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# Salmon Escapement Estimation in Alaska

by

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## ABSTRACT

Escapement estimation in Alaska is very decentralized. The Alaska Department of Fish and Game's local biologists use their own judgment to select escapement estimation methods that seem most appropriate to the local situation. Across Alaska the local biologists have varied resources available to them for this purpose. To date, there is no standardized database of escapement estimates for all of Alaska, and no formal standardization of methods. The methods fall into five categories that are generally thought to go from the least reliable to the most reliable in terms of accuracy and precision: (1) aerial and stream-walk surveys, (2) mark-recapture methods, (3) fixed-station hydroacoustic surveys, (4) counting towers, and (5) weir counts. General principles and rules that have guided most biologists are discussed, as is recent work on understanding the bias and variation found in Alaska's estimates. Major escapement projects in Alaska are indicated.

## INTRODUCTION

In principle, Alaska's salmon managers control fishing effort in response to observed attributes of escapement to achieve fixed escapement goals (Royce 1989). Still, escapement cannot be estimated for all streams and rivers in the state. The Alaska Department of Fish and Game (1994) has cataloged more than 15,000 streams that can support Pacific salmon spawning. This figure represents an unknown fraction of all such streams in Alaska; the current estimate may represent something like only 50% of the actual number. Salmon spawning takes place from spring to winter, when observations become impossible due to weather. Even with current technology and resources, escapement cannot be measured accurately for most runs. Alternatives to escapement-based management, such as management based on perceived abundance or fixed fishing effort, are used as less-preferred methods when necessary. Practical limitations on managers make the actual practice of escapement-based management imperfectly achieved. Even so, escapement information, in some form, provides the main support for most of Alaska's salmon management decisions.

In Alaska, escapement is estimated by methods that fall into five categories. They are listed in an order that generally goes from the least reliable to the more reliable: (1) aerial surveys and stream-walk surveys, (2) mark-recapture methods, (3) fixed-station hydroacoustic surveys, (4) counting towers, and (5) weir counts. Aerial-escapement methods are the most common. The quality of an escapement-estimate series varies from "useful as an absolute estimate of escapement" to "useful as an index of escapement," all the way to "unusable for most needs as a time series of escapement."

There is little information available to categorize an escapement series into one of these subjective categories. Indeed there has been very little centerization of any escapement data. Fried (1994) calaloged escapement goals and methods for monitoring escapement for Prince William Sound, Cook Inlet, and Bristol Bay, but behond that most data is held and controled by local managers.

Generally, a series is useful as an absolute estimate if the series is fairly long, has a consistently low bias, and was collected with the same methods and same type of data-collection instruments over the whole series. The Bristol Bay (Figure 1) sockeye escapement series nearly meets these criteria. A series is usable as an index (or useful in rank order) if it has an unknown but possibly large, yet fairly consistent bias. The pre-oil spill Prince William Sound (Figure 1) pink salmon escapement series probably meets this criterion. A series is unusable as an historical time series, if it has a fluctuating and unmeasured bias. Many of the aerial-escapement estimates, especially those based on peak abundance, and those with multiple changes to the observers, meet this criterion.

# OVERVIEW OF METHODS

## *Aerial and Stream-Walk Estimates*

Alaska's salmon managers have a tradition of flying over spawning streams in small, low-speed aircraft to subjectively ensure a fishery is allowing well-distributed and adequate escapement. Generally, managers visually estimate how many fish have escaped into freshwater spawning areas during each survey flight. These observations are recorded, at least for a sample of the larger streams.

Often the peak aerial observations, or similar statistics, are used as an index of the escapement to follow trends across seasons. These estimates are known to be low and are only expected to be roughly proportional to escapement. The term *indexed escapement* is used in many Alaskan management reports to distinguish these estimates from those that are expected to estimate escapement with little bias. In some cases, only a single flight is used to estimate the peak number of spawners present by flying as close as possible to the expected mid-point of the run.

Aerial observations are the main escapement indicator for pink salmon in major pink salmon-producing areas of Alaska. Because of their relative low cost, aerial observations are used when the resources are not available for more accurate and precise estimates.

When an aerial survey is repeated over the course of a season, a series of observations will generally show the number of fish in the escapement rising early in the season, peaking near midseason, and descending to zero at the end of the season. On any given day an observer will see some new fish, as well as a number of fish that were present at the time of the previous observation. Generally, a number of fish that were present at the time of the previous observation will have died. Finally, the observer will misjudge the actual number of fish present by some, possibly large, amount.

The series of aerial observations available over the course of a season can be converted into an estimate of escapement by considering the statistical aspects of the problem. The process that generates the aerial observations is a *birth-and-death process* (Hillier and Liberman 1980) with observational error. The basic structure and methods for the problem are the same for stream-walk surveys as they are for aerial surveys. Only the observational error's level is likely to change. The *birth* part of the random process generates the additional fish that escape the fishery and are added to the escapement pool by migration each day. An unknown *stream life* controls the *death* portion of the random process, which involves the removals from the escapement pool. An observer estimates the number of fish in the escapement pool at various intervals with a large and random *observational error*. The number of fish alive each day is defined as the number of *fish-days*.

The total number of fish-days over the entire year is estimated by a method informally called *connecting the dots*. With fish-days plotted against survey date, the analyst interpolates between observations and integrates across date to accumulate an estimate of the total fish-days for the season. When a survey is terminated before the number of fish present drops to near zero, a zero point must be arbitrarily assigned to some date late in the season.

To go from total fish-days to total escapement with the *connect-the-dots* method, the analyst needs an independent estimate of stream life. This quantity is often assumed to be constant and is not reestimated each year. The estimated total fish-days is converted to the estimated escapement by adjusting for stream life: the estimated escapement is the estimated fish-days divided by the estimated average number of days a fish remains alive in the escapement.

References to the methods include Purtle (1977) and Johnson and Barrett (1988). A more complete discussion of the problem is found in English et al. (1992). Important work on errors and shortcomings of the aerial and stream-walk methods include Dangel and Jones (1987), Sharr et al. (1990), and Jones (1995). Table 1 lists the approximate number of aerial or stream-walk projects, by location in the state.

### *Hydroacoustics*

Escapement is measured with hydroacoustics in systems that are large, turbid, or are otherwise unsuitable for aerial-escapement estimation. Mesiar et al. (1990) described techniques for estimating fish migration in large rivers and listed the Alske, Copper, Kenai, Kuskokwim, Noatak, Nushagak, Stikine, Susitna, Taku, and Yukon Rivers in Alaska as rivers that are good candidates for hydroacoustic surveys because they have large salmon runs and are wide or have braided channels full of silt-laden water.

Beginning in 1961 the Alaska Department of Fish and Game began investigations into fixed-station hydroacoustics to estimate escapement in glacially turbid systems. By 1967 managers believed they had a reliable tool for enumerating migrating salmon using a system produced by the Bendix Corporation (Davis 1968), specifically designed for escapement estimation in Alaska. There are now three models of these Bendix counters in use: the 1978 model, a 1981 model, and a 1984 model. These counters use side-scanning sonar operating at 515 kHz. The pulse width is 100 μs. These Bendix machines have been tested at 20 different sites in Alaska. King and Tarbox (1989) describe the use of these counters to estimate escapement in Upper Cook Inlet, Alaska. The operation, design, history, and evaluation of the equipment is described in Gaudet (1990).

Currently, the Alaska Department of Fish and Game operates hydoaccoustic projects in 14 different systems, with more than one hydroacoustic sites in some systems (Table 2). The original Bendix equipment is used at ten of these sites, with newer equipment in use at four other sites (e.g., Miller 1994). The United States Fish and Wildlife Service operates other sonar sites in Alaska (e.g., Daum and Osborne 1995), and has contracted for sonar estimates of salmon escapement in various areas.

Many of these projects are still undergoing development. Some series have undergone several shifts in level (of what is being measured), as methods and equipment have changed over the life of the project.

### *Counting Towers*

Counting towers have been used on medium-size, clear rivers to estimate sockeye salmon escapement since before Alaska took over management of its fisheries (Rietze 1957). Observers are placed on elevated towers or other structures, such as bridges, with a view of the stream bottom. A light-colored background is placed on the stream bottom for contrast. The observers count the number of fish passing over the light background for a portion of each hour. The counts are then expanded by the inverse of that proportion (Seibel 1967). This method still provides a low-cost, reliable, and accurate means of estimating salmon escapement in some important systems, notably Bristol Bay (Weiland et al. 1994). See Table 3 for a list of counting-tower projects currently operation in Alaska.

### *Mark-recapture*

The idea of marking a sample of a wildlife population and then sampling to observe the ratio of marked to unmarked animals to estimate the total population size is one of the most basic ideas in quantitative fisheries and wildlife biology. In its simplest form, this kind of study is called a Petersen estimate or Lincoln index (Seber 1982). Seber and other authors discuss many variations on this theme, including time-structured sampling events and multiple marks.

Mark-recapture studies have been used in a number of situations for estimating salmon escapement in Alaska. In some cases these methods have been used in conjunction with hydroacoustics (Eggers et al. 1995). Often adult salmon are captured by electrofishing and then marked with visible, external tags. Tags are recovered through a creel survey or census of spawned-out carcasses. Estimates are generated with Chapman's modified Petersen estimator (Seber 1982) or Darroch's estimator (1961). Skaugstad (1992) and Evenson (1992) provide worked examples of this kind of escapement estimation in Alaska. In other cases, radiotags are used to mark the fish to allow study of the fish movement and distribution. Johnson et al. (1993) provides a worked example of this kind of mark-recapture study. Escapement estimates are routinely generated with mark-recapture methods in Southeast Alaska for Mainstem Taku River (calculated with mark-recapture and weir data), and Speel Lake. In the Yukon River drainage, projects are ongoing in the Tanana on Fall chum salmon, and on chinook salmon in the Chena and Sulch Rivers. Tags are placed on Fall chum and chinook salmon on the Alaskan side of the border for studies conducted in Canada, and new studies are being initiated in the Upper Tanana River on Fall chum salmon.

Mark-recapture studies are generally thought to be relatively precise. Bias in these studies can be measured, studied, and controlled. These studies are generally very expensive, as they involve very labor-intensive marking and escapement monitoring in remote areas that require expensive transportation to access. Most of the escapement studies in Alaska using these methods involve chinook populations.

### *Weir Estimates*

In many small systems a weir or fence is constructed with removable pickets. A technician will pull a few of the pickets and count fish moving upstream one at a time at regular intervals or when a noticeable buildup of fish occurs. In principle, this method should produce the most accurate estimates, with precision not even an issue. However, in some cases fish enter the system by finding alternate ways in, or high water flow washes the weir out or renders it ineffective. When these problems are known, marks can be applied to the fish at the weir site and a measurement of the mark ratio can be obtained at the spawning grounds. The inverse of the mark ratio is then used to expand the incomplete weir counts to an estimate of total escapement. Table 4 lists principal weir sites in Alaska.

## The Lessons About Aerial-Escapement Estimates From the *Exxon Valdez* Oil Spill

Aerial-escapement data collected on pink salmon in Prince William Sound is considered to be among the very best pink escapement series in Alaska. Many of the rivers and streams in Prince William Sound are short and visible from the air. Much of the spawning, particularly in the western Sound, occurs in intertidal areas visible to aerial observers. Throughout the series, there have been relatively few observers that have intentionally trained and calibrated new observers to estimate fish at the same level. The Prince William Sound pink salmon stocks are a very significant fraction of Alaska's salmon resource — harvests from Prince William Sound can make up in excess of one-quarter of the Alaska's total pink salmon harvest.

Following the *Exxon Valdez* oil spill, anticipated litigation over damage to the salmon resource created a strong need to either defend or attack the historical estimates, depending on whose side in the litigation one supported. Considerable resources were devoted to studying historical biases and improving the estimates of escapement in Prince William Sound for upcoming court actions. As part of this effort, weirs were used to conduct stream-life studies and to directly observe the bias associated with individual observers and the bias associated with habitat type. See Sharr et al. (1990) for the most current summary of this research.

The major findings of these studies were that (1) previous estimates considerably underestimated the actual escapement, (2) there is considerable interobserver variation in observational error, (3) there is a strong odd-year/even-year component to observer bias that is driven by the changing relative proportion of intertidal spawning, and (4) interannual and within-year spatial variation in stream life are important elements of the escapement process. Figure 2 shows the previous escapement estimates together with revised estimates that are believed to be much improved. The newer series was derived by stratifying Prince William Sound by spawning habitat type and adjusting for habitat-associated observer bias. The newer series also had the advantage of improved estimates of average stream life. New information on historical average stream life was unavailable. The lack of year-specific stream life is probably the most important unexamined source of error remaining in the series.

## CONCLUSIONS

Obviously, knowing the limitations of any data are essential before using them in an analysis. In the case of this escapement data, a series useful as an index of abundance may lead to misleading ratio estimates, such as estimates of harvest rates. Yet, this same series might be very useful for forecasting. Aerial-survey estimates may be inaccurate and imprecise, but the act of observing fish presence or absence in stream mouths, observing fleet deployment, and observing streamflow conditions might be extremely useful to local managers when making inseason management decisions.

Aerial-survey estimates are the most common escapement estimates in Alaska, but they can be expected to have a strong downward bias (Dangel and Jones 1987, Sharr et al. 1990, Jones 1995), a bias that is correlated with run size (Jones 1995), and a large fluctuations in bias if multiple observers are used throughout the series (Sharr et al. 1990, Jones 1995). Aerial surveys that are not based on observations over the entire season should also be considered a questionable time series of abundance because of variation in stream life and run timing. Naturally, a series with a fluctuating bias may be unusable even when transformed to rank order. That is, the largest estimate in the escapement series might have arisen in a year when escapement was much lower than the year with the smallest estimated escapement in the series.

Escapement estimation is very decentralized in Alaska. There is no statewide estimation program using standard methods. Moreover, the resources available to the individual biologists for this purpose vary from none to what can only be described as considerable — as in the case, for example, of Prince William Sound immediately following the *Exxon Valdez* oil spill. A quantitative analysis of the quality of the escapement data is beyond the scope of this review. Individual biologists are free to estimate escapement in their area using whatever means they feel is appropriate, subject to very limited oversight. Currently, there is no database or single, compiled collection of these estimates for all of Alaska, although this has been identified as an important task within the Alaska Department of Fish and Game.

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Table 1. Approximate number of streams included in aerial or stream-walk escapement surveys by Alaska Department of Fish and Game, by Region (Figure 1) and location.

| Region | Location in the State | Species of Interest | Number of Different Streams or Tributaries | Reference |
|---|---|---|---|---|
| A-Y-K | Yukon River | Chum | 21 | |
| | Yukon River | Coho | 8 | |
| | Yukon River | Chinook | 17 | |
| | Kuskokwim | Chum, Chinook | 15 | |
| | Kuskokwim | Sockeye | 2 | |
| | Kotzebue | Chum | 10 | |
| | Norton Sound | Chum | 11 | |
| Central | Bristol Bay | Chum, Sockeye | 27 | |
| | Lower Cook Inlet | Sockeye | 12 | Bucher and |
| | Lower Cook Inlet | Pink | 28 | Hammarstrom (1995) |
| | Copper River | Sockeye, Coho | 38 | Donaldson et al. |
| | Copper River | Chinook | 9 | (1993) |
| | Berring River | Sockeye, Coho | 12 | Donaldson et al. |
| | Prince William Sound | Pink, Chum, Sockeye | 209 | (1993) |
| Southeast | | Pink, Chum | 830 | |
| | | Sockeye | 43 | |
| | | Coho | 50 | |
| | | Chinook | 26 | |

Table 1. (Continued)

| Region | Location in the State | Species of Interest | Number of Different Streams or Tributaries | Reference |
|---|---|---|---|---|
| Westward | Afognak District | Sockeye, Pink, Coho | 37 | Brennan (1995) |
| | Northwest Kodiak | Sockeye, Pink, Coho, Chum | 40 | Brennan (1995) |
| | Southwest Kodiak | Sockeye, Pink, Coho, Chum | 6 | Brennan (1995) |
| | Alitak District | Sockeye, Pink, Coho, Chum | 21 | Brennan (1995 |
| | Eastside Kodiak | Sockeye, Pink, Coho, Chum | 63 | Brennan (1995) |
| | Northeast Kodiak | Chum, Pink, Coho | 30 | Brennan (1995) |
| | Kodiak Mainland | Sockeye, Pink, Coho, Chum | 41 | Brennan (1995) |
| | Northern Alaska Peninsula | Sockeye, Chum | 71 | |
| | Northern Alaska Peninsula | Chinook | 10 | |
| | Southern Alaska Peninsula | Pink, Chum | 160 | |

Table 2. Systems with fixed-station hydroacoustic sites for escapement estimation in Alaska.

| Site | Location in the state | Species of Interest | First Year of Operation | Manufacture |
|---|---|---|---|---|
| Miles Lake | Prince William Sound | Sockeye and Chinook(undifferentiated) | 1978 | Bendix |
| Kenai River | Cook Inlet | Chinook | 1985 | HTI |
| Kenai River | Cook Inlet | Sockeye | 1968 | Bendix |
| Kasilof River | Cook Inlet | Sockeye | 1968 | Bendix |
| Yentina River | Cook Inlet | Sockeye | 1978 | Bendix |
| Cresent River | Cook Inlet | Sockeye | 1979 | Bendix |
| Nushagak River | Bristol Bay | Sockeye, Chinook, Chum, Pink, and Coho, "other" fishes | 1979 | Bendix |
| Kuskokwim River | Arctic-Yukon-Kuskokwim | Sockeye, Chinook, Chum, Coho | 1988 | Biosonics |
| Aniak River | Arctic-Yukon-Kuskokwim | Chum | 1980 | Bendix |
| Anvik River | Arctic-Yukon-Kuskokwim | Chum | 1979 | Bendix |
| Sheenjek River | Arctic-Yukon-Kuskokwim | Chum | 1981 | Bendix |
| Noatak River | Arctic-Yukon-Kuskokwim | Chum | 1989 | Biosonics |
| Toklat River | Arctic-Yukon-Kuskokwim | Chum | 1994 | Bendix |
| Yukon River | Arctic-Yukon-Kuskokwim | Chinook, Chum, Coho | 1986 | Biosonics |
| Chandalar River[1] | Arctic-Yukon-Kuskokwim | Chum | 1990 | HTI |

[1] Operated by the U. S. Fish and Wildlife Service

Table 3. Locations of counting towers used to estimate salmon escapement in Alaska.

| Region | Location in the State | Site | Species of Interest |
|---|---|---|---|
| A-Y-K | Norton Sound | Niukouk River | Chum, Coho, Pink |
| A-Y-K | Norton Sound | Snake River[2] | Chum, Pink |
| A-Y-K | Norton Sound | Kwiniuk River. | Chum |
| A-Y-K | Norton Sound | Nome River | Chum |
| A-Y-K | Norton Sound | El Dorado River[3] | Chum |
| A-Y-K | Fairbanks | Shacha River | Chinook, Chum |
| A-Y-K | Fairbanks | Chena River | Chinook, Chum |
| A-Y-K | Yukon | Kaltag Creek[4] | Chinook, Chum |
| A-Y-K | Yukon | Nulato[5] | Chinook, Chum |
| A-Y-K | Yukon | Chena River | Chinook, Chum |
| A-Y-K | Yukon | Salcha River | Chinook, Chum |
| Central | Bristol Bay | Igushik | Sockeye |
| Central | Bristol Bay | Wood River | Sockeye |
| Central | Bristol Bay | Togiak | Sockeye |
| Central | Bristol Bay | Kvichak | Sockeye |
| Central | Bristol Bay | Egegik | Sockeye |
| Central | Bristol Bay | Ugashik | Sockeye |
| Central | Bristol Bay | Naknek | Sockeye |

[2] Operated by Kawerak Inc.
[3] Operated by the Sitnasuak Native Corporation
[4] Operated by the University of Alaska
[5] Operated by the Tanana Chief's Conference

Table 4. Locations of principal weirs used to estimate salmon escapement in Alaska.

| Region | Location in the State | Specific Stream | Species of Primary Interest |
|---|---|---|---|
| A-Y-K | Yukon | Barton Creek (Toklat) | Chum, Coho |
| | Yukon | Clear Creek[6] | Chum |
| | Yukon | East Fork of the Andreafski[7] | Chinook, Chum, Coho |
| | Yukon | Gisasa River[7] | Chinook, Chum |
| | Kuskokwim | Kogrukluk River | Sockeye, Chum |
| | Kuskokwim | Goodnews River | Sockeye, Chinook, Chum |
| Central | Prince William Sound | Cohill Lake | Sockeye |
| | Prince William Sound | Eshamy | Sockeye |
| | Lower Cook Inlet | Chenik River | Sockeye |
| | Upper Cook Inlet | Fish Creek (Bear Lake) | Sockeye |
| | Upper Cook Inlet | Campbell Creek | Coho |
| | Upper Cook Inlet | Little Susitna | Coho |
| Southeast | | Hugh Smith | Sockeye |
| | | Little Tahltan(Canadian) | Sockeye |
| | | Tatsamenie(Canadian) | Sockeye |
| | | Trapper(Canadian) | Sockeye |
| | | Auke Creek | Sockeye |
| | | Kook Lake | Sockeye |
| | | Redoubt Lake | Sockeye |

[6] Operated by the Tanana Cheifs Conference
[7] Operated by the U.S. Fish and Wildlife Service

Table 4. (Continued)

| Region | Location in the State | Specific Stream | Species of Primary Interest |
|---|---|---|---|
| Southeast (cont.) | | Chilkat Lake | Sockeye |
| | | Chilkoot Lake | Sockeye |
| | | Alsek R. (Klukshu weir, Canadian) | Sockeye |
| | | Situk | Sockeye |
| Westward | Kodiak | Dog Salmon | Sockeye |
| | Kodiak | Frazer Lake | Sockeye |
| | Kodiak | Upper Station | Sockeye |
| | Kodiak | Ayakulik | Sockeye |
| | Kodiak | Karluk | Sockeye |
| | Kodiak | Akaluara | Sockeye |
| | Kodiak | Litnik | Sockeye |
| | Kodiak | Pauls Bay | Sockeye |
| | Kodiak | Saltery | Sockeye |
| | Kodiak | Buskin | Sockeye |
| | Kodiak | Malina | Sockeye |
| | Chignik | Chignik | Sockeye |
| | Alaska Peninsula | Orzinski | Sockeye |
| | Alaska Peninsula | Thin Point | Sockeye |
| | Alaska Peninsula | Middle Lagoon | Sockeye |
| | Alaska Peninsula | Nelson River | Sockeye |
| | Alaska Peninsula | Bear River | Sockeye |
| | Alaska Peninsula | Ilnik River | Sockeye |
| | Alaska Peninsula | Sandy Rive | Sockeye |

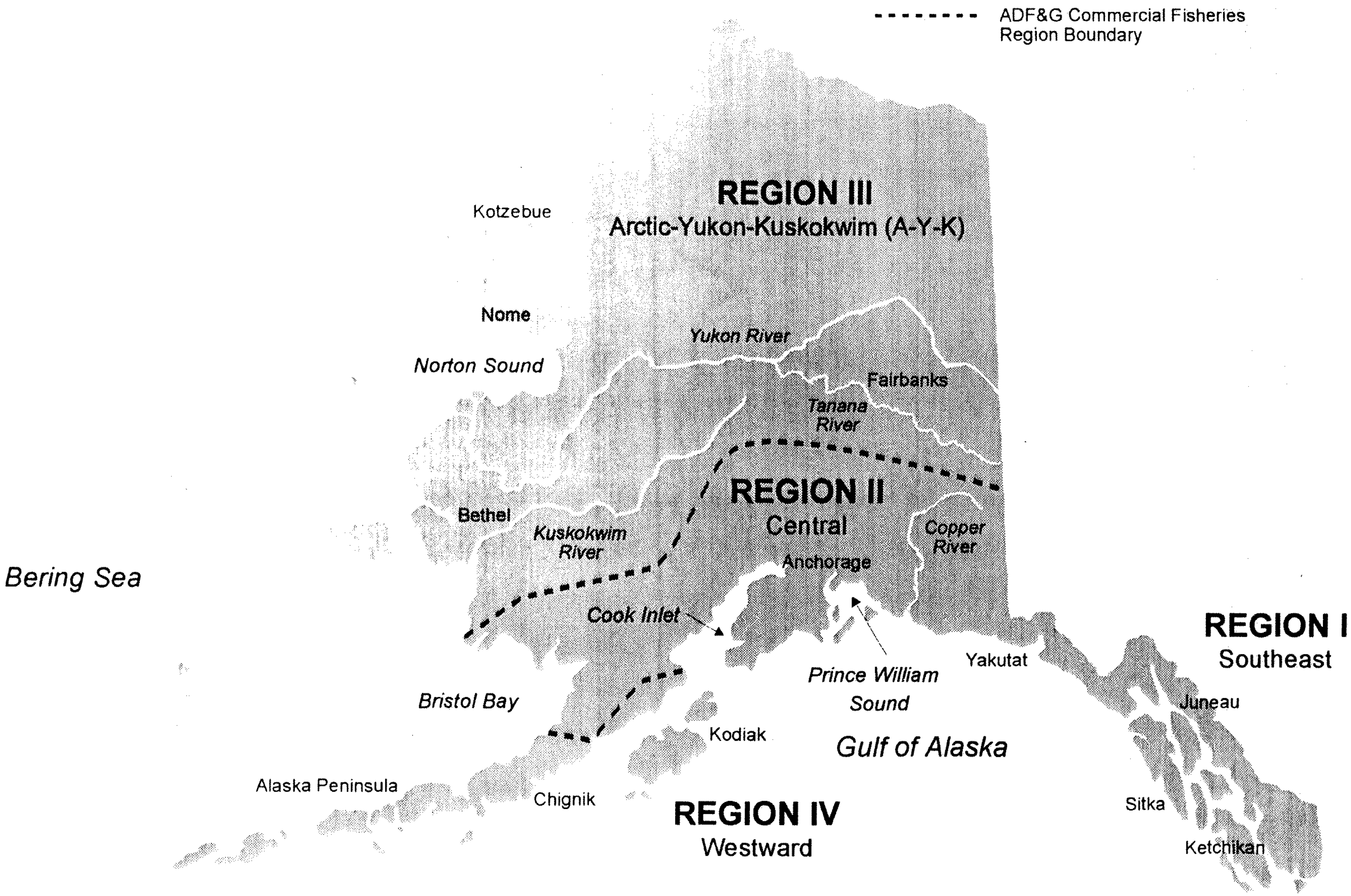


Figure 1. The four commercial fisheries management regions (Southeast, Central, A-Y-K, and Westward) of the Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division.

Figure 2. Estimated escapement series for Prince William Sound pink salmon. The solid line shows the older escapement-index series. The dashed line shows the revised series from Sharr et al. (1990). The revised series was generated using improved stream-life estimates, improved adjustments for observer bias, by habitat type, and improved accounting for streams not surveyed.