | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sitka | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 29 | 47 | 0 | 20 |
| | Craig | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 29 | 47 | 0 | 20 |
| Alaska Total | | 155 | 435 | 226 | 451 | 204 | 385 | 723 | 688 | 701 | 917 | 1,366 | 1,018 | 392 | 238 |
| B.C. Troll | | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Catch | | 155 | 435 | 226 | 451 | 204 | 389 | 723 | 688 | 701 | 917 | 1,366 | 1,018 | 392 | 238 |
| Escapement | | 202 | 197 | 211 | 275 | 225 | 419 | 395 | 489 | 595 | 647 | 686 | 398 | 193 | 177 |
| Total | | 356 | 633 | 437 | 725 | 429 | 808 | 1,118 | 1,177 | 1,296 | 1,564 | 2,052 | 1,416 | 586 | 415 |

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Appendix A3.– continued (page 2 of 2).

| Fishery | Area | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska Troll | NW | 764 | 961 | 525 | 512 | 447 | 655 | 555 | 648 | 265 | 394 | 635 | 630 | 459 | 543 |
| | NE | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 5 | 0 | 0 | 4 | 3 | 0 | 2 |
| | SW | 2 | 7 | 0 | 4 | 4 | 2 | 0 | 0 | 0 | 0 | 4 | 6 | 2 | 2 |
| | SE | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 765 | 971 | 525 | 516 | 451 | 660 | 558 | 653 | 265 | 394 | 642 | 638 | 461 | 547 |
| Alaska Seine | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| | 103 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 104 | 0 | 5 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 2 |
| | 112 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 113 | 0 | 49 | 6 | 100 | 6 | 135 | 68 | 44 | 3 | 37 | 25 | 140 | 25 | 42 |
| | Subtotal | 0 | 54 | 6 | 103 | 9 | 145 | 68 | 44 | 3 | 37 | 25 | 146 | 25 | 45 |
| Alaska Gillnet | 106 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 111 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 115 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | 212 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 0 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Alaska Sport | Gustavus | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 4 | 1 | 0 | 0 |
| | Elfin Cove | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 10 | 22 | 4 | 6 | 5 | 2 | 2 |
| | Sitka | 57 | 97 | 39 | 24 | 37 | 112 | 238 | 17 | 13 | 82 | 12 | 32 | 6 | 32 |
| | Craig | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | Subtotal | 57 | 97 | 39 | 24 | 37 | 115 | 238 | 27 | 35 | 86 | 23 | 39 | 9 | 34 |
| Alaska Total | | 823 | 1,125 | 570 | 643 | 497 | 919 | 864 | 724 | 303 | 518 | 690 | 824 | 495 | 626 |
| B.C. Troll | NBC | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Catch | | 823 | 1,125 | 570 | 643 | 497 | 919 | 864 | 724 | 303 | 518 | 690 | 824 | 495 | 626 |
| Escapement | | 768 | 874 | 339 | 258 | 171 | 816 | 912 | 299 | 220 | 483 | 291 | 724 | 218 | 425 |
| Total | | 1,591 | 1,999 | 908 | 901 | 668 | 1,735 | 1,776 | 1,023 | 523 | 1,001 | 981 | 1,547 | 714 | 1,051 |

Appendix A4.–Estimated number of adult Ford Arm Creek coho salmon harvested by fishery, estimated adult escapement, and number of jacks counted at the weir, 1982–2009 (excluding 1984).

| Fishery | Area | 1982 | 1983 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska Troll | NW | 1,757 | 3,302 | 2,482 | 2,410 | 1,458 | 2,801 | 3,782 | 2,982 | 3,139 | 5,217 | 7,732 | 6,814 | 3,582 | 3,083 |
| | NE | 0 | 0 | 0 | 45 | 0 | 16 | 17 | 0 | 15 | 21 | 0 | 42 | 0 | 0 |
| | SW | 113 | 41 | 0 | 28 | 0 | 0 | 0 | 0 | 49 | 15 | 17 | 0 | 0 | 0 |
| | SE | 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 1,927 | 3,344 | 2,482 | 2,483 | 1,458 | 2,816 | 3,799 | 2,982 | 3,203 | 5,252 | 7,749 | 6,856 | 3,582 | 3,083 |
| Alaska Seine | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 103 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 104 | 106 | 0 | 0 | 46 | 0 | 46 | 0 | 0 | 0 | 26 | 61 | 0 | 0 | 0 |
| | 112 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 113 | 0 | 912 | 0 | 17 | 81 | 0 | 185 | 93 | 44 | 207 | 373 | 1,020 | 759 | 0 |
| | Subtotal | 106 | 912 | 0 | 63 | 81 | 46 | 185 | 100 | 44 | 233 | 434 | 1,020 | 759 | 0 |
| Alaska Gillnet | 106 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 111 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 115 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 212 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 |
| Alaska Sport | Gustavus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Elfin Cove | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sitka | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 176 | 384 | 0 | 281 |
| | Craig | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 176 | 384 | 0 | 281 |
| Alaska Total | | 2,033 | 4,256 | 2,482 | 2,545 | 1,539 | 2,862 | 3,984 | 3,082 | 3,257 | 5,485 | 8,360 | 8,259 | 4,341 | 3,364 |
| B.C. Troll | | 0 | 0 | 0 | 0 | 0 | 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Catch | | 2,033 | 4,256 | 2,482 | 2,545 | 1,539 | 2,893 | 3,984 | 3,082 | 3,257 | 5,485 | 8,360 | 8,259 | 4,341 | 3,364 |
| Escapement | | 2,655 | 1,931 | 2,324 | 1,552 | 1,694 | 3,119 | 2,176 | 2,192 | 2,761 | 3,866 | 4,202 | 3,227 | 2,446 | 2,500 |
| Total | | 4,688 | 6,187 | 4,806 | 4,097 | 3,233 | 6,012 | 6,160 | 5,274 | 6,018 | 9,351 | 12,562 | 11,486 | 6,787 | 5,864 |
| Jacks (Weir Count) | | 37 | 97 | 276 | 220 | 129 | 293 | 261 | 248 | 226 | 281 | 389 | 213 | 181 | 224 |

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Appendix A 4.– (continued) page 2 of 2.

| Fishery | Area | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska Troll | NW | 4,691 | 7,753 | 5,893 | 4,569 | 5,774 | 5,712 | 4,131 | 7,664 | 5,134 | 3,866 | 5,606 | 4,499 | 4,579 | 4,460 |
| | NE | 0 | 0 | 0 | 0 | 0 | 25 | 23 | 58 | 0 | 0 | 31 | 21 | 0 | 12 |
| | SW | 12 | 55 | 0 | 35 | 47 | 14 | 0 | 0 | 0 | 0 | 36 | 42 | 25 | 20 |
| | SE | 0 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| | Subtotal | 4,702 | 7,835 | 5,893 | 4,604 | 5,821 | 5,751 | 4,154 | 7,722 | 5,134 | 3,866 | 5,673 | 4,563 | 4,604 | 4,494 |
| Alaska Seine | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 0 | 1 |
| | 103 | 0 | 0 | 0 | 0 | 0 | 84 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| | 104 | 0 | 38 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 26 | 0 | 14 |
| | 112 | 0 | 0 | 0 | 0 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | 113 | 0 | 397 | 66 | 890 | 82 | 1,176 | 504 | 524 | 60 | 367 | 217 | 1,003 | 248 | 342 |
| | Subtotal | 0 | 435 | 66 | 916 | 115 | 1,260 | 504 | 524 | 60 | 367 | 217 | 1,047 | 248 | 361 |
| Alaska Gillnet | 106 | 0 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 111 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | 115 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 |
| | 212 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Subtotal | 0 | 20 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 2 |
| Alaska Sport | Gustavus | 0 | 0 | 0 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 38 | 8 | 0 | 2 |
| | Elfin Cove | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 123 | 423 | 41 | 55 | 39 | 21 | 26 |
| | Sitka | 351 | 785 | 436 | 211 | 480 | 974 | 1,770 | 196 | 249 | 802 | 108 | 230 | 61 | 278 |
| | Craig | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 |
| | Subtotal | 351 | 785 | 436 | 211 | 480 | 998 | 1,770 | 319 | 672 | 844 | 202 | 277 | 93 | 307 |
| Alaska Total | | 5,053 | 9,075 | 6,395 | 5,744 | 6,415 | 8,009 | 6,429 | 8,564 | 5,867 | 5,078 | 6,098 | 5,887 | 4,945 | 5,163 |
| B.C. Troll | NBC | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Total Catch | | 5,053 | 9,075 | 6,395 | 5,744 | 6,415 | 8,009 | 6,429 | 8,564 | 5,867 | 5,078 | 6,098 | 5,887 | 4,945 | 5,164 |
| Escapement | | 4,718 | 7,049 | 3,800 | 2,304 | 2,209 | 7,109 | 6,789 | 3,539 | 4,257 | 4,737 | 2,567 | 5,173 | 2,181 | 3,447 |
| Total | | 9,771 | 16,124 | 10,195 | 8,048 | 8,624 | 15,118 | 13,218 | 12,103 | 10,124 | 9,815 | 8,665 | 11,060 | 7,126 | 8,612 |
| Jacks (Weir Count) | | 490 | 307 | 174 | 351 | 306 | 355 | 775 | 325 | 313 | 307 | 98 | 162 | 28 | 262 |

Appendix A5.–Estimated percent of the total Ford Arm Creek coho salmon return harvested by fishery and escaping to spawn, 1982–2009 (excluding 1984).

| Fishery | Area | 1982 | 1983 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska Troll | NW | 37.5 | 53.4 | 51.6 | 58.8 | 45.1 | 46.6 | 61.4 | 56.5 | 52.2 | 55.8 | 61.6 | 59.3 | 52.8 | 52.6 |
| | NE | 0.0 | 0.0 | 0.0 | 1.1 | 0.0 | 0.3 | 0.3 | 0.0 | 0.3 | 0.2 | 0.0 | 0.4 | 0.0 | 0.0 |
| | SW | 2.4 | 0.7 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 |
| | SE | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Subtotal | 41.1 | 54.0 | 51.6 | 60.6 | 45.1 | 46.8 | 61.7 | 56.5 | 53.2 | 56.2 | 61.7 | 59.7 | 52.8 | 52.6 |
| Alaska Seine | 102 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 103 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 104 | 2.3 | 0.0 | 0.0 | 1.1 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.3 | 0.5 | 0.0 | 0.0 | 0.0 |
| | 112 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 113 | 0.0 | 14.7 | 0.0 | 0.4 | 2.5 | 0.0 | 3.0 | 1.8 | 0.7 | 2.2 | 3.0 | 8.9 | 11.2 | 0.0 |
| | Subtotal | 2.3 | 14.7 | 0.0 | 1.5 | 2.5 | 0.8 | 3.0 | 1.9 | 0.7 | 2.5 | 3.5 | 8.9 | 11.2 | 0.0 |
| Alaska Gillnet | 106 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 111 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 115 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 212 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Subtotal | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Alaska Sport | Gustavus | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Elfin Cove | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Sitka | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.4 | 3.3 | 0.0 | 4.8 |
| | Craig | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Subtotal | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.4 | 3.3 | 0.0 | 4.8 |
| Alaska Total | | 43.4 | 68.8 | 51.6 | 62.1 | 47.6 | 47.6 | 64.7 | 58.4 | 54.1 | 58.7 | 66.5 | 71.9 | 64.0 | 57.4 |
| B.C. Troll | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total Catch | | 43.4 | 68.8 | 51.6 | 62.1 | 47.6 | 48.1 | 64.7 | 58.4 | 54.1 | 58.7 | 66.5 | 71.9 | 64.0 | 57.4 |
| Escapement | | 56.6 | 31.2 | 48.4 | 37.9 | 52.4 | 51.9 | 35.3 | 41.6 | 45.9 | 41.3 | 33.5 | 28.1 | 36.0 | 42.6 |
| Total | | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

- Continued -

Appendix A5.– continued (page 2 of 2).

| Fishery | Area | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alaska Troll | NW | 48.0 | 48.1 | 57.8 | 56.8 | 66.9 | 37.8 | 31.3 | 63.3 | 50.7 | 39.4 | 64.7 | 40.7 | 64.3 | 52.4 |
| | NE | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.2 | 0.5 | 0.0 | 0.0 | 0.4 | 0.2 | 0.0 | 0.1 |
| | SW | 0.1 | 0.3 | 0.0 | 0.4 | 0.5 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 | 0.3 | 0.3 |
| | SE | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| | Subtotal | 48.1 | 48.6 | 57.8 | 57.2 | 67.5 | 38.0 | 31.4 | 63.8 | 50.7 | 39.4 | 65.5 | 41.3 | 64.6 | 52.9 |
| Alaska Seine | 102 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 |
| | 103 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 104 | 0.0 | 0.2 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.2 |
| | 112 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 113 | 0.0 | 2.5 | 0.7 | 11.1 | 0.9 | 7.8 | 3.8 | 4.3 | 0.6 | 3.7 | 2.5 | 9.1 | 3.5 | 3.7 |
| | Subtotal | 0.0 | 2.7 | 0.7 | 11.4 | 1.3 | 8.3 | 3.8 | 4.3 | 0.6 | 3.7 | 2.5 | 9.5 | 3.5 | 3.9 |
| Alaska Gillnet | 106 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 111 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | 115 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| | 212 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Subtotal | 0.0 | 0.1 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Alaska Sport | Gustavus | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.1 | 0.0 | 0.0 |
| | Elfin Cove | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 1.0 | 4.2 | 0.4 | 0.6 | 0.4 | 0.3 | 0.3 |
| | Sitka | 3.6 | 4.9 | 4.3 | 2.6 | 5.6 | 6.4 | 13.4 | 1.6 | 2.5 | 8.2 | 1.2 | 2.1 | 0.9 | 2.5 |
| | Craig | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 |
| | Subtotal | 3.6 | 4.9 | 4.3 | 2.6 | 5.6 | 6.6 | 13.4 | 2.6 | 6.6 | 8.6 | 2.3 | 2.5 | 1.3 | 2.8 |
| Alaska Total | | 51.7 | 56.3 | 62.7 | 71.4 | 74.4 | 53.0 | 48.6 | 70.8 | 57.9 | 51.7 | 70.4 | 53.2 | 69.4 | 59.6 |
| B.C. Troll | NBC | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total Catch | | 51.7 | 56.3 | 62.7 | 71.4 | 74.4 | 53.0 | 48.6 | 70.8 | 57.9 | 51.7 | 70.4 | 53.2 | 69.4 | 59.6 |
| Escapement | | 48.3 | 43.7 | 37.3 | 28.6 | 25.6 | 47.0 | 51.4 | 29.2 | 42.1 | 48.3 | 29.6 | 46.8 | 30.6 | 40.4 |
| Total | | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

# APPENDIX B:
# SOCKEYE SALMON POPULATION

## SOCKEYE SALMON ASSESSMENT

Ford Arm Creek has a small sockeye salmon population that has been intermittently fished by a local subsistence fishery at the mouth of the creek and in the estuary. The majority of the sockeye salmon run entered the lake well before the weir was installed in mid-August and, therefore, the weir count was not representative of total escapement. However, methods were developed early in the history of the project to estimate the total number of fish escaping to the system, as well as the age-sex-length composition of the escapement.

### Escapement Estimation

The primary method used to estimate escapement of sockeye salmon in Ford Arm Creek was a simple mark-recapture technique constructed around the Chapman model. Other methods, including expansion of survey counts or the number of carcasses washed up on the weir were occasionally used when data were insufficient for mark-recapture estimation.

Most spawning occurs in beach areas around the perimeter of the lake during late August to mid-September, with some spawning occurring in the outlet area above the weir. Beginning in 1982, scales and associated length and sex data were collected from sockeye salmon spawners as part of a larger project to sample stocks throughout the region to develop standards for apportionment of commercial catches to individual stock (or grouping of stocks) based on scale pattern analysis. Fish were seined and sampled from spawning areas around the lakeshore and in the outlet upstream of the weir using a 15 m beach seine. As part of that sampling effort, the fish were adipose clipped to avoid repeat sampling of the same fish.

During the first season, the crew leader noticed that a substantial number of carcasses drifted out of the lake and washed up on the weir (hereafter, these fish will be referred to as wash-ups). Therefore, beginning in 1983 systematic sampling of weir wash-ups was initiated and a record was kept of the number of carcasses found on the weir that were in sufficient physical condition to be sampled for the presence or absence of an adipose clip, as well as the number of adipose clips recovered. A Chapman estimate was generated from this information, with the number marked ($M$) being the number of fish captured and sampled for age-length-sex, marked with an adipose clip, and released. The recovery sample ($C$) was the number of dead fish that washed up on the weir that were examined for the presence or absence of an adipose clip, and the number of recaptures ($R$) represented the number of adipose-clipped fish in the sample.

Beginning in 1988, a record was also kept of the total number of carcasses counted on the weir regardless of whether they were in sufficient condition to be sampled. Also, a substantial change in marking was initiated in that same year. Only lakeshore spawners were marked with an adipose clip while outlet spawners were marked with an opercular punch. All late migrants through the weir were marked with a dorsal clip. The primary impetus for the change was concern that outlet spawners, although usually much fewer in number, had a higher probability of washing up on the weir than lake spawners, some of which drift the full length of the lake. Subsequent observations have indicated that this is not consistently the case. Outlet spawners are subject to intensive bear predation, particularly in dry years with lower average water level, and many are killed and removed on or near their redds before they die and drift away. In contrast, beach spawners are much more difficult for bears to catch in lakeshore spawning areas, and carcasses from beach spawners are generally available to bears for only a short period when they drift through the outlet and onto the weir. Some beach spawners sink or are detained from drifting to the outlet by woody debris or aquatic vegetation. Higher water levels facilitated transport of more lakeshore spawners to the outlet and also helped protect outlet spawners from predation.

Generally, outlet spawners, while relatively few in most years, were easily captured for sampling so were thought to be marked at a substantially higher rate, approaching 100% in some years. Therefore, beginning in 1998, the number marked in the outlet with an opercular punch and the number of late upstream migrants marked with a dorsal clip were added to a Chapman estimate based on a recovery sample ($C$), comprised only of unmarked fish ($U$) and adipose clipped fish from lakeshore sampling ($R$).

Marking data were insufficient to generate mark-recapture estimates in 2 years, 1986 and 1996. In 1986, the escapement estimate was generated by dividing the number of sampleable wash-ups (174) by the average proportion of the escapement estimate observed as sampleable wash-ups in 1983–2009 (0.245).

The 1996 escapement was estimated in two ways, (1) by dividing the number of all wash-ups by the average proportion of the escapement estimate observed as total wash-ups in 1988–2009 (0.276) and, (2) by dividing the peak survey count (282 spawners) by the average proportion of the escapement estimate represented by the peak survey count in 1988–2009 (0.170). The two estimates (2,409 spawners based on wash-ups and 1,658 spawners based on the peak survey count) were weighted by the inverse of their associated variance to generate a total escapement estimate of 1,884 spawners. The combined estimate gave a 70% weighting to the peak survey count and 30% to total wash-ups.

Escapement estimates varied by more than an order of magnitude from 712 spawners in 1986 to 10,255 spawners in 1999, around a long-term average of 3,211 spawners (Appendixes B1 and B2). There were two periods of relatively high escapements during 1991–1993 and 1997–2000 but escapements during the other 19 years averaged only 2,097 spawners. Confidence bounds around the 1993 escapement estimate of 6,362 spawners were very broad (95% CI: 3,958–17,864 spawners), because of a very low marked fraction (2.5%) combined with a low observed wash-up rate of 7.7%. The low wash-up rate was the result of prolonged dry conditions that reduced transport of carcasses down the lake.

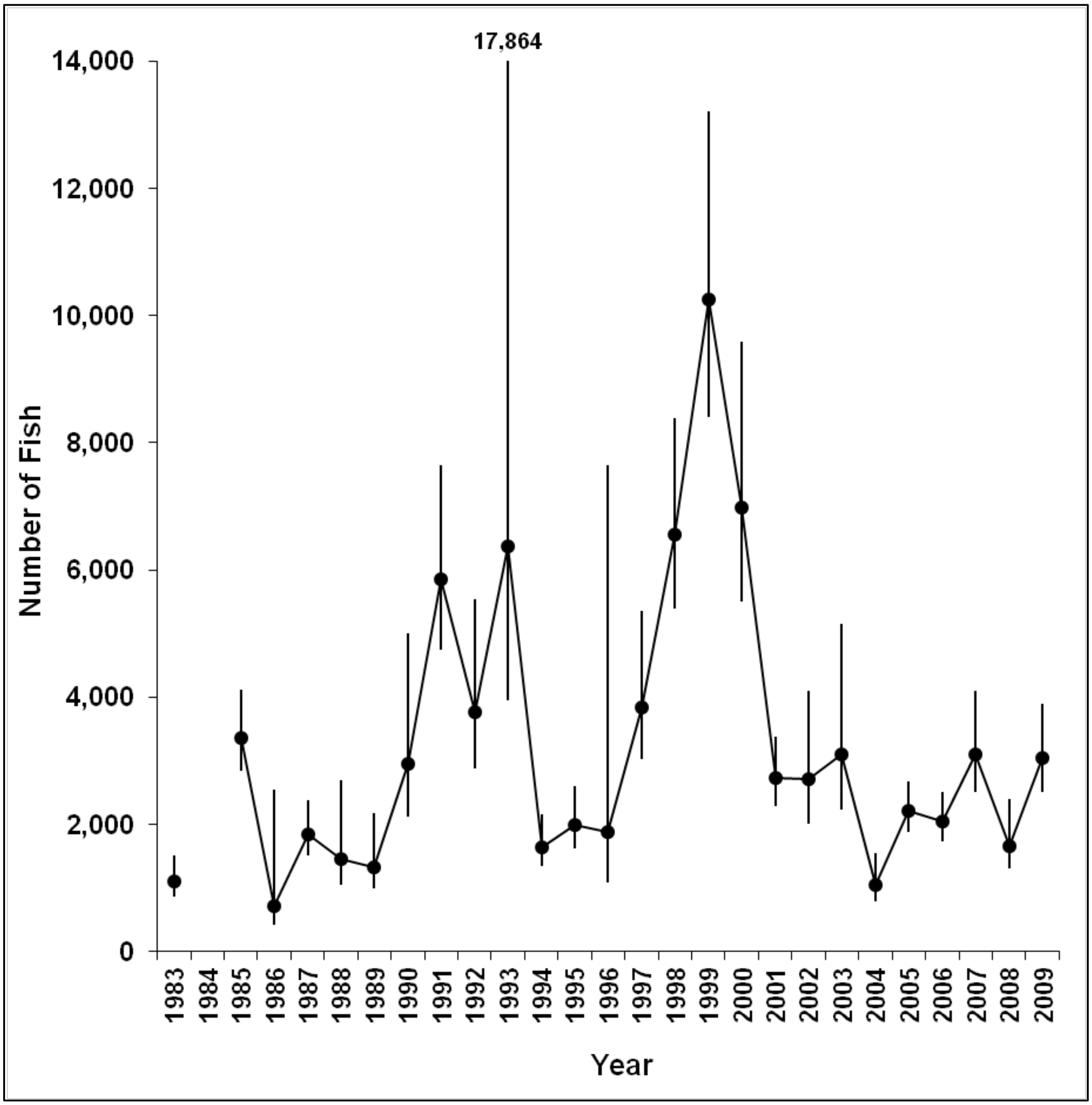
## Harvest Estimates

Information on the timing and probable migration route of sockeye salmon returning to Ford Arm Creek suggests that fishery exploitation is practically nil except for a directed subsistence fishery in the estuary and lower creek.

### *Commercial and Sport Catch*

Sockeye salmon are harvested in commercial troll and purse seine fisheries in outer coastal and offshore waters of Districts 113 and 154 near the Ford Arm system, and small mixed stock catches are taken in other outer coastal areas of northern Southeast and Yakutat. We were unable to determine the contribution of Ford Arm Creek sockeye salmon to those fisheries; however, based on the following examination of the magnitude and temporal and spatial distribution of sockeye catches, we concluded that the commercial and sport harvest of the Ford Arm Creek stock was likely insignificant, and excluding those catches would have little effect on assessment of the stock.

The purse seine fishery in the Khaz Bay area is managed to target local pink salmon stocks in late July and August, during which a small number of sockeye salmon are incidentally harvested. Fishing effort is often concentrated in areas where pink salmon stocks from Slocum Arm and Klag Bay intermingle, but fishing sometimes occurs within Ford Arm proper. During 1982–2009, the annual harvest of sockeye salmon in the Khaz Bay purse seine fishery averaged only 534 fish, ranging from 73 fish in 1982 to 1,960 fish in 1997, with catches exceeding 1,000 fish in only 5 years, 1996–1997 and 2005–2007.




Appendix B 1.–Estimates of total sockeye salmon escapement to Ford Arm Creek with 95% confidence bounds, 1983 and 1985–2009.

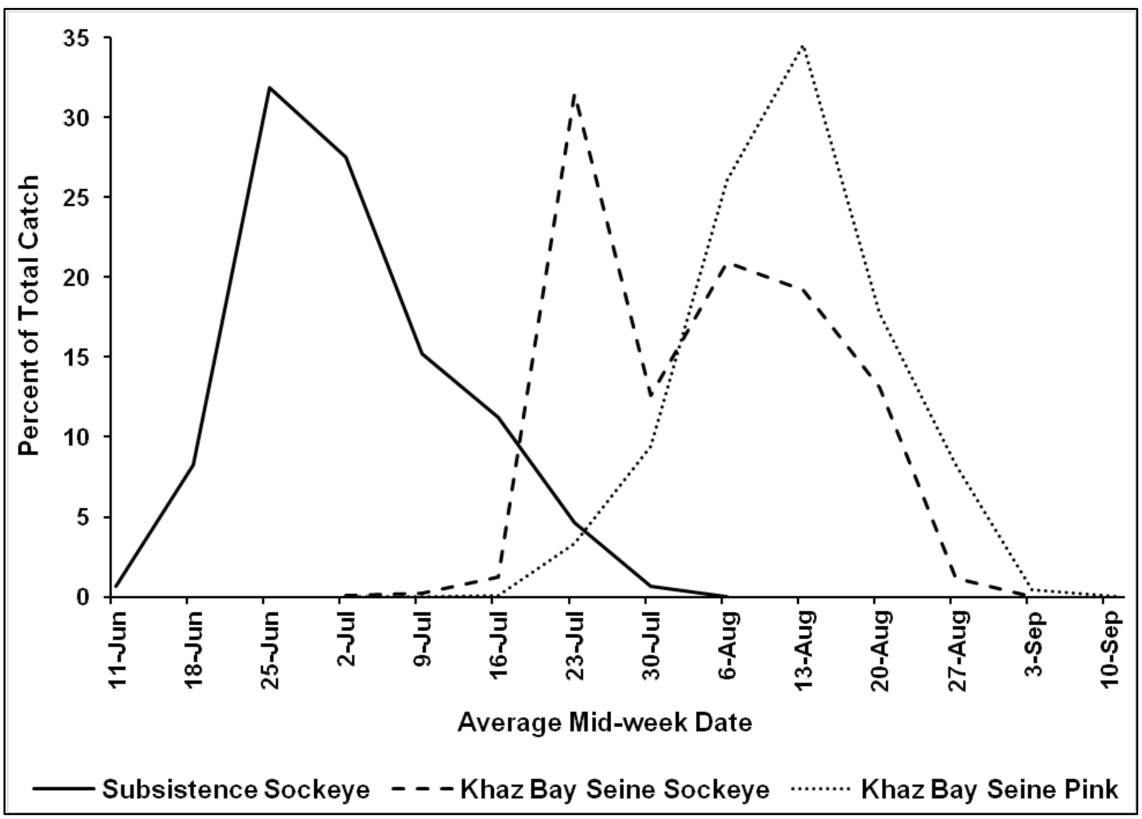
Appendix B 2.–Mark-recapture estimates of total sockeye salmon escapement to Ford Arm Lake, the number of wash-ups (total observed and the number in adequate condition to sample for fin marks), peak survey count in spawning areas, and reported subsistence catch[a].

| | | | | | | | | | Total Wash-ups | | Sample able Wash-ups | | Peak Survey Count | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brood Year | Number Marked | Recapture Sample | Recaptures | Chapman Estimate | Additions | Total Escapement | 95% C.I. Bounds Lower | 95% C.I. Bounds Upper | No. | Percent Wash-ups | No. | Percent of Escapement | Total Count | Percent of Escapement | Subsistence Catch | Permits Fished |
| 1983 | 205 | 265 | 49 | 1,095 | 0 | 1,095 | 858 | 1,513 | – | – | 265 | 24.2% | – | – | – | – |
| 1984 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 1985 | 502 | 739 | 111 | 3,322 | 41 | 3,363 | 2,845 | 4,117 | – | – | 739 | 22.0% | – | – | 556 | 24 |
| 1986 | –[b] | – | – | – | – | ***712*** | ***414*** | ***2,543*** | – | – | 174 | – | – | – | 35 | 4 |
| 1987 | 214 | 661 | 76 | 1,847 | 0 | 1,847 | 1,510 | 2,378 | – | – | 661 | 35.8% | – | – | 26 | 2 |
| 1988 | 127 | 146 | 14 | 1,253 | 201 | 1,454 | 1,039 | 2,687 | 258 | 17.7% | 214 | 14.7% | 250 | 17.2% | 12 | 1 |
| 1989 | 137 | 175 | 20 | 1,156 | 174 | 1,330 | 986 | 2,175 | 255 | 19.2% | 238 | 17.9% | – | – | 21 | 2 |
| 1990 | 173 | 311 | 19 | 2,713 | 228 | 2,941 | 2,124 | 4,996 | 446 | 15.2% | 398 | 13.5% | 248 | 8.4% | 10 | 1 |
| 1991 | 249 | 1,498 | 65 | 5,677 | 175 | 5,852 | 4,751 | 7,650 | 1,619 | 27.7% | 1,540 | 26.3% | 450 | 7.7% | 10 | 2 |
| 1992 | 215 | 581 | 34 | 3,591 | 182 | 3,773 | 2,885 | 5,530 | 664 | 17.6% | 605 | 16.0% | 550 | 14.6% | 53 | 2 |
| 1993 | 174 | 277 | 7 | 6,080 | 282 | 6,362 | 3,958 | 17,864 | 340 | 5.3% | 318 | 5.0% | 502 | 7.9% | 165 | 6 |
| 1994 | 225 | 333 | 52 | 1,423 | 212 | 1,635 | 1,334 | 2,158 | 421 | 25.7% | 367 | 22.4% | 378 | 23.1% | 53 | 3 |
| 1995 | 215 | 552 | 62 | 1,895 | 91 | 1,986 | 1,611 | 2,606 | 575 | 29.0% | 564 | 28.4% | 318 | 16.0% | 20 | 2 |
| 1996 | –[b] | – | – | – | – | ***1,884*** | ***1,076*** | ***7,649*** | 664 | – | 639 | – | 282 | – | 72 | 3 |
| 1997 | 207 | 737 | 42 | 3,569 | 278 | 3,847 | 3,029 | 5,356 | 964 | 25.1% | 763 | 19.8% | 1,007 | 26.2% | 270 | 9 |
| 1998 | 296 | 1,592 | 74 | 6,307 | 248 | 6,555 | 5,394 | 8,393 | 1,874 | 28.6% | 1,619 | 24.7% | 1,309 | 20.0% | 1,153 | 43 |
| 1999 | 195 | 3,701 | 72 | 9,939 | 316 | 10,255 | 8,403 | 13,207 | 3,954 | 38.6% | 3,761 | 36.7% | 1,322 | 12.9% | 353 | 17 |
| 2000 | 203 | 1,673 | 49 | 6,829 | 155 | 6,984 | 5,507 | 9,586 | 1,828 | 26.2% | 1,707 | 24.4% | 852 | 12.2% | 737 | 35 |
| 2001 | 245 | 960 | 91 | 2,569 | 154 | 2,723 | 2,287 | 3,382 | 1,071 | 39.3% | 1,008 | 37.0% | 508 | 18.7% | 1,115 | 55 |
| 2002 | 121 | 701 | 31 | 2,675 | 26 | 2,701 | 2,016 | 4,106 | 752 | 27.8% | 703 | 26.0% | 319 | 11.8% | 1,156 | 33 |
| 2003 | 87 | 791 | 22 | 3,029 | 64 | 3,093 | 2,221 | 5,152 | 860 | 27.8% | 802 | 25.9% | 331 | 10.7% | 603 | 28 |
| 2004 | 158 | 182 | 30 | 938 | 101 | 1,039 | 796 | 1,544 | 266 | 25.6% | 212 | 20.4% | 244 | 23.5% | 265 | 13 |
| 2005 | 272 | 1,014 | 126 | 2,181 | 27 | 2,208 | 1,885 | 2,667 | 1,049 | 47.5% | 1,020 | 46.2% | 331 | 15.0% | 51 | 2 |
| 2006 | 308 | 598 | 96 | 1,907 | 134 | 2,041 | 1,725 | 2,515 | 720 | 35.3% | 626 | 30.7% | 341 | 16.7% | 97 | 4 |
| 2007 | 316 | 541 | 58 | 2,911 | 185 | 3,096 | 2,506 | 4,088 | 875 | 28.3% | 562 | 18.2% | 588 | 19.0% | 0 | 1 |
| 2008 | 194 | 239 | 32 | 1,417 | 246 | 1,663 | 1,304 | 2,390 | 392 | 23.6% | 308 | 18.5% | 507 | 30.5% | 35 | 2 |
| 2009 | 198 | 921 | 66 | 2,737 | 302 | 3,039 | 2,511 | 3,899 | 1,451 | 47.7% | 971 | 31.9% | 856 | 28.2% | 120 | 5 |
| Average | 218 | 800 | 54 | 3,211 | 159 | 3,211 | 2,499 | 5,006 | 968 | 27.6% | 799 | 24.5% | 547 | 17.0% | 280 | 12 |

[a] Dashes indicate no data available.

[b] Mark-recapture data were insufficient to generate population estimates in 1986 and 1996. The 1986 estimate is based on the number of sample able wash-ups while the 1996 estimate is based on the peak survey count and total wash-ups (individual estimates weighted by the inverse of variance).

Using the 1985–2009 average reported subsistence harvest as an indicator of the migratory timing of sockeye salmon entering Ford Arm Creek (Appendix B3) suggests that about 95% of the escapement into the creek occurred before a significant proportion of the sockeye salmon catch was taken in the Khaz Bay seine fishery. The sockeye salmon run in neighboring Klag Bay is substantially larger and peaks in the subsistence fishery about 2 to 3 weeks later than the Ford Arm stock. While the 1985–2009 reported subsistence catch for the Ford Arm stock averaged only 280 fish (range 0–1,156), the reported catch at Klag Bay averaged 1,628 fish (range 23–5,788). In 2001–2005, the estimated total run to Klag Lake averaged about 19,300 sockeye salmon (Conitz and Cartwright 2002; Conitz et al. 2005; Lorrigan et al. 2004; Stahl et al. 2007; Woody and Conitz 2008) compared with an average of only about 3,000 fish returning to Ford Arm Creek. The Klag Bay stock has likely contributed a substantial proportion of the sockeye salmon caught in the Khaz Bay purse seine fishery, based on its later timing and larger average size, with some of the remaining harvest probably contributed by other passing stocks. Therefore, we have assumed the purse seine harvest of the smaller, earlier Ford Arm Creek stock to be nil.




Appendix B 3.–Average weekly percent of the total number of sockeye salmon caught in the Ford Arm Creek subsistence fishery compared with the sockeye and pink salmon catch in the Khaz Bay purse seine fishery, 1985–2009.

The troll harvest in waters that likely include the migratory path of Ford Arm Lake sockeye salmon averaged only 9,542 sockeye salmon annually during 1985–2009 (range 839–36,233). The troll sockeye harvest in the Northwest Quadrant (Districts 113, 114, 116, 154, 156, 157, and 181–191) exceeded 10,000 fish in only 6 years. The average mid-point of the troll harvest during the period was 24 July, suggesting that most of the catch occurred well after most Ford Arm

Creek fish had already entered freshwater (Appendix B3). The majority of the large 1997 troll harvest of 36,233 fish occurred after mid-August, well past the peak of most Alaska and northern British Columbia runs. Many of these fish were probably bound for the Fraser River in southern British Columbia. The Pacific Salmon Commission estimated the region-wide Alaska troll harvest of Fraser River sockeye salmon in 1997 at a record 23,000 fish (Pacific Salmon Commission 1999) or over half of the total Alaska troll catch of 39,400 sockeye salmon. Given the small catch and highly mixed stock nature of the sockeye troll harvest, it is likely that the troll catch of the early migrating Ford Arm Creek stock has been negligible.

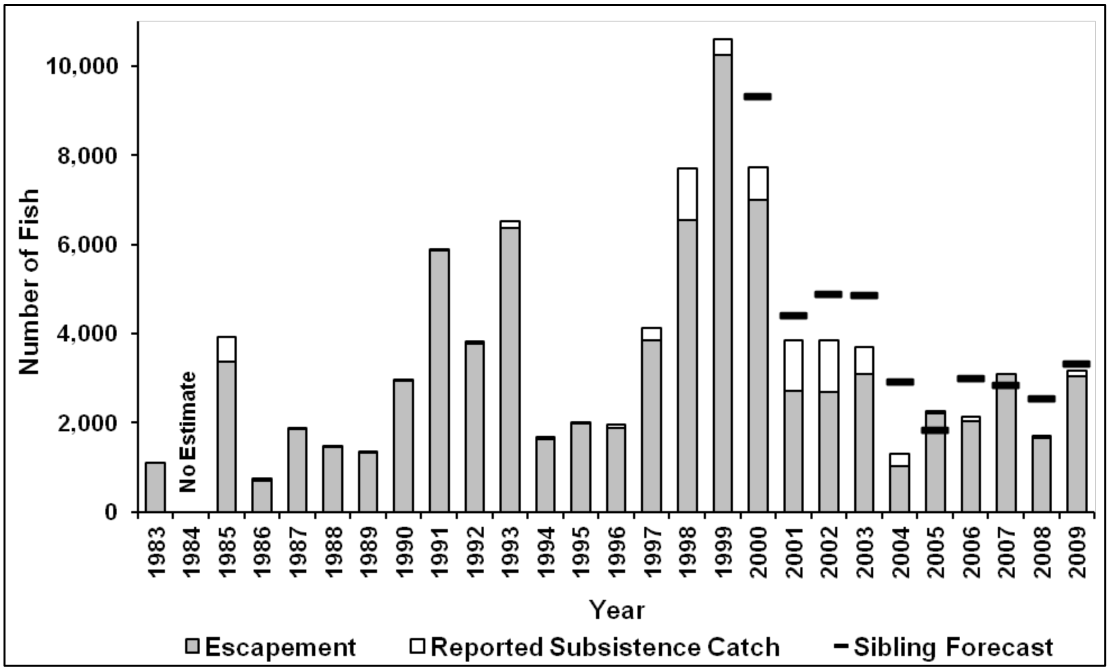
There were no reported sockeye salmon sport catches in either freshwater or saltwater in Ford Arm during 1996–2009. Creel survey estimates indicate that fewer than 700 sockeye salmon have been harvested in most years by the Sitka marine sport fishery (Mike Jaenicke, ADF&G, Division of Sport Fish, personal communication). A high 1999 estimate for that fishery of over 5,000 fish included marine hook and line harvest near Redoubt Lake where the catch was likely comprised almost entirely of the local stock. It is, therefore, unlikely that there has been any significant sport harvest of Ford Arm Lake sockeye salmon in either fresh or marine waters.

### *Subsistence Catch*

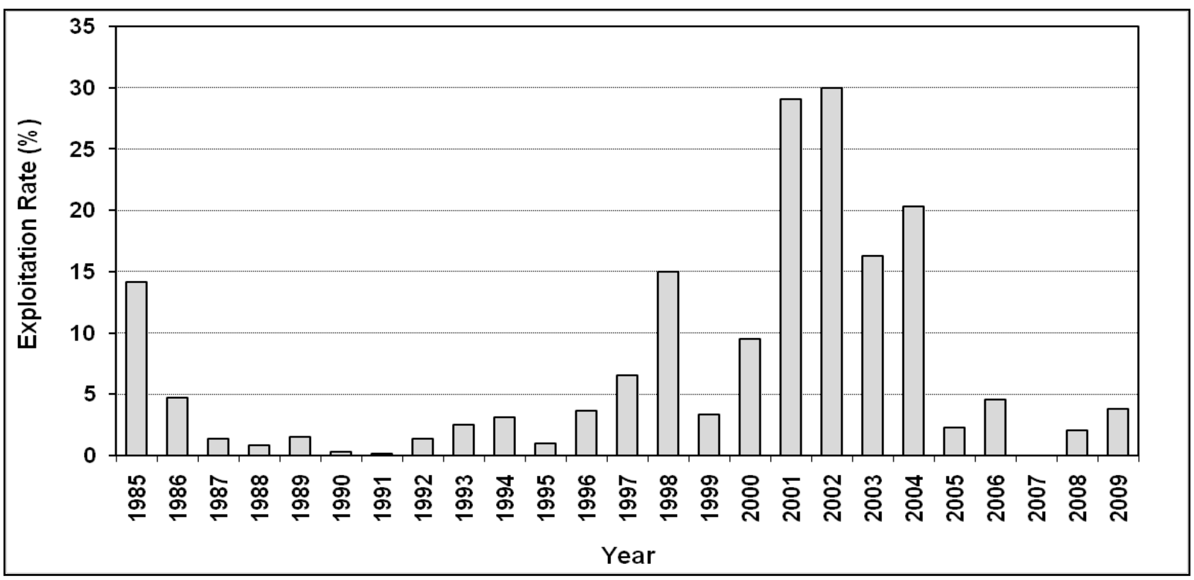
We used the subsistence harvest, reported as required of all permit holders since 1985. There has been less than 100% compliance in returning permit reports and it is also possible that catches were under-reported. In order to address these data concerns at nearby Klag Bay, an on-site interview program was implemented during 2001–2005 (Conitz and Cartwright 2002; Conitz et al. 2005; Lorrigan et al. 2004; Stahl et al. 2007; Woody and Conitz 2008). On-site survey estimates varied from 25% under to 21% over the reported catch on returned permits, and averaged 6% lower than the reported catch. Therefore, results from the study at Klag Bay suggest that no adjustment is warranted for potential under-reporting at Ford Arm where many of the same subsistence harvesters fish.

The 1985–2009 reported subsistence catch for the Ford Arm stock averaged only 280 fish and ranged from 0 fish in 2007 when the fishery was closed by emergency order (based on a low inseason aerial survey count) to 1,156 fish in 2002 (Appendix B2 and B4) when there was strong interest in the fishery because the other early subsistence sockeye harvest opportunity in the Sitka area (Redoubt Lake) was restricted due to low returns. The number of subsistence permits reported to have been fished at Ford Arm Creek averaged 12 permits and ranged from only 1 permit in 1988, 1990 and 2007 to 55 permits in 2001.

The estimated exploitation rate by the subsistence fishery averaged only 7% of the total Ford Arm Creek sockeye salmon run during 1985−2009, ranging from 0% in 2007 to 30% in 2002 (Appendix B5). After reaching peak rates of 16−30% (average 24%) in 2001−2004, exploitation fell again to 0−4% (average 3%) in 2005−2009. The exploitation rate has not been significantly correlated with estimated run abundance ($R^2 = 0.02$).




Appendix B 4.–Estimated Ford Arm Lake sockeye salmon catch and escapement in 1983 and 1985–2009, with preseason sibling forecasts shown for 2000–2009.




Appendix B 5.–Estimated exploitation rate by the subsistence fishery on the total sockeye salmon run to Ford Arm Lake, 1985–2009.

## Age Distribution

Sockeye salmon runs to Ford Arm Lake were composed of many age classes (Appendixes B6−B8) with ages 1.2 and 1.3 predominating at 32.5% and 36.9% of the run, on average. Age-1.1 jacks were also common (10.1%), as were age-2.2 adults (8.9%) and age-2.3 adults (8.1%).

In aggregate, 9 other observed age classes contributed only 3.5% of the run, on average, of which most (3.0%) were age-2.1 jacks.

Appendix B6.–Number of sockeye salmon sampled at Ford Arm Lake for which age could be determined, by age class.

| | Age (Number of Fish) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 0.1 | 0.2 | 0.3 | 1.1 | 1.2 | 1.3 | 1.4 | 2.1 | 2.2 | 2.3 | 2.4 | 3.1 | 3.2 | 3.3 | Total |
| 1982 | 0 | 0 | 1 | 51 | 31 | 106 | 0 | 2 | 26 | 41 | 0 | 0 | 4 | 0 | 262 |
| 1983 | 0 | 0 | 1 | 83 | 52 | 91 | 0 | 6 | 8 | 60 | 0 | 0 | 0 | 0 | 301 |
| 1984 | 0 | 0 | 1 | 8 | 180 | 166 | 0 | 2 | 9 | 8 | 0 | 0 | 0 | 0 | 374 |
| 1985 | 0 | 0 | 1 | 19 | 214 | 291 | 0 | 11 | 19 | 12 | 0 | 0 | 1 | 0 | 568 |
| 1986 | 0 | 0 | 1 | 16 | 57 | 52 | 0 | 1 | 25 | 11 | 0 | 0 | 0 | 0 | 163 |
| 1987 | 0 | 0 | 0 | 73 | 218 | 105 | 1 | 34 | 43 | 28 | 0 | 0 | 0 | 2 | 504 |
| 1988 | 0 | 0 | 1 | 4 | 149 | 114 | 0 | 7 | 30 | 20 | 0 | 0 | 0 | 0 | 325 |
| 1989 | 0 | 1 | 0 | 35 | 37 | 146 | 0 | 33 | 22 | 37 | 0 | 4 | 0 | 0 | 315 |
| 1990 | 0 | 0 | 0 | 22 | 93 | 143 | 0 | 12 | 73 | 54 | 0 | 0 | 2 | 2 | 401 |
| 1991 | 1 | 0 | 3 | 43 | 116 | 120 | 0 | 11 | 34 | 30 | 0 | 0 | 0 | 0 | 358 |
| 1992 | 0 | 0 | 0 | 25 | 245 | 51 | 0 | 14 | 54 | 30 | 1 | 2 | 1 | 1 | 424 |
| 1993 | 0 | 0 | 1 | 35 | 26 | 238 | 0 | 12 | 33 | 39 | 1 | 0 | 0 | 0 | 385 |
| 1994 | 0 | 0 | 0 | 10 | 142 | 106 | 3 | 35 | 48 | 36 | 0 | 0 | 0 | 0 | 380 |
| 1995 | 0 | 0 | 0 | 28 | 25 | 300 | 1 | 26 | 30 | 18 | 0 | 0 | 0 | 0 | 428 |
| 1996 | 0 | 0 | 0 | 52 | 54 | 257 | 2 | 7 | 37 | 76 | 0 | 0 | 1 | 1 | 487 |
| 1997 | 0 | 0 | 0 | 215 | 124 | 55 | 1 | 9 | 41 | 35 | 0 | 0 | 0 | 0 | 480 |
| 1998 | 0 | 0 | 1 | 55 | 221 | 177 | 0 | 18 | 15 | 4 | 0 | 0 | 0 | 0 | 491 |
| 1999 | 0 | 0 | 0 | 1 | 163 | 257 | 0 | 6 | 42 | 9 | 0 | 0 | 0 | 0 | 478 |
| 2000 | 0 | 0 | 0 | 22 | 83 | 208 | 0 | 3 | 41 | 47 | 0 | 0 | 0 | 0 | 404 |
| 2001 | 0 | 0 | 0 | 70 | 209 | 84 | 0 | 16 | 24 | 68 | 0 | 0 | 0 | 0 | 471 |
| 2002 | 0 | 0 | 0 | 5 | 348 | 53 | 0 | 3 | 27 | 8 | 0 | 0 | 0 | 0 | 444 |
| 2003 | 0 | 0 | 0 | 14 | 129 | 223 | 0 | 6 | 24 | 31 | 0 | 0 | 0 | 0 | 427 |
| 2004 | 0 | 0 | 1 | 22 | 44 | 172 | 0 | 8 | 53 | 36 | 0 | 0 | 0 | 0 | 336 |
| 2005 | 0 | 0 | 0 | 67 | 196 | 91 | 2 | 30 | 49 | 38 | 0 | 0 | 0 | 0 | 473 |
| 2006 | 0 | 0 | 0 | 6 | 282 | 94 | 0 | 8 | 53 | 22 | 0 | 0 | 0 | 0 | 465 |
| 2007 | 0 | 0 | 0 | 63 | 13 | 240 | 0 | 13 | 11 | 62 | 0 | 0 | 0 | 0 | 402 |
| 2008 | 0 | 0 | 0 | 96 | 231 | 8 | 2 | 10 | 85 | 5 | 1 | 0 | 0 | 0 | 438 |
| 2009 | 0 | 0 | 1 | 5 | 154 | 229 | 0 | 3 | 27 | 16 | 0 | 0 | 0 | 0 | 435 |
| Average | 0 | 0 | 0 | 41 | 137 | 149 | 0 | 12 | 35 | 31 | 0 | 0 | 0 | 0 | 408 |

Appendix B7.–Ford Arm Lake sockeye salmon age composition (percent of grand total sample) by total age class and European age category.

| | Age 2 | Age 3 | | | Age 4 | | | | Age 5 | | | | Age 6 | | | | Age 7 | | | Grand | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Return | 0.1 | 0.2 | 1.1 | Total | 0.3 | 1.2 | 2.1 | Total | 1.3 | 2.2 | 3.1 | Total | 1.4 | 2.3 | 3.2 | Total | 2.4 | 3.3 | Total | Total | of Samples |
| 1982 | 0.0 | 0.0 | 19.5 | 19.5 | 0.4 | 11.8 | 0.8 | 13.0 | 40.5 | 9.9 | 0.0 | 50.4 | 0.0 | 15.6 | 1.5 | 17.2 | 0.0 | 0.0 | 0.0 | 100.0 | 262 |
| 1983 | 0.0 | 0.0 | 27.6 | 27.6 | 0.3 | 17.3 | 2.0 | 19.6 | 30.2 | 2.7 | 0.0 | 32.9 | 0.0 | 19.9 | 0.0 | 19.9 | 0.0 | 0.0 | 0.0 | 100.0 | 301 |
| 1984 | 0.0 | 0.0 | 2.1 | 2.1 | 0.3 | 48.1 | 0.5 | 48.9 | 44.4 | 2.4 | 0.0 | 46.8 | 0.0 | 2.1 | 0.0 | 2.1 | 0.0 | 0.0 | 0.0 | 100.0 | 374 |
| 1985 | 0.0 | 0.0 | 3.3 | 3.3 | 0.2 | 37.7 | 1.9 | 39.8 | 51.2 | 3.3 | 0.0 | 54.6 | 0.0 | 2.1 | 0.2 | 2.3 | 0.0 | 0.0 | 0.0 | 100.0 | 568 |
| 1986 | 0.0 | 0.0 | 9.8 | 9.8 | 0.6 | 35.0 | 0.6 | 36.2 | 31.9 | 15.3 | 0.0 | 47.2 | 0.0 | 6.7 | 0.0 | 6.7 | 0.0 | 0.0 | 0.0 | 100.0 | 163 |
| 1987 | 0.0 | 0.0 | 14.5 | 14.5 | 0.0 | 43.3 | 6.7 | 50.0 | 20.8 | 8.5 | 0.0 | 29.4 | 0.2 | 5.6 | 0.0 | 5.8 | 0.0 | 0.4 | 0.4 | 100.0 | 504 |
| 1988 | 0.0 | 0.0 | 1.2 | 1.2 | 0.3 | 45.8 | 2.2 | 48.3 | 35.1 | 9.2 | 0.0 | 44.3 | 0.0 | 6.2 | 0.0 | 6.2 | 0.0 | 0.0 | 0.0 | 100.0 | 325 |
| 1989 | 0.0 | 0.3 | 11.1 | 11.4 | 0.0 | 11.7 | 10.5 | 22.2 | 46.3 | 7.0 | 1.3 | 54.6 | 0.0 | 11.7 | 0.0 | 11.7 | 0.0 | 0.0 | 0.0 | 100.0 | 315 |
| 1990 | 0.0 | 0.0 | 5.5 | 5.5 | 0.0 | 23.2 | 3.0 | 26.2 | 35.7 | 18.2 | 0.0 | 53.9 | 0.0 | 13.5 | 0.5 | 14.0 | 0.0 | 0.5 | 0.5 | 100.0 | 401 |
| 1991 | 0.3 | 0.0 | 12.0 | 12.0 | 0.8 | 32.4 | 3.1 | 36.3 | 33.5 | 9.5 | 0.0 | 43.0 | 0.0 | 8.4 | 0.0 | 8.4 | 0.0 | 0.0 | 0.0 | 100.0 | 358 |
| 1992 | 0.0 | 0.0 | 5.9 | 5.9 | 0.0 | 57.8 | 3.3 | 61.1 | 12.0 | 12.7 | 0.5 | 25.2 | 0.0 | 7.1 | 0.2 | 7.3 | 0.2 | 0.2 | 0.5 | 100.0 | 424 |
| 1993 | 0.0 | 0.0 | 9.1 | 9.1 | 0.3 | 6.8 | 3.1 | 10.1 | 61.8 | 8.6 | 0.0 | 70.4 | 0.0 | 10.1 | 0.0 | 10.1 | 0.3 | 0.0 | 0.3 | 100.0 | 385 |
| 1994 | 0.0 | 0.0 | 2.6 | 2.6 | 0.0 | 37.4 | 9.2 | 46.6 | 27.9 | 12.6 | 0.0 | 40.5 | 0.8 | 9.5 | 0.0 | 10.3 | 0.0 | 0.0 | 0.0 | 100.0 | 380 |
| 1995 | 0.0 | 0.0 | 6.5 | 6.5 | 0.0 | 5.8 | 6.1 | 11.9 | 70.1 | 7.0 | 0.0 | 77.1 | 0.2 | 4.2 | 0.0 | 4.4 | 0.0 | 0.0 | 0.0 | 100.0 | 428 |
| 1996 | 0.0 | 0.0 | 10.7 | 10.7 | 0.0 | 11.1 | 1.4 | 12.5 | 52.8 | 7.6 | 0.0 | 60.4 | 0.4 | 15.6 | 0.2 | 16.2 | 0.0 | 0.2 | 0.2 | 100.0 | 487 |
| 1997 | 0.0 | 0.0 | 44.8 | 44.8 | 0.0 | 25.8 | 1.9 | 27.7 | 11.5 | 8.5 | 0.0 | 20.0 | 0.2 | 7.3 | 0.0 | 7.5 | 0.0 | 0.0 | 0.0 | 100.0 | 480 |
| 1998 | 0.0 | 0.0 | 11.2 | 11.2 | 0.2 | 45.0 | 3.7 | 48.9 | 36.0 | 3.1 | 0.0 | 39.1 | 0.0 | 0.8 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 100.0 | 491 |
| 1999 | 0.0 | 0.0 | 0.2 | 0.2 | 0.0 | 34.1 | 1.3 | 35.4 | 53.8 | 8.8 | 0.0 | 62.6 | 0.0 | 1.9 | 0.0 | 1.9 | 0.0 | 0.0 | 0.0 | 100.0 | 478 |
| 2000 | 0.0 | 0.0 | 5.4 | 5.4 | 0.0 | 20.5 | 0.7 | 21.3 | 51.5 | 10.1 | 0.0 | 61.6 | 0.0 | 11.6 | 0.0 | 11.6 | 0.0 | 0.0 | 0.0 | 100.0 | 404 |
| 2001 | 0.0 | 0.0 | 14.9 | 14.9 | 0.0 | 44.4 | 3.4 | 47.8 | 17.8 | 5.1 | 0.0 | 22.9 | 0.0 | 14.4 | 0.0 | 14.4 | 0.0 | 0.0 | 0.0 | 100.0 | 471 |
| 2002 | 0.0 | 0.0 | 1.1 | 1.1 | 0.0 | 78.4 | 0.7 | 79.1 | 11.9 | 6.1 | 0.0 | 18.0 | 0.0 | 1.8 | 0.0 | 1.8 | 0.0 | 0.0 | 0.0 | 100.0 | 444 |
| 2003 | 0.0 | 0.0 | 3.3 | 3.3 | 0.0 | 30.2 | 1.4 | 31.6 | 52.2 | 5.6 | 0.0 | 57.8 | 0.0 | 7.3 | 0.0 | 7.3 | 0.0 | 0.0 | 0.0 | 100.0 | 427 |
| 2004 | 0.0 | 0.0 | 6.5 | 6.5 | 0.3 | 13.1 | 2.4 | 15.8 | 51.2 | 15.8 | 0.0 | 67.0 | 0.0 | 10.7 | 0.0 | 10.7 | 0.0 | 0.0 | 0.0 | 100.0 | 336 |
| 2005 | 0.0 | 0.0 | 14.2 | 14.2 | 0.0 | 41.4 | 6.3 | 47.8 | 19.2 | 10.4 | 0.0 | 29.6 | 0.4 | 8.0 | 0.0 | 8.5 | 0.0 | 0.0 | 0.0 | 100.0 | 473 |
| 2006 | 0.0 | 0.0 | 1.3 | 1.3 | 0.0 | 60.6 | 1.7 | 62.4 | 20.2 | 11.4 | 0.0 | 31.6 | 0.0 | 4.7 | 0.0 | 4.7 | 0.0 | 0.0 | 0.0 | 100.0 | 465 |
| 2007 | 0.0 | 0.0 | 15.7 | 15.7 | 0.0 | 3.2 | 3.2 | 6.5 | 59.7 | 2.7 | 0.0 | 62.4 | 0.0 | 15.4 | 0.0 | 15.4 | 0.0 | 0.0 | 0.0 | 100.0 | 402 |
| 2008 | 0.0 | 0.0 | 21.9 | 21.9 | 0.0 | 52.7 | 2.3 | 55.0 | 1.8 | 19.4 | 0.0 | 21.2 | 0.5 | 1.1 | 0.0 | 1.6 | 0.2 | 0.0 | 0.2 | 100.0 | 438 |
| 2009 | 0.0 | 0.0 | 1.1 | 1.1 | 0.2 | 35.4 | 0.7 | 36.3 | 52.6 | 6.2 | 0.0 | 58.9 | 0.0 | 3.7 | 0.0 | 3.7 | 0.0 | 0.0 | 0.0 | 100.0 | 435 |
| Average | 0.0 | 0.0 | 10.1 | 10.1 | 0.1 | 32.5 | 3.0 | 35.6 | 36.9 | 8.9 | 0.1 | 45.8 | 0.1 | 8.1 | 0.1 | 8.3 | 0.0 | 0.0 | 0.1 | 100.0 | 408 |

Appendix B8.–Ford Arm Lake sockeye salmon estimated escapement and return by brood year.[a]

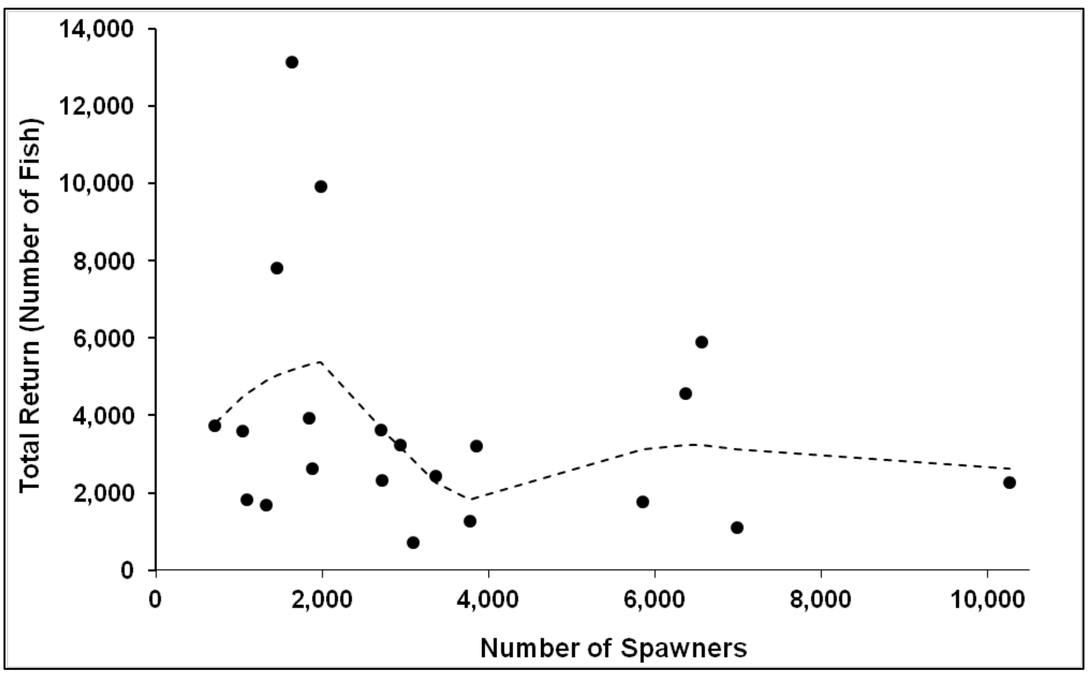
| Brood | | Age (Number of Fish) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Escapement | Age 2 | Age 3 | Age 4 | Age 5 | Age 6 | Age 7 | Total |
| 1982 | – [b] | 0 | 131 | 270 | 550 | 90 | 0 | 1,041 |
| 1983 | 1,095 | 0 | 73 | 937 | 650 | 159 | 15 | 1,833 |
| 1984 | – [b] | 0 | 271 | 708 | 737 | 412 | 0 | 2,129 |
| 1985 | 3,363 | 0 | 18 | 300 | 1,590 | 491 | 18 | 2,417 |
| 1986 | 711 | 0 | 154 | 773 | 2,522 | 280 | 17 | 3,745 |
| 1987 | 1,847 | 0 | 162 | 2,129 | 965 | 661 | 0 | 3,917 |
| 1988 | 1,454 | 0 | 704 | 2,337 | 4,595 | 173 | 0 | 7,809 |
| 1989 | 1,330 | 16 | 226 | 661 | 684 | 89 | 4 | 1,680 |
| 1990 | 2,941 | 0 | 593 | 786 | 1,547 | 317 | 0 | 3,244 |
| 1991 | 5,852 | 0 | 44 | 239 | 1,181 | 309 | 0 | 1,773 |
| 1992 | 3,773 | 0 | 131 | 245 | 823 | 63 | 0 | 1,262 |
| 1993 | 6,362 | 0 | 209 | 1,141 | 3,014 | 200 | 0 | 4,564 |
| 1994 | 1,635 | 0 | 1,844 | 3,768 | 6,635 | 898 | 0 | 13,145 |
| 1995 | 1,986 | 0 | 863 | 3,750 | 4,759 | 554 | 0 | 9,927 |
| 1996 | 1,884 | 0 | 22 | 1,644 | 880 | 70 | 0 | 2,615 |
| 1997 | 3,847 | 0 | 420 | 1,833 | 695 | 268 | 0 | 3,217 |
| 1998 | 6,555 | 0 | 570 | 3,049 | 2,138 | 140 | 0 | 5,898 |
| 1999 | 10,255 | 0 | 43 | 1,169 | 873 | 191 | 0 | 2,276 |
| 2000 | 6,984 | 0 | 121 | 206 | 669 | 101 | 0 | 1,097 |
| 2001 | 2,723 | 0 | 85 | 1,079 | 676 | 478 | 4 | 2,322 |
| 2002 | 2,701 | 0 | 320 | 1,333 | 1,933 | 27 | 0 | 3,614 |
| 2003 | 3,093 | 0 | 28 | 200 | 361 | 116 | ***1*** | 705 |
| 2004 | 1,039 | 0 | 485 | 934 | 1,859 | ***327*** | ***4*** | 3,610 |
| 2005 | 2,208 | 0 | 372 | 1,148 | – | – | – | – |
| 2006 | 2,041 | 0 | 36 | – | – | – | – | – |
| 2007 | 3,096 | 0 | – | – | – | – | – | – |
| 2008 | 1,663 | 0 | – | – | – | – | – | – |
| 2009 | 3,039 | – | – | – | – | – | – | – |
| Average | 3,211 | 1 | 317 | 1,277 | 1,754 | 279 | 3 | 3,645 |

[a] The age 7 return for the 2003 brood year and the age 6 and 7 returns for the 2004 brood year (shown in bold italics) were extrapolated based on the average proportions returning at those ages for the 1982−2002 brood years.
[b] Escapement estimates not available for 1982 and 1984.

## Spawner-Recruit Relationship

A plot of total return estimates by brood year escapement is shown in Appendix B9. Although a 0.7 LOESS fit is shown, we did not attempt to fit a Ricker model or other standard spawner-recruit model. The spawner-recruit relationship shows no particular pattern, with most returns ranging from 1,000 to 4,000 fish, regardless of brood year escapement. However, three particularly large brood year returns (1988, 1994 and 1995) ranging from 7,809 to 13,145 spawners were all produced by escapements within a narrow range estimated at 1,454–1,986 spawners. Two other brood year escapements within that range (1,884 spawners in 1996 and 1,847 spawners in 1987) produced more normal returns of 2,615–3,917 fish, similar to the overall median and average brood year returns of 2,615 fish and 3,645 fish, respectively. Seven intermediate escapements from 2,701–3,847 spawners produced the poorest average return (2,397 fish). The 4 smallest brood year escapements (711–1,330 spawners) produced estimated returns averaging 2,717 fish while the 5 largest escapements (5,852–10,255 spawners) produced only slightly larger average returns (3,121 fish).

We do not recommend an escapement goal for this stock in light of the poorly defined spawner-recruit relationship that shows no evidence of reduced returns from lower observed escapements. Other contributing factors are the low average exploitation rate (7%; range 0–30%) and lack of correlation between run size and exploitation; and the fact that it is almost exclusively a subsistence stock, for which MSY may be a less important goal than stable harvest opportunity. It appears that smaller observed escapements of 1,500–2,000 spawners can produce large returns under favorable environmental conditions, but it is unclear to us what those conditions are. The increase in total salmon spawner biomass in the system has not increased sockeye salmon returns as it has for coho salmon. That may be in part due to the fact that most carcass biomass is deposited in the outlet where many juvenile coho salmon and steelhead rear, whereas most sockeye salmon likely rear in the lake.




Appendix B9.–Ford Arm sockeye salmon estimated spawners and returns for the 1983 and 1985−2004 brood years with a 0.7 LOESS fit.

## Sibling Forecasting

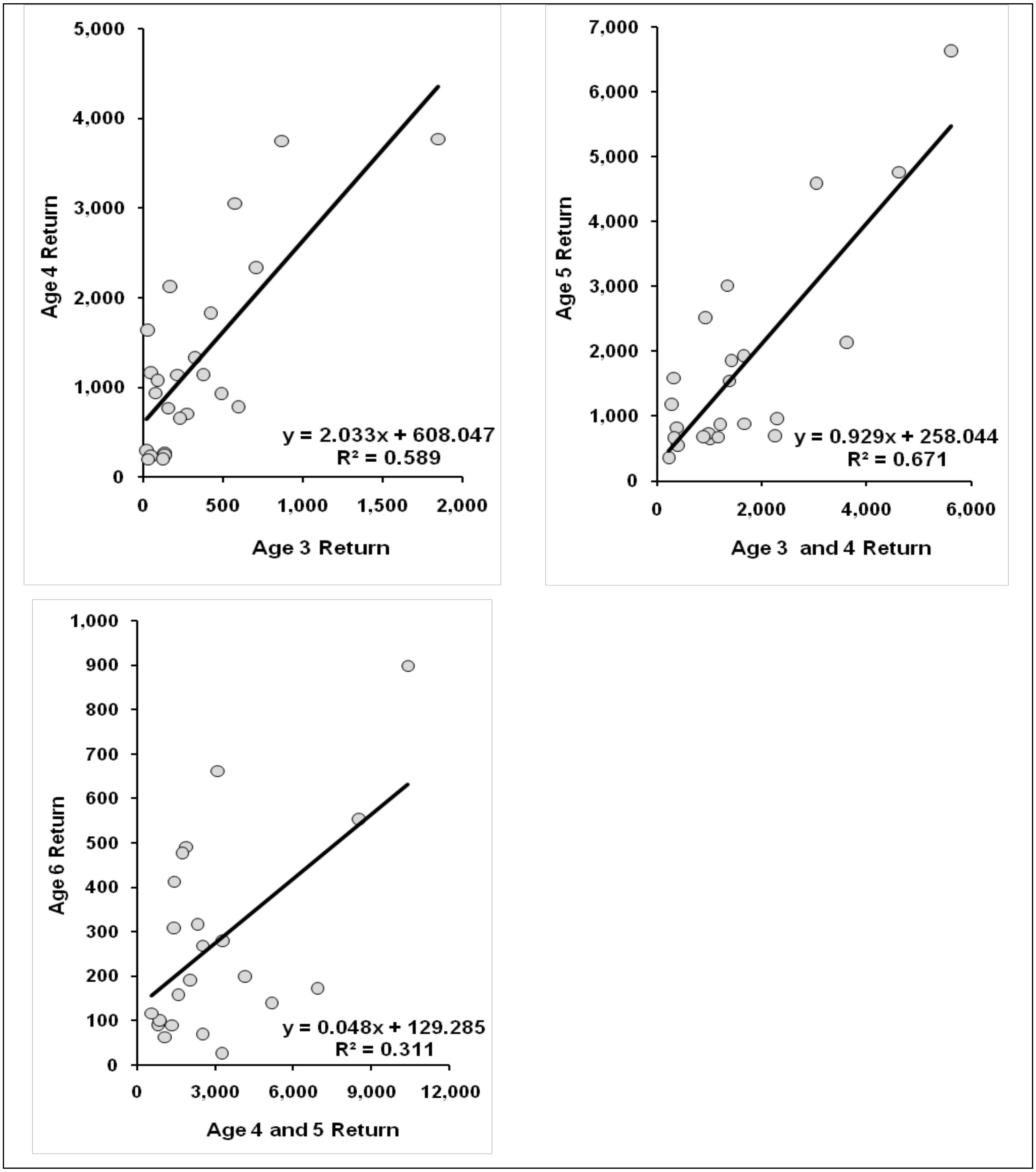
During 2000−2009, we forecasted the return of sockeye salmon to Ford Arm Lake (Appendix B10) based on linear relationships between age classes. The return at age 3 was used to forecast the age 4 return, while the combined return at ages 3 and 4 was used to forecast age 5 (Appendix B11). Finally, the return at ages 4 and 5 combined was used to forecast the return at age 6. The historical average return at age 3 (about 8%) was added to the forecast for other age classes.

Like most salmon forecasts, those for Ford Arm Lake sockeye salmon have shown substantial error (Appendix B10). However, with a mean absolute percent error (MAPE) of 34% the sibling forecast out-performed an assumed long-term average run (MAPE = 52%; Appendix B12) as well as trailing average returns from 1 to 5 years, the best of which was the prior year's estimate with a MAPE of 53%.

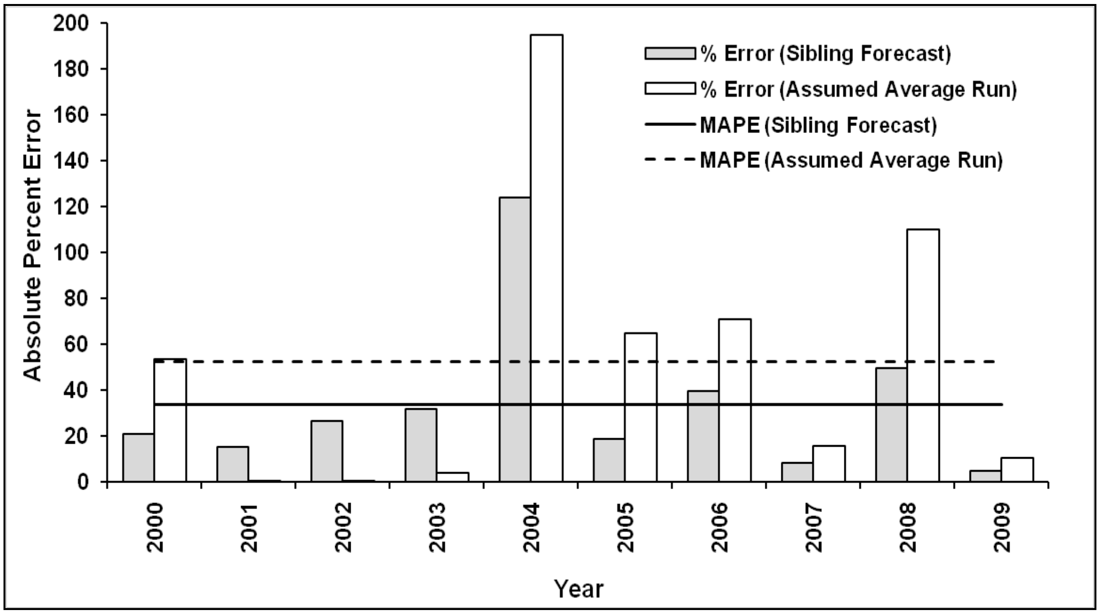
There has been substantial variability in the maturity schedule, with the estimated mean age at return ranging from 4.25 years for the 1997 brood year to 5.06 years for the 1985 brood year, and averaging 4.59 years. Mean age at return at Ford Arm Lake appears to have followed a somewhat cyclical trend with peaks in 1985 and 1991 and troughs in 1989 and 1997 (Appendix B13). Consistent positive forecast errors for the 2000−2004 returns averaging 44% (Appendixes B4 and B10) coincided with a trough in average age at return for the 1995−1999 brood years, averaging 4.40 years compared with the 1982−1994 average of 4.64 years. Ocean age by sea-entry year has been a highly variable component of overall age, with the percent returning at age 3 versus age 2 averaging 50% but ranging from 17−85% (Appendix B14). Significant improvement of precision of sibling forecasts would require indentifying and incorporating environmental variables or characteristics of early returning fish that may provide predictive power for anomalies in the maturity schedule.

Appendix B10.–Sibling forecasts of the sockeye salmon return to Ford Arm Lake compared with estimated returns, 2000−2009.

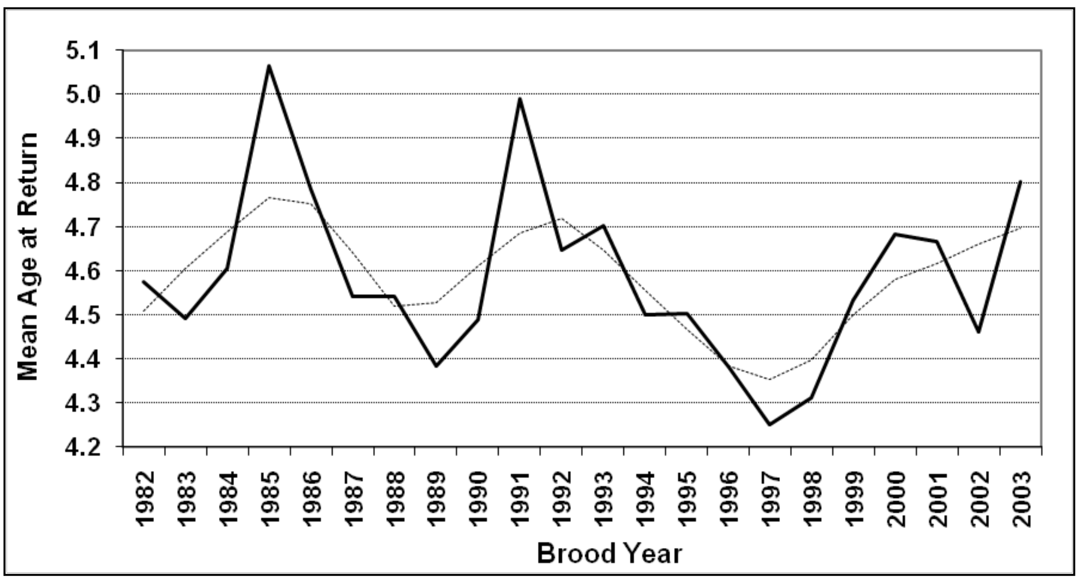
| Return | Forecast | | | | | Estimated | | | Absolute |
|---|---|---|---|---|---|---|---|---|---|
| Year | Age 3 | Age 4 | Age 5 | Age 6 | Total | Return | Error | % Error | % Error |
| 2000 | 185 | 672 | 8,132 | 336 | 9,324 | 7,721 | 1,603 | 21% | 21% |
| 2001 | 209 | 1,530 | 2,065 | 610 | 4,414 | 3,838 | 576 | 15% | 15% |
| 2002 | 217 | 1,849 | 2,527 | 288 | 4,882 | 3,857 | 1,024 | 27% | 27% |
| 2003 | 209 | 745 | 3,638 | 273 | 4,865 | 3,696 | 1,168 | 32% | 32% |
| 2004 | 185 | 920 | 1,403 | 412 | 2,920 | 1,304 | 1,616 | 124% | 124% |
| 2005 | 162 | 848 | 595 | 236 | 1,841 | 2,259 | -418 | -19% | 19% |
| 2006 | 185 | 1,298 | 1,326 | 175 | 2,985 | 2,138 | 847 | 40% | 40% |
| 2007 | 162 | 673 | 1,787 | 213 | 2,834 | 3,096 | -262 | -8% | 8% |
| 2008 | 185 | 1,594 | 455 | 302 | 2,537 | 1,698 | 839 | 49% | 49% |
| 2009 | 209 | 1,365 | 1,577 | 160 | 3,311 | 3,159 | 152 | 5% | 5% |
| Average | 191 | 1,149 | 2,351 | 301 | 3,991 | 3,277 | 715 | 28% | 34% |



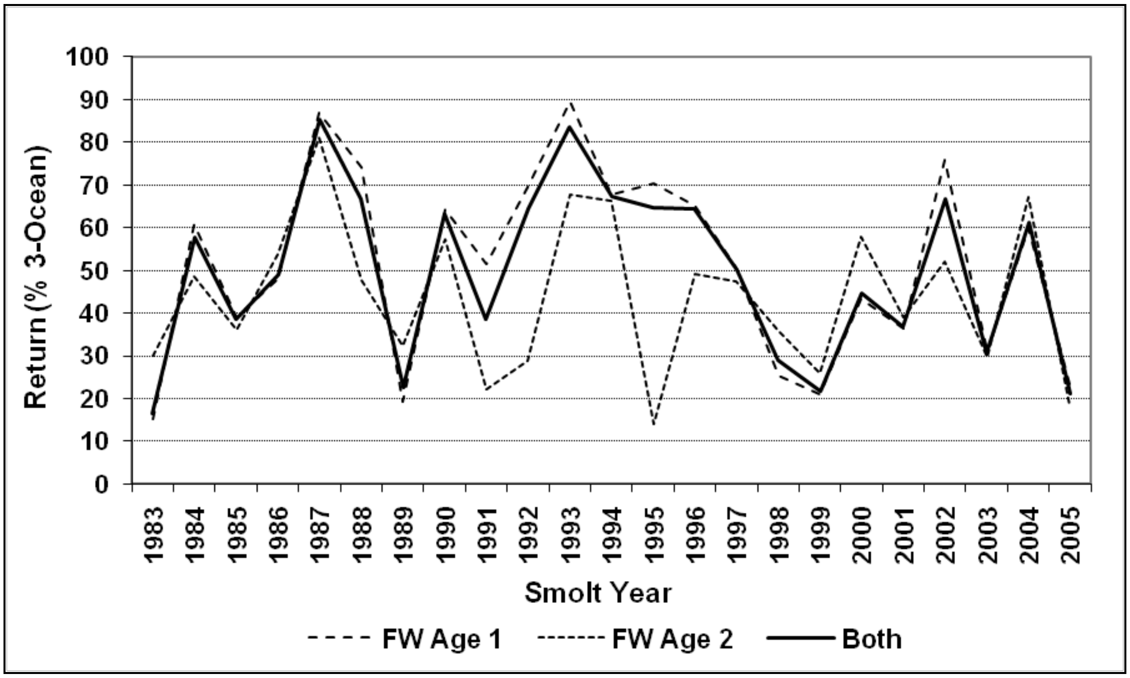

Appendix B11.–Linear relationships among sibling group age classes available to forecast the 2010 sockeye salmon return to Ford Arm Lake.




Appendix B12.–Sibling forecasts of the sockeye salmon return to Ford Arm Lake compared with estimated returns, 2000−2009.




Appendix B13.–Mean age of sockeye salmon returning to Ford Arm Lake by brood year (solid line) and a 0.33 LOESS fit (dotted line).




Appendix B14.–Estimated percent age 3-ocean of combined 2-ocean and 3-ocean sockeye salmon returns to Ford Arm Lake by smolt year for age 1 and 2 smolts.

# APPENDIX C:
# PINK SALMON, CHUM SALMON, AND STEELHEAD

## Pink Salmon

Ford Arm Creek supports a substantial pink salmon population that contributes to the local commercial purse seine fishery in Khaz Bay and accounts for the majority of total marine-derived nutrient loading in the system. Most pink salmon spawn in Ford Arm Creek below the lake but some pass through the lake and spawn in the inlets. As described above, large escapements in some recent years have increased nutrient loading as well as oxygen demand in the system.

The peak survey count (aerial and foot) is likely the best single indicator of the pink salmon escapement in Ford Arm Creek. During 1960−2009, the peak count occurred on 27 August, on average, and 80% of peak counts occurred during 17 August−11 September. The lowest peak count of 4,500 pink salmon occurred in the first year of the project (1982), and average counts increased over 3-fold from 27,459 fish in 1982–1989 to 114,177 fish in the 1990s, and increased again by 6% to 121,560 fish in 2000–2009 (Appendix C1; Figure 21).

Weir counts of pink salmon also exhibited an increasing trend during the study (Figure 21). However, the weir is located in the upper portion of the spawning area for pink salmon, and weir counts comprise a variable fraction of the run, depending on spawner density, stream conditions, and possibly odd- or even-year cycle. Inconsistent migration past the weir is exacerbated by the fact that some smaller pink salmon were able to pass upstream between the weir pickets, particularly in years of smaller average spawner size. The average weir count increased sharply from 4,842 fish in 1982–1989 to 32,046 fish in the 1990s, and increased again to an average of 41,161 fish in the 2000s.

The fishing effort and mixed stock harvest in the Khaz Bay purse seine fishery were affected not only by pink salmon abundance but also by price and relative economic opportunity for the seine fleet in the local fishery relative to other fishing areas. However, the pink salmon harvest showed a strong increasing trend, from an average 128,355 fish in 1982–1989 to 217,858 fish in the 1990s and 554,611 fish in the 2000s (Appendix C1).

Ford Arm Creek is one of seven pink salmon index streams that form the Slocum Arm pink salmon management stock group (Heinl et al. 2008). In addition to Ford Arm Creek, the streams in the index include Khaz Creek, Rust Creek (Sister Lake), SE Head of Sister Lake, Slocum Arm Head, Waterfall Cove Creek, and South Ford Arm Creek. The Slocum Arm stock group is managed for an aggregate pink salmon escapement index of 160,000–520,000 spawners (combined peak aerial counts; Heinl et al. 2008). Ford Arm Creek has contributed an average 30.0% to the Slocum Arm index, which prorates to a de facto goal of 48,000–156,000 index spawners in Ford Arm Creek. Our analysis of the relationship with coho salmon production provides potential nutrient-based pink salmon escapement reference points for Ford Arm Creek of 74,000–116,000 spawners based on 90–99% of maximum coho salmon production (see Pink Salmon Reference Points).

Major pre-spawn die-offs of salmon in the outlet creek occurred in 1995, 1996, 2001, 2002, and 2005. Although extended periods of sunny weather and low precipitation have been an obvious causal factor in these die-offs, they have all occurred in years with peak pink salmon survey counts of 90,000 or more spawners (Appendix C1). Die-offs usually began in the morning, around 7:00–8:00 a.m., when the weir was first checked. One event was described in a journal entry as being reminiscent of a theater fire, with a sudden panicked rush of fish from downstream involving progressively more fish; fish impacted the weir in large numbers and pinned each other sideways against the pickets. Mass mortality usually followed, involving 100% of larger salmon species in the stream, mostly coho and chum salmon, but usually fewer than 30% of the pink salmon, which appeared more tolerant of low oxygen levels. Davidson (1933) described a similar mortality event in a stream on Etolin Island, associated with an elevated level of $CO_2$. However, whereas his observation occurred at sunset, the incidents at Ford Arm Creek occurred almost exclusively in the morning. In recent years, the crew checked the weir earlier in the morning when conditions appeared conducive to the phenomenon. When the fish began their upstream rush, the field crew pulled most or all pickets in about five sections of weir to allow fish to pass through en mass and unimpeded, while attempting to count or estimate the number of each species.

### Chum Salmon

The chum salmon run in Ford Arm Creek is relatively protracted and appears to involve two runs: a summer run that is usually at peak spawning activity at about the time when the weir is installed in the second week of August, and an early fall run that peaks in passage at the weir in late August and early September. Chum salmon peak counts (Appendix C1) were restricted to those conducted on foot because of difficulty in differentiating the chum salmon intermixed with far more abundant pink salmon during aerial surveys (Eggers and Heinl 2008). Indicators of abundance show a similar increasing pattern to pink salmon. Average peak counts of chum salmon increased progressively from 1,368 fish in 1982–1989 to 1,860 fish in the 1990s and 2,717 fish in the 2000s. Weir counts increased from an average of 219 fish in 1982–1989 to 1,271 fish in the 1990s and 1,295 fish in the 2000s. The average mixed stock harvest of chum salmon in the Khaz Bay seine fishery increased from 10,258 fish in 1982–1989 to 23,589 fish in the 1990s to 34,745 fish in the 2000s.

Major chum salmon hatchery production has been developed in Southeast Alaska that dwarfs recent wild returns of that species (Piston and Heinl 2012). Nearly all hatchery chum salmon released in recent years have been otolith marked. Sampling and examination of otoliths indicates that hatchery fish have been present in the chum salmon escapement in Ford Arm Creek. In 2008, 2 (1.1%) out of 184 chum salmon sampled were identified as hatchery strays and in 2009, 8 fish (3.0%) out of 269 fish sampled were identified as strays (Piston and Heinl 2012). Of the 8 total strays identified to hatchery, 3 were from releases from Medvejie Hatchery in Deep Inlet in Sitka Sound, while 4 were from Hidden Falls Hatchery on East Baranof Island, and 1 was from Neets Bay Hatchery (Carroll River ancestry), released at Anita Bay near Wrangell (Andy Piston, ADF&G Commercial Fishery Research Biologist, Ketchikan, personal communication). However, these are likely underestimates because none (0%) of chum salmon released at Deep Inlet in 2006 were marked—those fish would have returned in 2008 and 2009. In 2010 the proportion of hatchery strays in Ford Arm Creek was 16.6% based on recovery of 12 otolith marked fish: 9 from Deep Inlet and 3 from Hidden Falls (Steve Heinl, ADF&G Commercial Fishery Research Biologist, Ketchikan, personal communication).

### Steelhead

Ford Arm Creek hosts a spring run of steelhead. The coded-wire tagging crew has encountered abundant juveniles in minnow trap catches from certain habitats. Smaller juveniles have been commonly caught in the inlet streams, particularly Stream B, and a mix of sizes are commonly found in the stream below the lake, including many large fish of potential smolt size.

Repeated systematic spawner counts using snorkel gear have been conducted since 1997 on two reaches totaling 1.4 km, including most of the outlet stream below the lake (Harding 2012). During 1997–2009, the peak count ranged from 28 fish in 2001 to 673 fish in 2007, and averaged 251 fish (Appendix C1). Counts in the most recent 6 years (2004–2009) averaged substantially higher (384; range 194–673) compared with the prior 7 years (136; range 28–296). Most steelhead rearing occurs within or in close to the primary pink and chum salmon spawning areas, suggesting that steelhead have also benefited from the greater nutrient subsidy provided by increasing salmon escapements during the study period.

Survey results indicate that the Ford Arm Creek steelhead population had the densest and probably largest population, on average, in the 11 index streams that are routinely surveyed in Southeast Alaska (Harding 2012). The 1997–2009 average count in Ford Arm Creek (251 fish) was well above the mean-average count of 92 fish (range 29–189 fish) in the other 10 systems. The average peak steelhead density counted in Ford Arm Creek (179 fish/km) was over 8 times the mean-average count (22 fish/km) in the other index streams and nearly 5 times the average for Sitkoh Creek, a well-known steelhead stream on Chichagof Island that had both the second highest average peak count (189 fish) and the second highest average density (38 fish/km). The average peak count per kilometer in Ford Arm Creek in 1997–2009 (179 fish/km) even exceeded the in 1993–1996 average (168 fish/km; range 112–210) reported by Bain et al. (2003) for float counts on the Situk River, one of the foremost steelhead producing systems Alaska.

In 1993, an interesting phenomenon was observed by both the tagging and weir crews. The tagging crew observed steelhead in the stream in early to mid July and, on 8 July, the crew leader (Kent Crabtree) counted 27 of them near a large rock in the lake by the outlet and indicated there were likely several more. He caught and released a 91 cm (snout-fork length) specimen using sport gear in the same area on 11 July and described the fish in his journal as being “chrome bright with a slight blush on the cheeks”. Two steelhead, including one noted as being “bright”, were counted during a survey from the weir to saltwater on 11 August, and another bright steelhead was noted above the weir on 12 August. Most of these fish appeared to remain in the system all fall until after the weir was removed on 24 October. During August–October, large steelhead could be observed while boating on the lake and were frequently seen in close company with much smaller rainbow trout. Journal entries by the weir crew on 3 October and 17 October noted occasional steelhead intermixed with coho salmon in the outlet area, and a dead steelhead washed up on the weir on 25 September.

All available evidence points to these fish being summer steelhead that entered freshwater in July and remained overwinter to spawn the following spring. However, observations from the other 28 years of field work on the system provided no other evidence of an over-wintering summer run, only a healthy run of spring steelhead that enter the creek in April and May and return to the sea shortly after spawning. An exceptionally late spring steelhead run occurred in 2007, when some fish remained in the system until early July. The peak snorkel count (an all-time record of 673 fish) occurred on 2 June 2007 while 86 fish were counted during a final survey on 21 June (Harding 2009). The tagging crew observed a few relatively dark steelhead with distinctive red stripes at the lake outlet and near the weir site during 4–5 July. However, while steelhead remained in the system unusually late in 2007, there was no evidence that they remained there through the summer and fall as happened in 1993.

Appendix C1.–Measures of abundance of pink and chum salmon and steelhead trout in Ford Arm Creek based on peak survey counts, weir counts, and the harvest in the Khaz Bay purse seine fishery.

| | Pink Salmon | | | | Chum Salmon | | | Steelhead |
|---|---|---|---|---|---|---|---|---|
| Year | Peak Count[a] | Weir Count | Slocum Arm Index | Khaz Bay Seine Catch | Peak Count[a] | Weir Count | Khaz Bay Seine Catch | Peak Count[b] |
| 1982 | 4,500 | 16 | 95,500 | 110,094 | ***541*** | 70 | 1,759 | – |
| 1983 | 17,000 | 3,895 | 195,374 | 155,351 | 2,000 | 294 | 3,302 | – |
| 1984 | 19,000 | –[c] | 104,000 | 126,510 | ***4,261*** | –[c] | 26,079 | – |
| 1985 | 27,100 | 4,866 | 228,746 | 435,104 | 450 | 158 | 12,630 | – |
| 1986 | 14,330 | 197 | 72,355 | 55,239 | 400 | 96 | 14,450 | – |
| 1987 | 58,700 | 12,755 | 110,582 | 16,897 | 651 | 477 | 2,206 | – |
| 1988 | 22,742 | 625 | 42,576 | 1,250 | 1,033 | 139 | 9,041 | – |
| 1989 | 56,300 | 11,543 | 172,192 | 126,394 | 1,610 | 296 | 12,600 | – |
| 1990 | 41,246 | 4,381 | 119,172 | 11,528 | 1,475 | 508 | 1,895 | – |
| 1991 | 86,700 | 23,455 | 289,676 | 149,099 | 1,456 | 3,712 | 10,005 | – |
| 1992 | 79,973 | 6,716 | 139,028 | 202,696 | 1,140 | 367 | 70,655 | – |
| 1993 | 30,400 | 4,259 | 74,342 | 2,168 | 1,559 | 587 | 9,474 | – |
| 1994 | 73,895 | 9,091 | 447,000 | 485,433 | 3,000 | 928 | 29,732 | – |
| 1995 | 90,000 | 64,293 | 280,917 | 611,324 | 1,416 | 1,081 | 51,735 | – |
| 1996 | 158,445 | 140,241 | 307,000 | 243,283 | 1,271 | 1,346 | 13,648 | – |
| 1997 | 32,942 | 2,928 | 563,000 | 74,874 | 2,955 | 423 | 8,756 | 296 |
| 1998 | 38,173 | 5,588 | 349,019 | 158,591 | 2,631 | 1,165 | 9,959 | 103 |
| 1999 | 510,000 | 59,503 | 1,190,500 | 239,579 | 1,697 | 2,596 | 30,029 | 89 |
| 2000 | 151,000 | 33,179 | 389,955 | 708,702 | 844 | 1,347 | 103,284 | 134 |
| 2001 | 180,000 | 104,796 | 568,000 | 235,758 | 5,900 | 519 | 15,581 | 28 |
| 2002 | 97,000 | 35,806 | 381,953 | 501,588 | 1,927 | 1,178 | 47,610 | 122 |
| 2003 | 175,000 | 81,078 | 717,000 | 426,043 | 1,770 | 3,179 | 14,870 | 181 |
| 2004 | 83,000 | 39,428 | 267,000 | 619,654 | 1,560 | 1,158 | 28,897 | 379 |
| 2005 | 160,000 | 79,332 | 496,000 | 776,243 | 540 | 563 | 13,666 | 364 |
| 2006 | 80,500 | 8,923 | 287,000 | 947,953 | 4,055 | 1,813 | 60,408 | 428 |
| 2007 | 93,000 | 3,028 | 345,000 | 841,832 | 1,280 | 786 | 29,200 | 673 |
| 2008 | 83,000 | 8,966 | 299,000 | 251,760 | 8,475 | 1,889 | 27,431 | 266 |
| 2009 | 113,100 | 17,076 | 239,000 | 236,572 | 820 | 518 | 6,501 | 194 |
| Average | | | | | | | | |
| 1982–1989 | 27,459 | 4,842 | 127,666 | 128,355 | 1,368 | 219 | 10,258 | – |
| 1990–1999 | 114,177 | 32,046 | 375,965 | 217,858 | 1,860 | 1,271 | 23,589 | 163 |
| 2000–2009 | 121,560 | 41,161 | 398,991 | 554,611 | 2,717 | 1,295 | 34,745 | 277 |
| All Years | 92,037 | 28,369 | 313,246 | 312,554 | 2,026 | 1,007 | 23,764 | 251 |

[a] Peak escapement survey counts for chum salmon include foot counts only, whereas peak pink salmon counts include both aerial and foot surveys. Values shown in bold italics were interpolated by Eggers and Heinl (2008) based on peak counts in other streams in the same index area.
[b] Systematic steelhead surveys were not conducted prior to 1997. Steelhead counts are from Harding (2012).
[c] Adult weir project was not operated in 1984.

The appearance in only 1 year of a substantial overwintering summer steelhead run in the Ford Arm Creek system remains a mystery. The nearest known summer steelhead population resides in the Plotnikof Lake system in Port Banks on South Baranof Island, 126 km south of Ford Arm Creek, although there could be undocumented summer runs elsewhere along the coast. The summer of 1993 was very dry and stream levels throughout the area were low for an extended period of time. It is possible that an extended period of low water made it particularly difficult for steelhead to ascend the challenging falls at saltwater that hinders access by fish into the Plotnikof system. However, straying of such a substantial number of fish from Port Banks to Ford Arm Creek seems improbable, given the large number of other accessible streams distributed over the intervening distance. The 1993 run of summer steelhead in Ford Arm Creek remains an intriguing mystery.

# APPENDIX D:
# HABITAT RESOURCE MAPPING AND INVENTORY

## Resource Mapping and Inventory Group Trip Summary—Ford Arm watershed

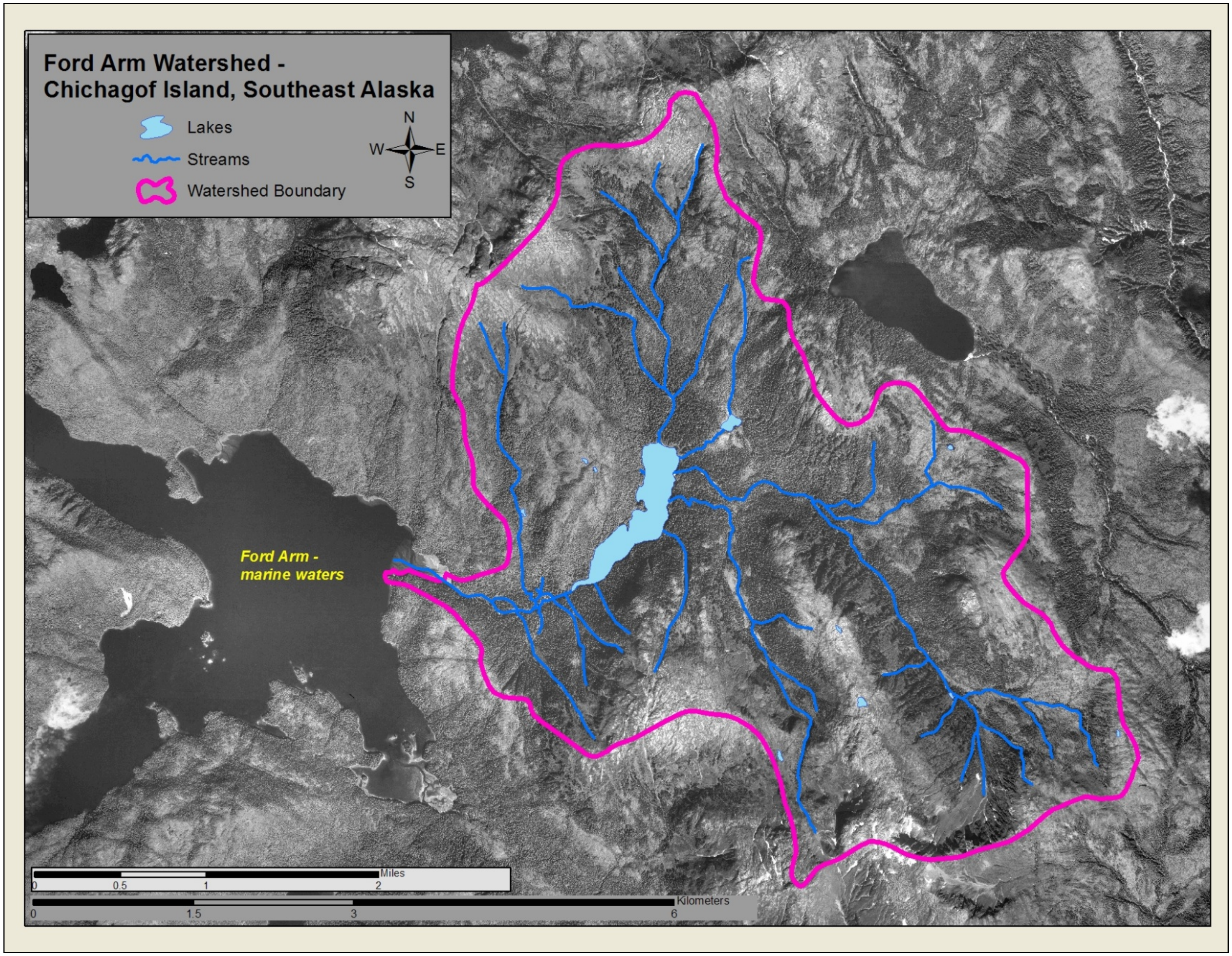
During 2001–2003, the Resource Mapping and Inventory Group (RMIG) of Alaska Department of Fish and Game, Division of Sport Fish (ADFG-SF) conducted stream habitat surveys in watersheds prioritized based on their status as 'Index Systems' by the ADFG-SF (Nichols and Williams (2012). These index systems include watersheds where steelhead or coho salmon populations are annually surveyed through standardized snorkel or foot surveys in precise stream reaches, thereby providing an annual index of abundance. Weir activities conducted on some index watersheds capture more robust stock assessment parameters, and, although these activities focused on coho salmon, additional information was also collected on other salmonids, including sockeye salmon.

The Ford Arm watershed was selected as one of the index systems to be evaluated by the RMIG in conjunction with these efforts. During 23–30 July 2003, the RMIG conducted stream habitat surveys in the Ford Arm watershed to address three primary objectives:

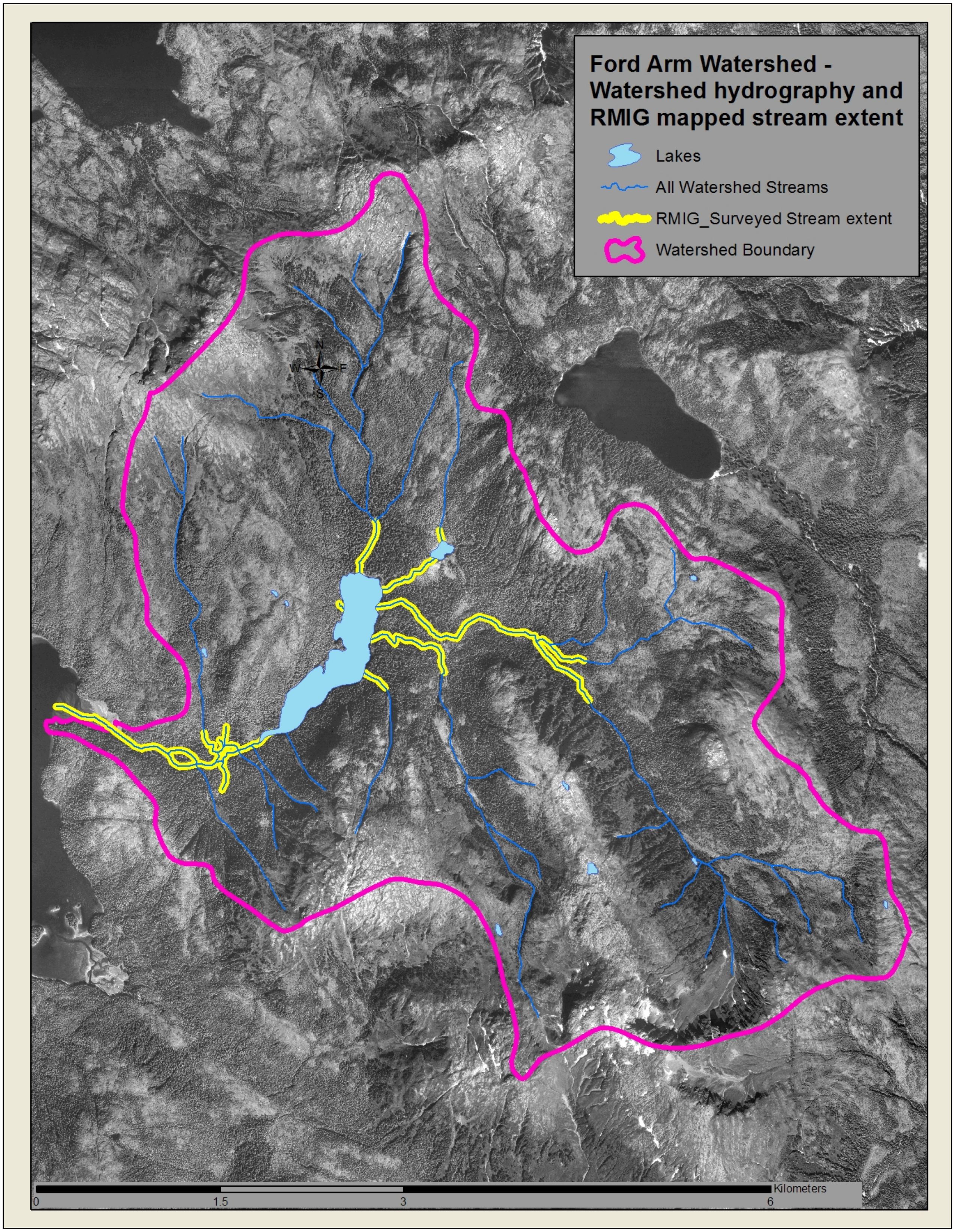
1. characterize the watered habitats of the watershed, including identifying the fluvial process groups and associated channel types of individual stream reaches, documenting riparian vegetation, and providing estimates of the amount of large woody debris (LWD) and macro pools;
2. identify and map stream features to assist in delineating accurate hydrography within the watershed and update all relevant GIS data layers; and
3. map all potential anadromous fish habitat, and document and characterize barriers to fish passage within the watershed.

The RMIG used a modified Tier II (USFS) stream habitat survey in conjunction with spatial data capture (GPS waypoints were collected at a minimum of every 30 m) to address the objectives identified above. Stream habitat surveys and associated GPS data collection was conducted in all freshwater and estuarine habitats within the Ford Arm watershed up to locations considered to be barriers to anadromous fish. This included mapping the following waterways (up to the extent considered to provide anadromous fish habitat): 1) Ford Arm Creek proper (the outlet stream of Ford Arm Lake) up to the lake outlet; 2) all side channel habitats associated with the mainstem channel of Ford Arm Creek; 3) all tributary streams exiting into Ford Arm Creek; and 4) all tributary and headwater or inlet streams exiting into Ford Arm Lake. Appendix D2 details the extent of stream habitat surveys and mapping efforts as identified above.

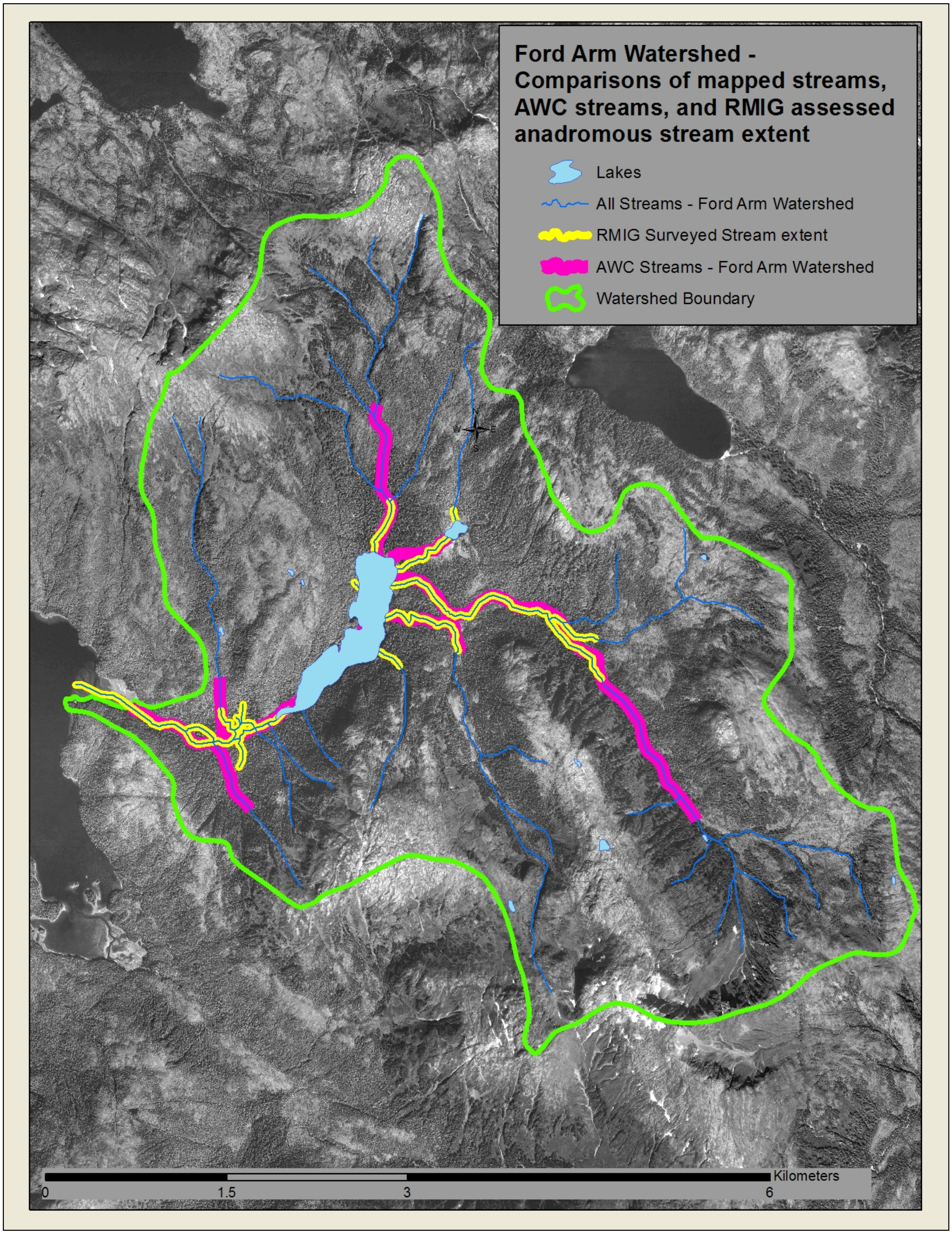
A total of 8.43 km of stream habitat was mapped during these efforts, out of a total of 40.97 km within the entire Ford Arm watershed. A minimum of 10.75 km of anadromous stream habitat exists within the watershed, based on previous Anadromous Waters Catalog designation and confirmed through fish habitat assessment surveys conducted during this trip. Appendix D3 illustrates the extent of freshwater stream and lake-habitat with respect to that identified in the Anadromous Waters Catalog, and the RMIG's assessment of the extent of potential anadromous habitat. Channel classification within the watershed is shown in Appendix D4. A suite of watershed statistics is presented in Appendixes D5–D8.



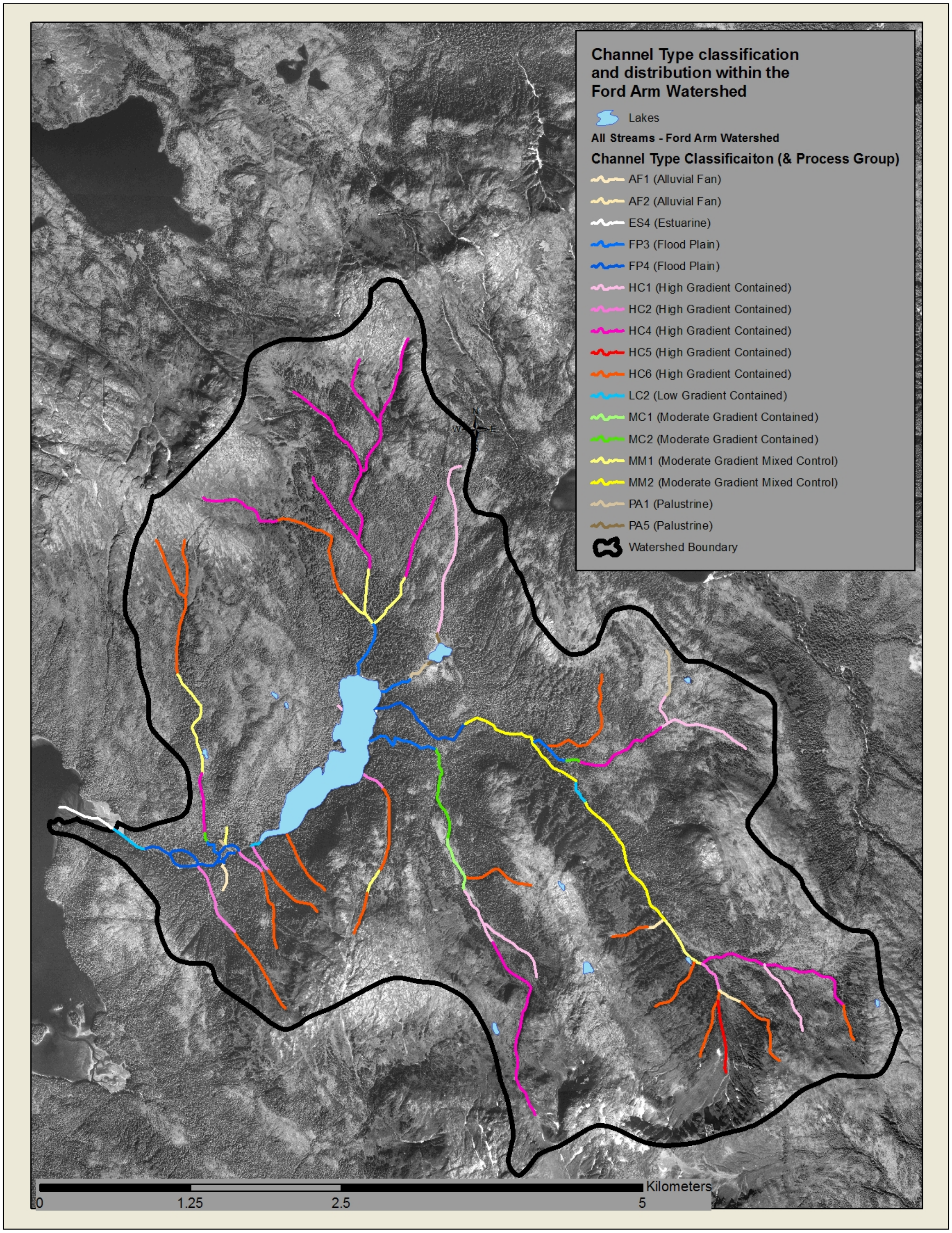

Appendix D1.–The Ford Arm Creek watershed on Chichagof Island, Southeast Alaska.




Appendix D2.–Extent of stream habitat mapping efforts by the Resource Mapping and Inventory Group (RMIG) within the Ford Arm Creek watershed, and total stream and lake hydrography.




Appendix D3.–Total freshwater stream and lake habitat within the Ford Arm Creek watershed compared to the extent of anadromous habitat designated in the Anadromous Waters Catalogue (AWC), and the extent of anadromous habitat as assessed by the Resource Mapping and Inventory Group (RMIG).




Appendix D4.–Distribution and classification of freshwater habitats within the Ford Arm Creek watershed.

Appendix D5.–Ford Arm Creek watershed land cover metrics (area).

**USGS Watershed (HUC 12):** 190102030807 Ford Arm

**Parent Watershed Name (HUC 8):** Baranof-Chichagof Island

**USGS Quads:** Sitka C-7; Sitka C-6

**Watershed Total Area (hectares):** 2,539.99

| Associated Classifications: | Hectares | Percent of Total |
|---|---|---|
| **Ecological Subsections:** | | |
| West Chichagof Complex | 2,534.66 | 99.79% |
| Ushk-Patterson Bay Granitics | 5.33 | 0.20% |
| **Land Ownership:** | | |
| Federal (USFS) | 2,534.66 | 99.79% |
| State | 5.33 | 0.20% |
| **Land Cover (by Type):** | | |
| Forested (dominated by vegetation > 5 m tall) | 1,531.15 | 60.28% |
| Shrub/Scrub (dominated by vegetation < 5 m tall) | 894.21 | 35.21% |
| Non-forested | 114.63 | 4.51% |
| Non-vegetated (exposed rock/clay/sand) | 61.60 | 2.43% |
| Ice/snow | 9.79 | 0.39% |
| Water | 43.24 | 1.70% |
| **Land Use (by Type):** | | |
| Natural state | 2,539.99 | 100.00% |
| Timber harvest | 0.00 | 0.00% |
| Urbanized | 0.00 | 0.00% |

Appendix D6.–Miscellaneous Ford Arm Creek watershed statistics.

| Watershed Statistics: | Quantity (and units) |
|---|---|
| Total length of roads in watershed | 0.00 km |
| Percent of watershed with slope < 2 % | 17.28 % |
| Percent of watershed below 500 feet (152.4m) | 23.83 % |
| Mean elevation of watershed | 256.68 m |
| Highest point in watershed | 977 m |
| Number of lakes (any size) | 11 |
| Number of lakes (< 1 acre) | 9 |
| Number of anadromous lakes (any size) | 2 |
| Total surface area of lakes (any size) | 43.24 ha |
| Total surface area of anadromous lakes (any size) | 41.12 ha |
| Total perimeter length of anadromous lakes (n=2) | 4,874 m |
| Total steam length in watershed | 40.97 km |
| Total anadromous stream length in watershed | 10.75 km |
| Total stream area in watershed | 284,272 $m^2$ |
| Total anadromous stream area in watershed | 126,980 $m^2$ |
| Total mainstem (outlet) stream area in watershed | 61,975 $m^2$ |
| Total anadromous habitat area in watershed (includes all anadromous streams and lakes) | 538,180 $m^2$ |
| Ford Arm Lake and mainstem habitat area (includes only Ford Arm Lake and mainstem outlet) | 456,083 $m^2$ |

Appendix D7.–Hydrologic (streams) network statistics (See Appendix D 4 for distribution of channel types across the Ford Arm watershed).

| Process Group[a] | Channel Type[b] | Total Stream Length (km) | Total Anadromous Stream Length (km) | % Anadromous of Total Length | Mapped Stream Length (km)[c] | LWD Density (#/km) of Mapped Streams[d] | Macro Pool Density (#/km) of Mapped Streams[e] |
|---|---|---|---|---|---|---|---|
| Alluvial Fan | AF1 | 0.25 | 0.00 | 0.0% | 0.25 | 130.36 | 4.07 |
| Alluvial Fan | AF2 | 0.37 | 0.00 | 0.0% | 0.00 | NA | NA |
| Estuarine | ES4 | 0.49 | 0.49 | 100.0% | 0.49 | NA[f] | NA[f] |
| Flood Plain | FP3 | 1.92 | 1.70 | 88.4% | 1.92 | 160.19 | 26.00 |
| Flood Plain | FP4 | 2.49 | 2.49 | 100.0% | 2.49 | 258.36 | 36.16 |
| High Gradient Contained | HC1 | 4.38 | 0.00 | 0.0% | 0.05 | 0.00 | 19.42 |
| High Gradient Contained | HC2 | 1.68 | 0.66 | 39.0% | 0.22 | 0.00 | 0.00 |
| High Gradient Contained | HC4 | 10.03 | 0.66 | 6.6% | 0.00 | NA | NA |
| High Gradient Contained | HC5 | 0.60 | 0.00 | 0.0% | 0.00 | NA | NA |
| High Gradient Contained | HC6 | 10.23 | 0.00 | 0.0% | 0.00 | NA | NA |
| Low Gradient Contained | LC2 | 0.72 | 0.72 | 100.0% | 0.72 | 28.29 | 4.47 |
| Moderate Gradient Contained | MC1 | 0.48 | 0.00 | 0.0% | 0.00 | NA | NA |
| Moderate Gradient Contained | MC2 | 0.98 | 0.30 | 30.7% | 0.42 | 245.73 | 55.41 |
| Moderate Gradient Mixed Control | MM1 | 3.01 | 0.88 | 29.2% | 0.16 | 234.26 | 0.00 |
| Moderate Gradient Mixed Control | MM2 | 2.37 | 2.37 | 100.0% | 1.15 | 156.36 | 26.06 |
| Palustrine | PA1 | 0.69 | 0.29 | 42.2% | 0.29 | 78.82 | NA[f] |
| Palustrine | PA5 | 0.13 | 0.13 | 100.0% | 0.13 | 0.00 | NA[f] |
| **TOTAL** | | **40.97** | **10.75** | **26.24%** | **8.43** | **161.55** | **19.07** |

[a] Process Groups describe the interrelationship between watershed runoff, landform relief, geology, and glacial or tidal influences on fluvial erosion and deposition processes.
[b] Channel Types define the characteristics of individual channels or reaches, thereby distinguishing between the various parts of a stream network; individual channel type classification units are further defined or qualified by physical attributes such as channel gradient, channel pattern, stream bank incision and containment, and riparian plant community composition.
[c] Mapped Stream Length is the length of stream in which stream habitat surveys were conducted by the RMIG, specific to each individual channel type designation.
[d] Large Woody Debris (LWD) Density is only computed for those stream reaches surveyed by RMIG and is computed as the total number of qualifying (* see note) pieces of wood divided by the total mapped stream length for a given channel type. * Qualifying pieces of LWD within a channel type must meet minimum length (> 1 m) and diameter (10 cm) requirements and be partially to fully contained within the Bankfull width of the channel in question.
[e] Similar to LWD Density, Macro Pool Density is computed for those stream reaches surveyed by RMIG and is computed as the total number of qualifying pools (** see note) divided by the total mapped stream length for a given channel type. ** Qualifying Macro Pools within a channel type must meet minimum depth requirements as established in a sliding scale determined by the width (Channel Bed Width approximating the 'wetted width') of the individual channel (e.g., larger or wider channels require deeper pools than smaller channels).
[f] Data for LWD density and Macro Pool density are not available for Estuarine stream reaches, due to the influence of large tidal stage differences and the effect this can have on observability of these habitat parameters. Additionally, Macro Pool density is unavailable for Palustrine stream reaches which generally include placid flow habitats that include one continuous 'pool' like habitat.

Appendix D8.–Hydrologic (streams) network–area statistics.

| Process Group | Channel Type | Total Stream Length (km) | Mapped Stream Length (km)[a] | Average Channel Bed-Width (m)[b] | Estimated Channel Area ($m^2$)[c] * denotes anadromous |
|---|---|---|---|---|---|
| Alluvial Fan | AF1 | 0.25 | 0.25 | 3.00 | 750 |
| Alluvial Fan | AF2 | 0.37 | 0.00 | 6.00 | 2,222 |
| Estuarine | ES4 | 0.49 | 0.49 | 33.00 | 16,170 * |
| Flood Plain | FP3 | 1.92 | 1.92 | 6.80 | 13,060 * |
| Flood Plain | FP4 | 2.49 | 2.49 | 15.50 | 38,600 * |
| High Gradient Contained | HC1 | 4.38 | 0.05 | 3.50 | 15,330 |
| High Gradient Contained | HC2 | 1.68 | 0.22 | 5.00 | 8,400 * |
| High Gradient Contained | HC4 | 10.03 | 0.00 | 5.40 | 54,160 * |
| High Gradient Contained | HC5 | 0.60 | 0.00 | 4.00 | 2,400 |
| High Gradient Contained | HC6 | 10.23 | 0.00 | 6.00 | 61,380 |
| Low Gradient Contained | LC2 | 0.72 | 0.72 | 19.50 | 14,040 * |
| Moderate Gradient Contained | MC1 | 0.48 | 0.00 | 6.00 | 2,880 |
| Moderate Gradient Contained | MC2 | 0.98 | 0.42 | 8.63 | 8,460 * |
| Moderate Gradient Mixed Control | MM1 | 3.01 | 0.16 | 3.75 | 11,290 * |
| Moderate Gradient Mixed Control | MM2 | 2.37 | 1.15 | 13.35 | 31,640 * |
| Palustrine | PA1 | 0.69 | 0.29 | 3.18 | 2,190 * |
| Palustrine | PA5 | 0.13 | 0.13 | 10.00 | 1,300 * |
| **TOTALS** | | | | | |
| All stream | | 40.97 | 8.43 | 8.98 | 284,272 |
| Anadromous streams only | | 10.75 | 8.43 | 11.28 | 126,980 |
| Mainstem streams below lake only) | | 2.690 | 2.690 | 25.50 | 61,975 |
| All anadromous habitat (lakes and streams) | | 2.690 | 2.690 | 25.50 | 538,180 |
| Ford Arm Lake and mainstem outlet only | | – | – | – | 456,083 |

[a] Mapped Stream Length is the length of stream in which stream habitat surveys were conducted by the RMIG, specific to each individual channel type designation.

[b] Average Channel Bed-Width is the calculation of the amount of area covered by water in individual channels. For all ‘Mapped Streams’ (see footnote a above), the Channel Bed-Width at three locations within the stream reach (channel type) was measured; the mean was then used to calculate Average Channel Bed-Width. For stream channels that were not surveyed by the RMIG, the field measures of Channel Bed-Width were unavailable; in these instances, the average bankfull channel width as published by the USFS (Channel Type User Guide; USFS, 1992) for individual channel types was used for calculations.

[c] Estimated Channel Area ($m^2$) is the product of Total Stream Length and Average Channel Bed-Width (as described individually above for Mapped and un-mapped stream reach channels).