U.S. Fish and Wildlife Service
Office of Subsistence Management
Fisheries Resource Monitoring Program

Eulachon subsistence use and ecology investigations of Cook Inlet, 2000-2002

Final Report for Study 00-041

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Final Report Summary Page

Title: Eulachon subsistence use and ecology investigations

Study Number: 00-041

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Geographic Area: Cook Inlet (Region 2)

Information Type: Stock Status and Trends

Issue(s) Addressed: The Eulachon fishery in Turnagain Arm is a popular subsistence and personal use fishery as well as an important forage fish for the beluga whale, another subsistence resource. This fishery occurs within Federal Jurisdiction as well as on lands claimed by the State of Alaska. Although most harvest probably occurs from Anchorage residents, this fishery provides subsistence opportunities for the communities of Hope, Whittier, Moose Pass, and others.

Overall, very little is understood about the ecology or subsistence use of eulachon in Turnagain Arm, and there is currently no reliable method for determining population, status or trends. Some users believe that eulachon in Turnagain Arm may be declining; however, we lack conclusive evidence. If, in fact, the population is declining and harvest success is low, there could be resource allocation and/or conservation issues in the future. This project is designed to determine current subsistence use of the Turnagain Arm eulachon fishery and characterize the ecology of these fish to learn more about their status. The feasibility of using a larval index to estimate population trends will also be determined. The results of this work could help managers that regulate other eulachon fisheries in the state of Alaska.

Study Cost: $146,952

Study Duration: April 2000 to December 2002

Abstract: The subsistence use and ecology of eulachon *(Thaleichthys pacificus)* was studied at Twentymile River, a tributary of Turnagain Arm located in southcentral Alaska from 2000 to 2002. Harvest in 2002 was estimated at 14,940 kg with fishermen representing both rural (9%) and non-rural (91%) communities. A baseline larval monitoring program to index adult population strength was designed and implemented successfully on the Twentymile River. To aid managers in development of future monitoring programs on Twentymile and other rivers, we investigated the environmental factors associated with the migration of adult eulachon and downstream drift of larval eulachon. We assessed run timing, freshwater duration, length, weight, age, presence or absence of teeth, fecundity, and gear selectivity for dip and gill nets. Catch per unit effort of migrating adult fish was correlated with water temperature, tide height, river discharge, light intensity, and the density of bald eagles (*Haliaeetus leucocephalus*) Water temperature, river discharge, tide height, and light intensity were related to downstream drift of larvae. Radio telemetry was used effectively to study the migration movements of adult eulachon and to determine possible spawning areas. Clusters of the upstream limits of migration identified four common spawning areas in two consecutive years.

Key Words: eulachon, (*Thaleichthys pacificus*), life history, movement, larvae, Twentymile River, Chugach National Forest, Alaska.

Project Data: _Description_ - Data for this study consist of biological samples (otoliths), creel, life history (age, weight, sex, length, fecundity), run timing, environmental, adult movement, and larval drift density of eulachon. _Format_ – Biological samples are stored in 10% ethanol, and data stored in Excel format. _Custodian(s)_ – Robert Spangler, U.S. Forest Service, 3301 C Street Suite 300, Anchorage, AK 99503. _Availability_ – Access to biological samples and data is available upon request to the custodian.

Report Availability: Please contact either the author(s) or Alaska Resources Library and Information Services to obtain a copy of this report.

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INTRODUCTION:

The eulachon (*Thaleichthys pacificus*, Richardson 1836) is an anadromous forage fish inhabiting temperate regions of western North America. They have been reported from the Russian River, California (Odemar 1964) to the southern Bering Sea, Alaska (Hart 1973). There appear to be reductions in the abundance of spawning fish in the rivers of British Columbia, Washington, Oregon, and California. Several factors may contribute to eulachon decline or change in range including: commercial fishing and bycatch (Smith and Saalfeld 1955; Langer et al. 1977; Hay et al., 1997a; Hay et al. 1999); industrial and thermal pollution (Smith and Saalfeld 1955; Snyder 1970; Blahm and McConnell 1971; Rogers et al. 1990; Hay et al. 1997a); predation from marine mammals within estuaries (Hay et al. 1997a; Hinrichsen 1998); oceanographic shifts in climate (Anderson et al. 1997; Hay et al. 1997a); catastrophic events (Browning 1976; Hay et al. 1997a; Hinrichsen 1998); and effects from upstream forest practices such as logging and dredging (Langer et al. 1977; Hinrichsen 1998).

As long ago as 1955, there was a suggestion of a decline in eulachon that prompted a petition to the National Marine Fisheries Service to classify populations in the Columbia River and its tributaries as ‘threatened’ under the Endangered Species Act (Wright 1999). Although this petition was declined due to lack of information, concerns continue for eulachon in those areas. There have not been any quantitative studies to substantiate population trends in Alaska.

The eulachon appears to be an important species within the ecosystem. These small fish contain a high lipid content making them a valuable prey item for many other animals (Payne et al. 1999; Hay and Boutillier 1999). The spatial and temporal variations in the abundance of eulachon and other osmerids are thought to influence the breeding seasons, locations, and movements of gulls (*Larus* spp.) and bald eagles (*Haliaeetus leucocephalus*; Rogers et al 1990; Betts 1994; Hinrichsen 1998). Fish that have been reported following eulachon migrations include sturgeon (*Agonus* spp.), Pacific halibut (*Hippoglossus stenolepis*), Pacific cod (*Gadus macrocephalus*), and salmon (*Oncorhynchus* spp; Clemens and Wilby 1961; Barraclough 1964; Betts 1994). Similarly, marine mammals, such as porpoise (*Phocoena* spp.), beluga whales (*Delphinapterus leucas*), fin whales (*Balaenoptera physalus*), killer whales (*Orcinus orca*), harbor seals (*Phoca vitulina*), northern fur seals (*Callorhinus ursinus*), and Steller sea lions (*Eumetopias jubatus*), have been observed following eulachon (Clemens and Wilby 1961; Barraclough 1964; Pitcher 1980; Seaman et al. 1982; Rogers et al 1990; Olesiuk 1993; Betts 1994; Hinrichsen 1998). In Alaska, beluga whales follow eulachon in Turnagain Arm into shallow systems such as Twentymile River (Authors’ observations).

Eulachon have been and continue to be an important resource for humans as well. Historically, native tribes harvested eulachon for oil and food (Clemens and Wilby 1961; Hart 1973; Samis 1977; Langer et al. 1977; Kuhnlein et al. 1982; Betts 1994; Pedersen et al. 1995; Hay et al. 1997a; Hinrichsen 1998; Hay and Boutiller 1999). Fish and rendered oil were bartered with inland tribes forming the “grease trails” of southeast Alaska and

British Columbia (Hart 1973; Bartlett 1994; Hay et al. 1997a). Eulachon are still considered to be an important subsistence and personal use fishery in Alaska (Bartlett 1994; Betts 1994).

Most subsistence harvest of eulachon occurs in the Twentymile River or in the estuary of Turnagain Arm. Historically, harvest averaged approximately 3700 kg in the Twentymile River (Mills 1991; Howe et al. 1998.) Fishermen have not been observed on Portage Creek or the Placer River in recent years though they reportedly fished there earlier in the twentieth century. The Placer River was reported to have a run much more substantial than the Twentymile River until the 1964 earthquake that caused a subsidence of approximately 2 m. According to local fishermen, effort then switched to the Twentymile River. Prior to this study, it was not known if eulachon populations still existed in the Placer River or Portage Creek. Occasionally, USFS biologists would note dead eulachon on the banks of these systems, but because of the strong tidal action of Turnagain Arm, these carcasses could have easily been washed up from the confluence with the Twentymile River.

Radio telemetry was used to study the migratory behavior of spawning eulachon. Initially, tagging methods were developed and verified with a radio tag retention test. Upon confirming the feasibility of using radio telemetry for eulachon, we investigated the migration movements of male and female fish. This included determining migration patterns for adult fish, retention time in freshwater, upstream spawning limits, and identifying spawning concentrations. Understanding the movements and spawning habitat of eulachon will provide the necessary information for managers to make informed decisions to safeguard essential eulachon spawning habitat.

There are no consistently reported environmental factors known to influence spawning run timing of adult eulachon throughout their range. In Washington, researchers reported a relationship with temperature (Smith and Saalfield 1955), whereas in Alaska, such a relationship is not evident (Barret et al. 1984). In B.C., there are differing reports of the association between spawning run timing and water temperature. In the Fraser River, Ricker et al. (1954) reported a positive relationship between adult catch per unit effort (CPUE) and water temperature, but Langer et al. (1977) found no such evidence. Tide height has been reported to be positively related to the intensity of adult migration in B.C. (Ricker et al. 1954; Langer et al. 1977), but in the limited work conducted in Alaska, tide height was reported not to influence the intensity or timing of migration (Barrett 1984). In British Columbia the timing and intensity of adult eulachon migration has been reported to be greatest at the minimum river discharge in the Nass River, but that is not the case in the Fraser River (Langer et al. 1977). Other researchers in B.C. have found a positive relationship between the density of predators and the timing and intensity of adult eulachon migration (Swan 1881; Langer et al. 1977). Although there have been no investigations in the role of light intensity in the run timing of eulachon, it is worthy of exploration. Light intensity has been reported to influence the migration timing of sockeye salmon (*Onchorhynchus nerka*), another anadromous fish (Egorova 1970).

Ecology of larval eulachon is not well understood. Larval eulachon were first sampled using fine mesh nets in 1939 (McHugh 1940). Since that time, other researchers have investigated the use of plankton nets to investigate the ecology of larval eulachon (Smith and Saalfield 1955; Pedersen et al. 1995; Hay et al. 1997b; McCarter and Hay 2001). In the Columbia River, eulachon larvae hatch between 30 and 40 days and drift downstream to the ocean for rearing (Smith and Saalfield 1955). Limited studies indicate that most larvae are found drifting near the bottom of the water column (Smith and Saalfield 1955). The density of larval drift appears to be related to temperature and accumulated thermal units (ATU; Smith and Saalfield 1955; Langer et. al. 1977). Larval fish appear to drift in high densities during periods when water temperatures remain relatively stable, varying by less then 2.8º C on the Cowlitz (Smith and Saalfeld 1955), Fraser (Hart 1973), and Nass Rivers (Langer et al. 1977) in British Columbia. There are no similar studies investigating the ecology of larval eulachon in Alaska for comparison.

The importance of eulachon and their apparent decline has necessitated the development of population monitoring programs. However, because so little is understood about eulachon ecology, it is difficult to design effective monitoring programs This is especially true in Alaska, where there is little detailed knowledge about eulachon spawning and movement within rivers. Therefore, we investigated the migration of adult and downstream drift of larval eulachon for a small glacial river in Alaska, and compared them with the following environmental factors: water temperature, tide height, river discharge, light intensity, and bald eagle (*Haliaeetus leucocephalus)* density. The objective of this study was to determine the relationships among these variables to aid in the development of future studies. The results of the current investigation will allow managers to design studies that are more time efficient and cost effective.

OBJECTIVES:

1. Determine user demographics and estimated harvest of the eulachon fishery (2002)
2. Determine run timing and other aspects of eulachon life history (fecundity, age, etc.) in Twentymile River. (2000, 2001).
3. Determine adult migratory behavior and characterize and map upper limits of spawning and critical spawning habitat (2000, 2001)
4. Conduct larval assessment as index of relative run strength. (2000, 2001)
5. Determine presence/absence of eulachon in the Portage Creek and Placer River drainages. (2000, 2001)
6. Collect samples for larger eulachon study to determine stock composition and interception in the Pacific. (2001)

METHODS:

Study Area

Twentymile River is a tributary of Turnagain Arm adjacent to the Portage and Placer Rivers in southcentral Alaska (Figure 1). Turnagain Arm has a large tidal range (> 10 m) with tapering basin geometry and water depths that systematically decrease upriver. These characteristics produce daily bore tides on the incoming tide, which are large (> 1 m) and advance quickly (up to 6.7 m/s). Bore tides are of greater amplitude with the onset of the spring tides. Twentymile River is a glacial system with a drainage area of approximately 115 km^2 and lacks any substantial man-made developments that could affect habitat quality. This system has a high-suspended sediment load with salinity effects on the lower river basin from tidal incursions (Blanchet 1995). There are two major unnamed tributaries to the Twentymile River in the upper drainage. The tributary to the west lacks substantial influence of glaciers resulting in water of greater clarity, whereas the tributary to the east is dominated by glacial runoff and is highly turbid. For the purposes of this study, they are referred to as the “Clear Fork” and “Glacier Fork.” The Placer River (approximately 112 km^2) and Portage Creek drainages (approximately 140 km^2) have physical and chemical characteristics similar to those of Twentymile River. However, both systems have experienced human impacts from past gravel extractions, and other developments such as roads and/or the railroad.

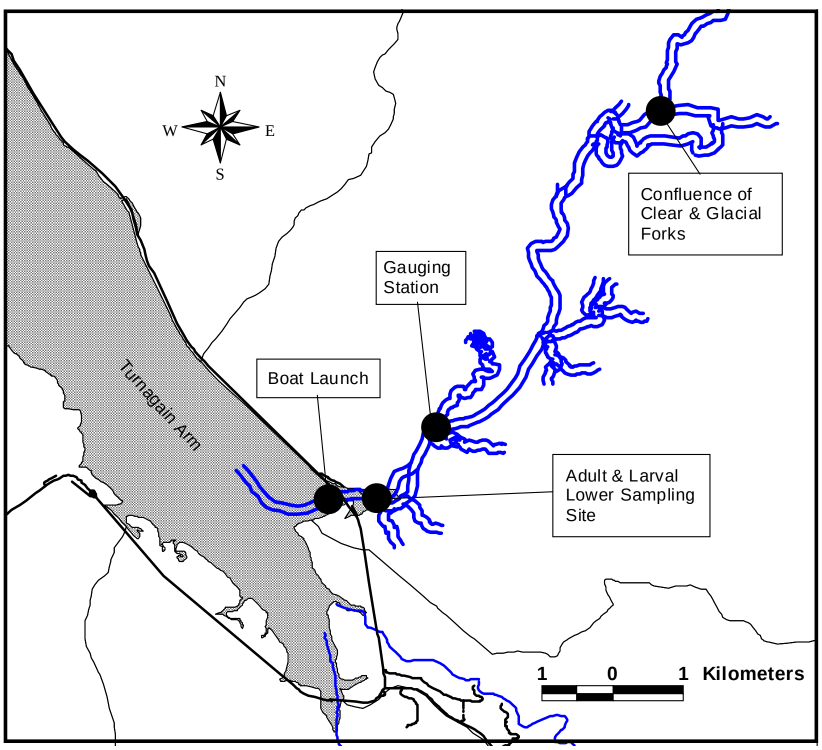

Figure 1. Study area map

Determine user demographics and estimate harvest of the eulachon fishery (2002)

A direct-access creel survey was used to estimate eulachon harvested by dipnetters at four access sites along Twenty-mile River (Figure 2). All anglers exiting the access site during the sampling period were interviewed. The following information was collected from each dip netter exiting the fishery: hours fished, number of eulachon caught, number in fishing party, number of dipnets used, and area of residency. Residency was defined as where a person resided for most of the past one year.

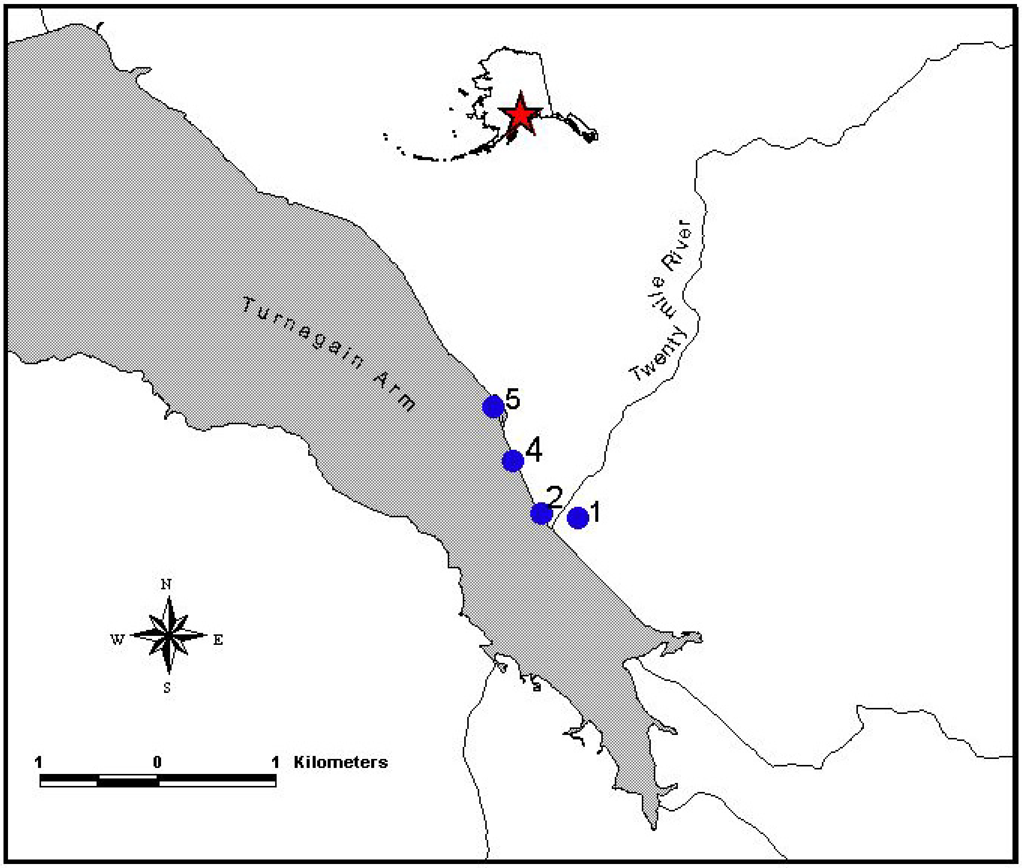

Figure 2. Location of creel sampling access sites

A stratified random sample design was used to develop the creel schedule for the survey. A total of four sites were surveyed. These sites represented where most people fished based on previous surveys. A sampling period was defined as a two hour period three hours before the high tide and were randomly chosen among access sites. Most days consisted of two sampling periods. Night tides in April were not considered fishable, as it was dark then, and were not included in the survey.

Total subsistence harvest of eulachon estimated from stratified random sampling used the following equations. First, mean harvest was estimated across all sampled periods within each access site (Cochran 1997).

$$\bar{y}_w = \frac{\sum_{i=1}^{n_w} y_{wi}}{n_w} \qquad (1)$$

i = sampling period
w = access site
y_{wi} = harvest obtained from the i^{th} sampling period at the w^{th} access site
n_w = number of sampling periods at access site w

Next the mean harvest was expanded by the total possible number of sampling periods at an access site to obtain an estimate of total harvest by access site.

$$\hat{y}_w = N_w \bar{y}_w \qquad (2)$$

N_w= total number available for sampling periods at access site w

Finally, total harvest across all sampling sites was calculated by summing the individual access site harvest estimates.

$$\hat{y}_{total} = \sum_{w=1}^{T} \hat{y}_w \qquad (3)$$

T= total number of access sites

The variance of total harvest was estimated using the following equation.

$$V(\hat{y}_{total}) = \sum_{w=1}^{T} N_w^2 \left(\frac{N_w - n_w}{N_w}\right)\left(\frac{s_w^2}{n_w}\right) \qquad (4)$$

where $s_w^2 = \sum_{i=1}^{n_w} \frac{(y_{wi} - \bar{y}_w)^2}{n_w - 1}$

Fishing effort and number in party and their variances were estimated by substituting the appropriate fishing effort/number in party statistics in place of harvest for equations 1 through 4 above.

Determine run timing and other aspects of eulachon life history (fecundity, age, et.) in Twentymile River (2000, 2001).

To determine timing and intensity of the spawning run, sampling for adult fish was conducted from 1 May to 21 June 2000 and 10 April to 22 June 2001. Sampling occurred Monday through Friday of each week. A total of 10 tides (five day and five night) were randomly selected within each two-week period. Sampling was always initiated two hours before the expected bore tide arrival time. Typically this was one hour after high tide in Anchorage. The same sampling site was used during both years.

Two persons stood approximately 20 m apart on the southeast bank of the Twentymile River. They each used a dip net and sampled concurrently. The dip nets were made of aluminum, with a handle 2.3 m long extendable to 4.1 m. The hoop was 40 cm in width and 50 cm in length. The net bag was constructed of black nylon mesh and was 70 cm in depth. Total fishing effort (both persons) was 0.5 hours in 2000 and increased to 1.5 hrs in 2001 to increase sample size. The same persons sampled throughout the season to limit bias. The dip nets were swept in the same direction as the river current just above the bottom. The nets were continuously swept through the water while avoiding hitting the bottom as this tended to scare fish. The average number of sweeps per hour varied from approximately 640 (0.6 m/s) to 750 (0.7m/s) sweeps/hour for each net depending on water velocity. Catch per unit effort was calculated as the number of fish caught per minute of sample time.

Fish Collections and Analysis

Dip net and gill nets were compared simultaneously in 2000 to test for differences in fish size and sex ratio. Gill net sampling followed the same time periods, sampling frequency, and site location as describe above for dip net sampling. Gill net sampling was conducted with monofilament net 9 meters long; 2 meters deep with a 3.2 cm mesh net size. The net was deployed from shore towards the middle of the river channel.

To test for differences in size and sex ratio, we supplemented dip net fishing with gill nets in 2000 and used both fishing gear simultaneously. Gill nets were monofilament net about ten meters long, two meters wide with a 3-cm mesh net size. The net was deployed from shore towards the middle of the river. Sex ratio and catch per unit effort were estimated by counting the total number of male and female pre-spawning fish. Only pre-spawned fish were used because at times, large numbers of post spawn fish exit the river system. The criteria used to classify spawning condition followed Alaska Department of Fish & Game (ADF&G) classifications (Barrett et al. 1984). Male spawning condition was as follows: (1) pre-spawners – testes with bright white coloration and thick milt; (2) spawners – testes with dark coloration and watery milt; and (3) post- spawners – testes essentially void of milt. Female spawning condition was further classified into the following criteria: (1) pre-spawners – eggs not expelled freely; (2) spawners – eggs expelled freely; and (3) post-spawners – ovaries essentially void of eggs. Males were visually identified by the presence of tubercles, a large mass of muscle along the lateral line, and long pelvic fins often extending to the anus. Females were smoother in appearance lacking tubercles and the large mass of muscle along the lateral line.

Life history characteristics were determined from the first 20 pre-spawn male and 20 pre-spawn females caught during each sampling episode. These fish were identified for sex by visually examining gonads. Fork length (1.0 mm), weight (0.01 g), and presence of teeth were recorded for sampled fish. Teeth presence or absence was assessed by gently rubbing a finger in the mouth of the fish. When teeth were present, they would catch on finger ridges. The ages of pre-spawn eulachon were determined by examining otoliths. A transverse cut was made above the preoperculum and both otoliths were removed with forceps. They were cleaned of saccule membrane and stored in vials with 10-15 percent ethanol. The otoliths were viewed with a stereomicroscope attached to a computer monitor. This allowed several people to view otoliths at the same time. To reduce glare otoliths were submerged in water. To improve contrast between the translucent and opaque zones otoliths were placed on a black background under a reflective light (Moffit 1999). The age of fish was assigned by counting the zones radiating out from the primordium. At least two regions on the otoliths were counted, and if the counts from the first two regions did not agree, a third was counted. If two of the three areas had the same count, this became the assigned age; otherwise, the process was repeated. Three individuals read all of the otoliths with the most common age assigned to each fish.

To determine fecundity, ovaries were removed, weighed to the nearest decigram and placed into individual marked vials containing 3.7 percent formalin in seawater. The ovaries were kept in a refrigerator and allowed to harden for two weeks. Fecundity was analyzed according to the methods of Hay et al. (1997b). The eggs were counted into three groups of 100 eggs and weighed. The three samples could not vary by more than 10 percent in weight. If they did, the process was repeated from the beginning. The weight of an egg was determined by dividing the mean weight by one hundred. Fecundity was determined by dividing the total egg sac weight by the weight of an egg.

Data Analysis

Sex ratio and teeth retention were modeled using generalized linear models (Agresti 1990; McCulloch 2001) as a binomial random variable using PROC LOGISTIC (SAS Institute, Inc. 20002) with a logit link function. Explanatory variables for sex ratio that were considered for inclusion in the model included time, length, weight, and age. Explanatory variables for teeth retention that were considered for inclusion in the model included sex and age.

Weight (male or female), length (male or female), age (male or female), and fecundity were modeled using generalized linear models (Agresti 1990; McCulloch 2001) as a gamma random variable using PROC GENMOD (SAS Institute, Inc. 20002) with a log link function. The explanatory variable for weight (male or female) and length (male or female) that was considered for inclusion in the model was age. The explanatory variable for age (male or female) that was considered for inclusion in the model was time. Explanatory variables for fecundity that were considered for inclusion in the model included length, weight, and age.

Likelihood ratio tests were used to develop the most parsimonious model possible for each response variable. Terms were eliminated in a stepwise fashion, until all remaining variables were statistically significant. A significance level of 0.05 was used to define statistical significance during model development.

Determine adult migratory behavior and characterize and map upper limits of spawning and critical spawning habitat (2000, 2001)

Radio telemetry was used to determine the upper limits of migration for adult eulachon, retention time in river, and to highlight possible spawning areas. Turbid water prevented direct observation of spawning activity or aggregations of fish.

Radio Tagging Procedure
Fish were collected using dip nets approximately one km above the mouth of Twentymile River (Figure 3). Selection of eulachon to be tagged was based on an external examination of physical characteristics and spawning condition. An assessment of body structures included gills, skin, fins, eyes and operculum. No eulachon that had obvious physical injuries or defects such as punctures or bites were included in tagging studies. Fish were selected in pre-spawning condition from visual observations.

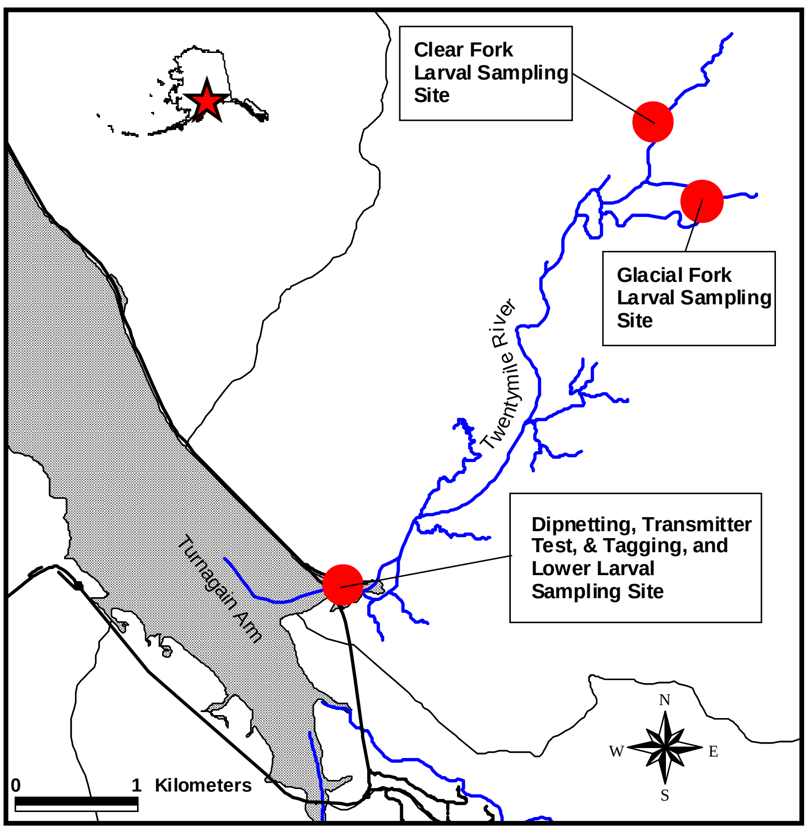

Figure 3. Radio telemetry study area

Eulachon were implanted with coded microprocessor radio tags. The radio tags (Lotek™ MCFT-3KM) weighed 1.4 g (air) and 0.8 g (water). The tags were 18.0 mm in length, 7.3 mm in cross section with an antenna length of 30.0 cm and were 2.0 mm x 4.0 mm in cross section. The radio tags had an operational life of 14 days. In 2000, frequencies included 149.600, 149.620, 149.640, 149.660, and 149.680 mHz with codes ranging from 1 through 5. In 2001, frequencies included 148.600, 148.620, 148.640, 148.660, 148.680, 148.700, 148.720, and 148.740 mHz with codes ranging from 6 through 20. They were programmed with a five second burst rate in both years.

Gastric implantation was selected over surgical implantation since the procedure is easier and most suitable for short-term studies (Martinelli et al. 1998). Additionally, this method is less invasive and faster than surgical implantation. Radio tags were inserted in the esophagus. Fish were held, dorsal side up, while the tag was inserted into the mouth. The antenna of the radio tag was threaded through a small drinking straw. The straw was guided down the throat until slight resistance was felt at the anterior portion of the stomach (Adams 1998; Martinelli et al. 1998). The straw was removed from the fish leaving the radio tag in place.

Radio tag retention test

Thirty adult fish were selected for the radio tag retention test. Fifteen had gastric implants and another 15 (control) were handled but without tag implants. Unique fin clip combinations, such as an anterior clip on the dorsal and upper caudal clip allowed for identification of individual fish. Tagged fish were kept in a small live well in the river prior to release and monitored for 30 minutes. Then they were transferred to a larger live well (~$1m^3$) subjected to ambient water temperature, current, salinity and photoperiod conditions. After three days tagged eulachon were checked for radio tag retention and condition. Large tides and changes in the accumulations of tidal mud threatened the live well and precluded a longer holding time.

Tracking procedure

The number of fish tagged was dependent and proportional to the intensity of daily run: as catch per unit effort (CPUE) increased, we tagged and released more fish.

The tracking was conducted in Twentymile River with a 4-m inflatable boat with a jet outboard engine. The spark plugs in the engine were replaced with shielded spark plugs to reduce interference with signals from radio tags in fish. A four-element Yagi® antenna was mounted on the boat and was set for full rotation for access of all locations at any time. During each sampling period, the antenna was slowly rotated from left to right bank, including any side channels.

The radio-tracking route was conducted every day from 15 May to 22 June 2000 and 19 April to 20 June 2001. The route began approximately 11 km upstream of the mouth of Twentymile River (Figure 3). The fish were tracked as the observer drifted downstream in the boat to the estuary, two km downstream of the highway bridge (Figure 3). The Clear Fork was not included in the manual-tracking route (Figure 3). Surveys were timed to miss salinity concentrations greater than 3.0 psu in the low river during high tide as the higher conductivity during this time attenuated radio tag signals making the tagged fish difficult to detect.

Tracking sessions were conducted using a Lotek™ SRX_400, W5 receiver. All frequencies were monitored with a scan setting of 6 seconds and gain, 85. Once the power reached 190 or above, the receiver was locked on that radio tag with a standard gain of 75. A positive location was identified when the power reached 230- 235 that were the maximum power ranges for the receiver. The power of the signal strength is expressed as dimensionless units ranging from 0 to 235. The highest signal (235) is roughly equivalent to 40 decibels of dynamic range (L. Egan, Lotek Engineering, Newmarket, Ontario, Canada; personal communication). This position was then recorded using a Geo Explorer 3™ Geographic Positioning System (GPS) unit. Additionally, date, time, frequency and code, salinity, and water temperature were recorded.

At times, interference or code collisions limited the ability to track radio tags. Interference was detected in the lower river from automobile traffic near the Seward Highway (Figure 3). Additionally, low-flying aircraft including helicopters and small airplanes frequently flew over the study area. During these events, there was a break in the tracking session until automobiles or aircraft moved out of the study area. Code collisions were caused when fish were in close proximity to one another and tags transmitted signals at the same time. To alleviate code collisions, the gain was incrementally reduced until the background interference was limited enough to allow scanning.

Migratory behavior

Movement patterns and retention time in the system were determined in 2000 and 2001. The daily radio tracked positions of individual fish were transferred from the GPS data logger into a software mapping program, ArcView Geographic Information System 3.1. An ArcView coverage was created for each fish to observe individual movement patterns and retention time. The mean and furthest upstream positions were summarized by male and female into one of five categories: 1) upstream and downstream movement above the initial tagging site, 2) upstream movement, followed by no movement until the life expectancy of the tag was reached, 3) limited movement adjacent to initial tagging site, 4) downstream and upstream movement, but occurring below the initial tagging site, and 5) only detected on day of initial tagging. Fish movements were categorized because in some cases it was unclear if some movement patterns were natural or due to tagging effect. Retention time in the river was calculated for categories one and four fish.

The furthest upstream migration positions for fish moving upstream and downstream above the initial tagging site (category one) were used to identify concentrated areas of spawning. A portion of river was classified as a spawning area if the upstream limits of five or more fish were located within a 700 m reach of river. The 700 m length was used because this was the maximum distance in which clusters of points were observed. Furthermore in the early season when water visibility was good, we visually observed a school of fish along a 700 m length of stream that were assumed to be one spawning aggregation of fish. A centrum point was then calculated from these five or more points and this centrum point was the basis for comparison between years. Spawning sites between years were classified as being similar when centrums varied by less than 350 m.

This ensured that at least 50 percent of the total spawning habitat must have overlapped between years for it to be considered a common spawning area.

To determine if the tracking procedure was successful in locating the upstream migration limits, the water was sampled for the presence of larvae. The larval sampling period occurred from 21 June to 21 July 2000 and from 15 May to 17 August 2001. The larvae sampling site was located approximately 200 to 300 m past the most upstream location at which eulachon were detected with radio telemetry. Larval sampling was conducted with bongo nets using methods described in Objective 4. The earliest incubation time has been reported at 30 to 40 days (Smith and Saalfield 1955). Therefore, larval sampling was initiated 30 days after adults were detected in Twentymile River. Although tracking was not conducted in the Clear Fork (Figure 3), larval sampling was completed to verify if eulachon spawned there successfully.

Conduct larval and biomass assessments as indices of relative run strength. (2000, 2001)

In the first year, we tested equipment and developed adaptations for smaller river environments during the first part of the season. Sampling for larval fish was initiated three weeks after the first adults were detected in the system because previous studies suggest the shortest incubation time was approximately three weeks in duration (Parente and Snyder 1970; Scott and Crossman 1973). Sampling was also conducted at various points up the river to determine where most of the spawning was occurring. The sample sites were referred to by river mile (RM) starting below the Twentymile River Bridge upstream to the Glacier Fork. One site was sampled at the mouth of the Clear Fork (RMC) to determine if eulachon spawned there. Sampling sites were located at RM 1.2, RM 2.5, RM 4.1, RM 5.9, RM 6.6 and RMC 6.7 (mouth of Clear Fork; Figure 4).

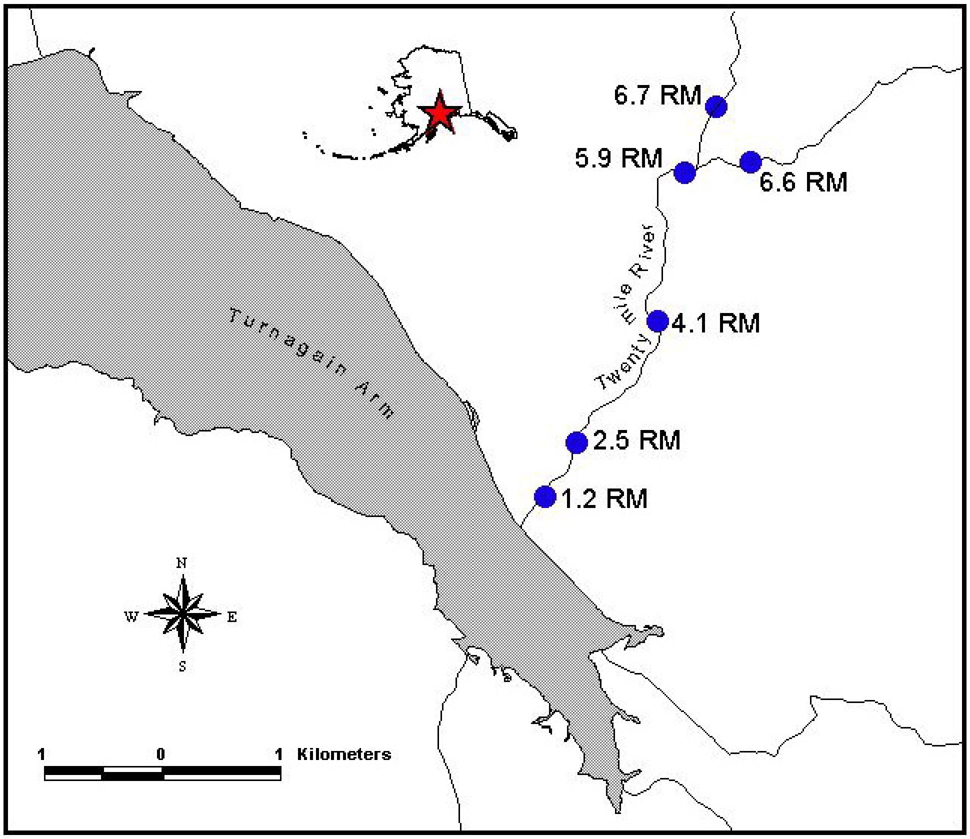

Figure 4. Bongo sample sites for egg and larvae samples by river mile (RM): (1) RM 1.2, (2) RM 2.5, (3) RM 4.1, (4) RM 5.9, (5) RM 6.6 and (6) RMC 6.7

Sampling occurred Monday through Friday of each week. A total of 10 low tides were randomly selected within each two-week period. All five sampling sites were surveyed on this schedule with the exception of the Clear Fork, which was sampled once per week. Sampling was always initiated two hours before the expected bore tide arrival time. Typically this was one hour after high tide in Anchorage. Sampling began at the lowest site and moving upstream as each site was completed. In 2001, sampling occurred near the mouth at site RM 1.2 as this site proved to be the lowest in the system while being stable and repeatable on an annual basis (Figure 4)

Larval fish were sampled with bongo nets from an inflatable boat (length, 4 m; width, 2 m). The boat was modified with an aluminum frame. The fishing apparatus attached to a manual cable on a steel arm and deployed from the bow of the boat. The cable was marked at 30-cm increments to track depths sampled. The net was in front of the boat and fished in the thalweg of the river, adjacent to the riverbank. Safety and depth restrictions precluded sampling in other adjacent areas. Samples were conducted at low slack tide to avoid collection of recirculated larval fish that may have been pushed upstream by the incoming tide. Each sampling session was completed in approximately 1.5 hours.

The sampling materials included bongo rings, nets, and codends (Hay et al. 1997b; McCarter and Hay 2001). The bongo rings were fabricated from steel with a bar in the center of one ring for the attachment of the Swoffer™ flow meter and YSI™ for water temperature. The rings had an outer diameter of 21.9 cm, inner diameter of 20.3 cm, and depth of 15.2 cm (Figure 5). The bongo nets were attached to rings with 2 hose clamps. The nets were 120 cm in length; 7.6 cm in diameter with 333 micron mesh net. The ends of the nets were attached to plastic piping with codends. The codends were 16.5 cm in length; 7.6 cm in diameter, and had 4 holes that were 1.3 cm in diameter constructed of 333 micron mesh material (Figure 6)

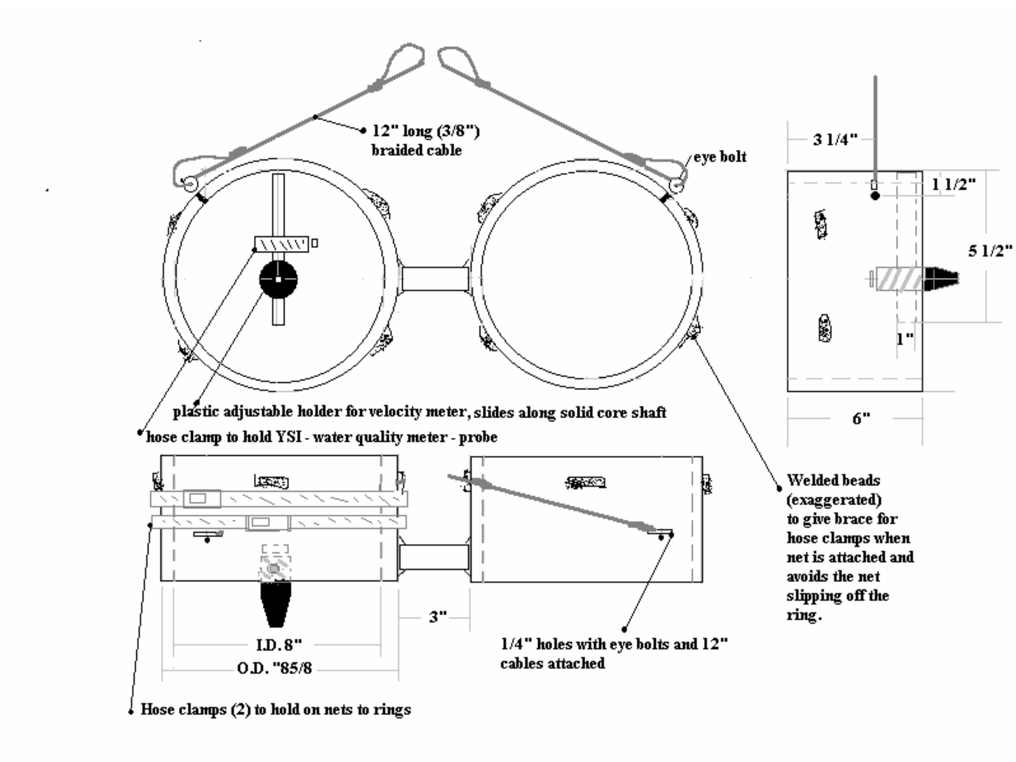

Figure 5. Bongo ring design for larval fish sampling Twentymile River Alaska (Eller, A.; USFS, Glacier Ranger District, Girdwood, Alaska).

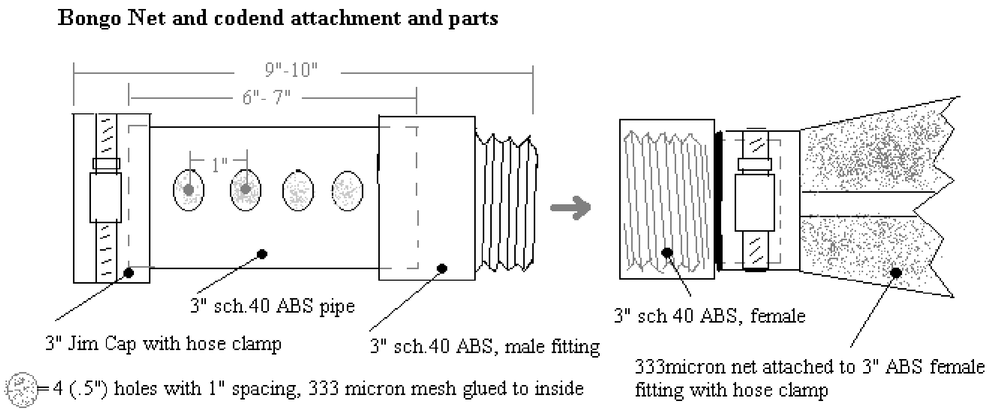

Figure 6. Codend and net attachment for larval fish sampling, Twentymile River Alaska (Eller, A.; USFS, Glacier Ranger District

The bongo samples were collected following the same protocol during each session. The overall water depth was measured at the beginning of each sampling session to allow for correct positioning of the bongo rings in the water column. Three samples were taken at each water depth (surface, mid-water, and bottom) for a total of nine samples. The duration of each sample was five minutes. The samples were separately placed in 500 ml bottles containing 3 percent buffered formalin. In the lab, eggs and larval fish were sorted, identified, and counted from each sample.

Productivity (P) of downstream drifting larvae was determined for each sampling session, composed of nine consecutive fishing events. For each fishing event, the number of larvae estimated to drift out of the river during the sampling time (t) was referred to as larval productivity (P_t). The mean of all the samples (P_t) were calculated to determine the productivity (P) for the sampling session. The productivity estimate assumed that rate of transport out of the river remained relatively constant throughout the sampling session. This was assumed since flow conditions during sampling varied little at low tide before the arrival of the incoming tide. Productivity of larvae (P_t) during the sampling time was the product of river discharge volume (V_t), the interval (I_t) of time sampled, and larval density (D_t, Hay et al. 1997b).

$$P_t = V_t * I_t * D_t$$

The river discharge volume (V_t) was the mean flow ($m^3\ s^{-1}$) during the sampling session. The interval of time (I_t) was measured in seconds (s). The larval density (D_t), expressed as number of larvae per m^3, was determined from total number of larval fish captured and the water volume filtered (V_f) through each net collection during each sampling session. The V_f was calculated using the equation:

$V_f = \pi r^2 (f*t)$, where radius (r) was the opening size of the net, (f) was the flow of water in m/s, and (t) was the amount of time fished in seconds.

$$D_t = \text{number of larvae} / V_f$$

The larval productivities (P_t) during the sampling time were compared among the three water depths (surface, mid water, bottom) to estimate vertical distribution in the water column. At each depth, three productivity samples (P_t) were obtained and the mean productivity was determined for each depth.

Incubation periods were estimated by calculating the number of days between peak daily abundances of adult CPUE and larval productivity. These peaks were plotted as smoothed curves from five-day running averages. Both adult CPUE and larval productivity were superimposed on each other to determine corresponding peaks. Incubation periods were classified with accumulated thermal units (ATU) using mean daily water temperature.

The daily P of larval eulachon was compared with simultaneous environmental factors including water temperature, tide height, river discharge, and light intensity. Water temperature, tide height and river discharge data were collected in the same manner as described for adults. To test if larval productivity was related to light intensity, a series of paired "day" and "night" samples were collected during the study. Samples were taken within 24-hr periods (0000 – 2400 h) that contained "day" (> 5 lumens) and "night" (≤ 5 lumens) light intensities. Times of low light intensity corresponding with low tide are limited at northern latitudes at this time of year. Therefore there were few opportunities to conduct paired day and night comparisons.

Data Analysis

Catch per unit effort of adults was modeled as a gamma random variable (continuous) using explanatory variables. The analysis began by fitting all measured environmental factors into a generalized linear model (Agresti 1990; McCulloch 2001). The analysis was completed using PROC GENMOD (SAS Institute, Inc. 2002) with a log link function. Initially, all variables were placed into the model. Terms were analyzed in a stepwise fashion, until all remaining environmental variables were statistically significant. A significance level of 0.05 was used to define statistical significance during model development.

Productivity of larvae was modeled as a gamma random variable using day of the year (DY), water temperature (W), tide height (T), and river discharge (D) as explanatory variables. The analysis began by fitting all measured environmental factors into a generalized linear model (Agresti 1990; McCulloch 2001). The analysis was completed using PROC GENMOD (SAS Institute, Inc. 2002) with a log link function. Initially, all variables were placed into the model. Terms were analyzed in a stepwise fashion, until all remaining environmental variables were statistically significant. A significance level of 0.05 was used to define statistical significance during model development. A paired t-test was used to determine if there were differences between larval productivity at day and night.

Determine presence/absence of eulachon in the Portage Creek and Placer River drainages. (2000, 2001)

Placer River and Portage Creek were sampled for presence or absence of eulachon in 2000 and 2001 (Figure 1). Gill nets were used in 2000 and dip nets in 2001 and sampling occurred two to three times per week using the same methods used in the Twentymile River described in Objective 2.

Collect samples for larger eulachon study to determine stock composition and interception in the Pacific. (2001)

One hundred fish were collected from the Twentymile River and sent to Dr. Douglas Hay at the Department of Fish and Oceans in Nanaimo, British Columbia. Dr. Hay is collaborating with others in an attempt to describe stock discreteness of eulachon from various rivers from Alaska, British Columbia, and Washington using meristics.

RESULTS:

Determine user demographics and estimate harvest of the eulachon fishery (2002**)**

The survey began on 26 April and ended 6 June 2002. Night tides in April were not considered fishable and were not included in the survey. The number of sampling periods at the access sites varied from three to fifteen. Unequal sampling resulted from difficulties in crew scheduling. Some sampling periods were dropped and others added in an ad hoc fashion. Unfortunately, due to this non-random selection of sampling periods estimates are assumed to be biased to an unknown degree.

A total of 530 fishermen were contacted during creel sampling. When expanded to all sites and sample periods, we estimated 2,294 people participated in the fishery. The ethnic backgrounds of respondents were as follows: Native (19%), Filipino (24%), Russian (11%), Caucasian (19%), Other (27%). Of all the fishermen, 9% were from rural areas, and 91% were from non-rural areas (Table 1). Interviewed fishermen caught 4,529 kg of eulachon. When this number was expanded to all sites and time periods, approximately 14,940 kg was harvested from the Twentymile River (Table 2). The harvest occurred both on lands under Federal jurisdiction, with 51% occurring at stations 1 and 2, at the mouth of the Twentymile River and on lands claimed by the State of Alaska, with 49% occurring at sites 4 and 5 further downstream in Turnagain Arm (Figure 2).

Table 1. Residency of fishermen contacted during the eulachon creel survey, Twentymile River, 2002.

Rural or Non Rural	Community	# Fishermen
Rural	Delta Junction	15
	Glenallen	2
	Hope	9
	Kotzebue	3
	Moose Pass	2
	Ninilchik	2
	Port Graham	5
	St. Marys	4
	Talkeetna	1
	Whittier	1
	Willow	6
Non Rural	Anchorage	422
	Anchor Point	2
	Chugiak	2
	Eagle River	8
	Fairbanks	1
	Fresno, CA[a]	5
	Homer	1

[a] illegal fishermen

Table 2. Estimated total fishing effort and harvest of Eulachon by dipnetters at 20-mile River.

Date	Total hours fished	SE	Total number party	SE	Total weight (kg)	SE
Site 1	309	99.9	481	161.0	3660.8	1676.5
Site 2	452	138.7	644	172.5	3880.0	2069.0
Site 4	731	357.2	909	430.9	7353.9	5203.1
Site 5	117	112.4	260	249.8	46.2	44.4
Total	1,609	708.2	2294	1,014.2	14,940.9	8,993.0

Determine run timing and other aspects of eulachon life history (fecundity, age, et.) in Twentymile River. (2000, 2001).

Run timing

Fish were detected from 4 May to 21 June 2000 and 17 April to 9 June 2001 during dip net sampling. There was one fish caught on 21 June 2000, but sampling had to be terminated that year due to limited funding. The spawning run started 18 days earlier in 2001 than in 2000. A total of 394 fish were caught in 2000 and 3,815 fish in 2001. The increased fishing effort in 2001 aided in the collection of more eulachon. The maximum

CPUE was 75 fish per hour in 2000 (10 June) and 93 fish per hour (20 May) in 2001 (Figure 7).

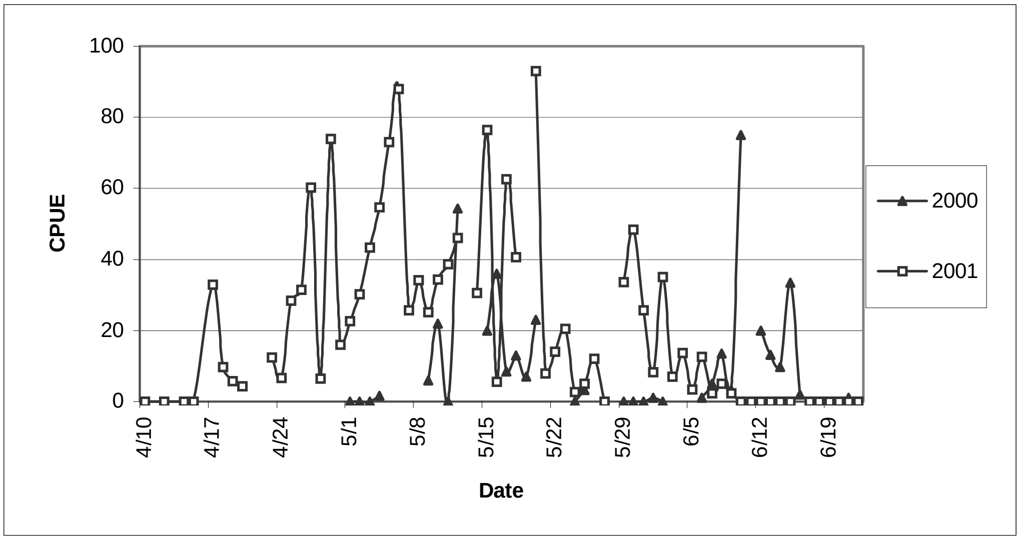

Figure 7. The daily catch per unit effort (CPUE) of eulachon during 2000 and 2001

Gill net sampling resulted in a 0.8: 1.0 sex ratio for males (n = 70) to females (n = 86) in 2000. Dip net sampling resulted in a sex ratio of 6.7: 1.0, males (n = 343) to females (n = 51) in 2000. In 2001 the sex ratio for males (n = 1862) to females (n = 849) was 2.1: 1.0 in dip net sampling. There were no significant changes in sex ratio over the course of the runs within a year for dip net sampling (2000, Table 3, p < 0.6687; 2001, Table 4, p < 0.9536).

Table 3. Life history dependent and independent variables in 2000.

Dependent Variables 2001	Independent Variables 2001	P_{2001}	n	β	SE
Sex Ratio	Day of the Year	< 0.6687	31	-.0214	0.0501
	Length	< 0.0001	271	0.0482	0.0099
	Weight	< 0.0001	271	0.0397	0.0102
	Age	< 0.0013	272	0.7419	0.2312
Teeth Retention	Sex	< 0.0001	271	-5.3752	0.5813
	Age- Males	< 0.9874	222	0.0092	0.5837
	Age- Females	< 0.7094	49	-0.1990	0.5338
Age	Day of the Year- Males	< 0.0001	223	0.0060	0.00010
	Day of the Year- Females	< 0.1137	49	0.0041	0.0026
Weight	Age- Males	< 0.0001	222	0.2097	0.0167
	Age- Females	< 0.0001	49	0.3078	0.0458
Length	Age- Males	< 0.0001	222	0.0619	0.0048
	Age- Females	< 0.0001	49	0.0885	0.0015

Table 4. Life history dependent and independent variables in 2001.

Dependent Variables 2001	Independent Variables 2001	P_{2001}	n	β	SE
Sex Ratio	Day of the Year	< 0.9536	35	0.0037	0.0636
	Length	< 0.0001	1011	0.0566	0.0067
	Weight	< 0.0001	1011	0.0488	0.0064
	Age	< 0.0024	1010	0.5211	0.1717
Teeth Retention	Sex	< 0.0001	1011	4.1904	0.2952
	Age- Males	< 0.5960	585	-0.1155	0.2179
	Age- Females	< 0.2383	425	-0.9323	0.7906
Fecundity	Age	< 0.0397	370	0.0332	0.0161
	Weight	< 0.0001	370	0.0015	0.0001
	Length	< 0.0001	370	0.0010	0.0001
Age	Day of the Year- Males	< 0.0001	585	0.0020	0.0004
	Day of the Year- Females	< 0.3968	425	0.0004	0.0005
Weight	Age- Males	< 0.0001	585	0.1409	0.0178
	Age- Females	< 0.0001	425	0.1401	0.0228
Length	Age- Males	< 0.0001	585	0.0436	0.0053
	Age- Females	< 0.0001	425	0.0459	0.0083

Run timing was related to age for males during 2000 (Table 3, $p < 0.0001$) and 2001 (Table 4, $p < 0.0001$). Age 2 males were more frequent during the earlier part of the runs, whereas the frequency of age 4 and 5 increased in the later part of the spawning runs (Figures 8 and 9). Age 3, the dominant age of spawners, was present throughout the runs during both years. The age frequency of females did not change significantly during the run timing in 2000 (Table 3, $p < 0.1137$, Figure 10) or 2001 (Table 4, $p < 0.3968$, Figure 11).

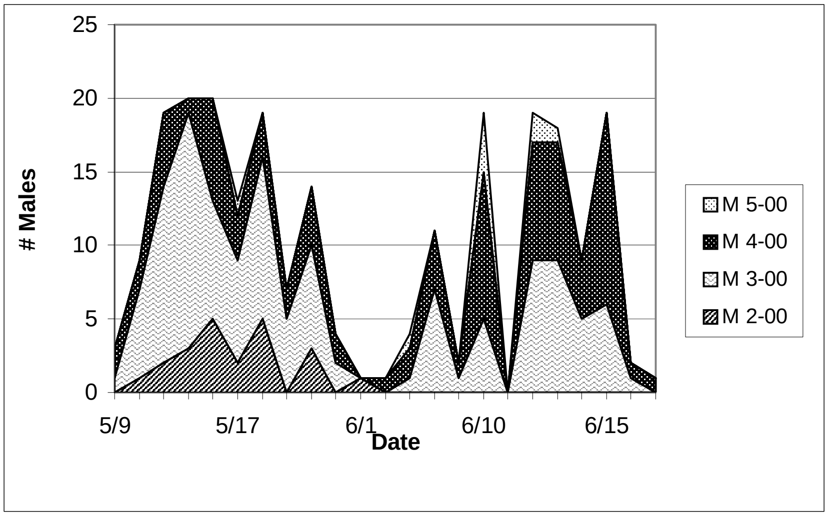

Figure 8. The age distribution over run timing for male eulachon, 2000

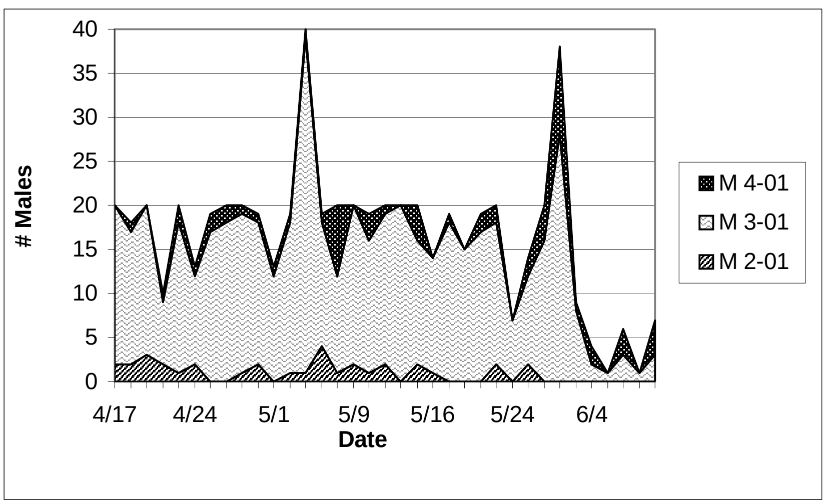

Figure 9. The age distribution over run timing for male eulachon, 2001.

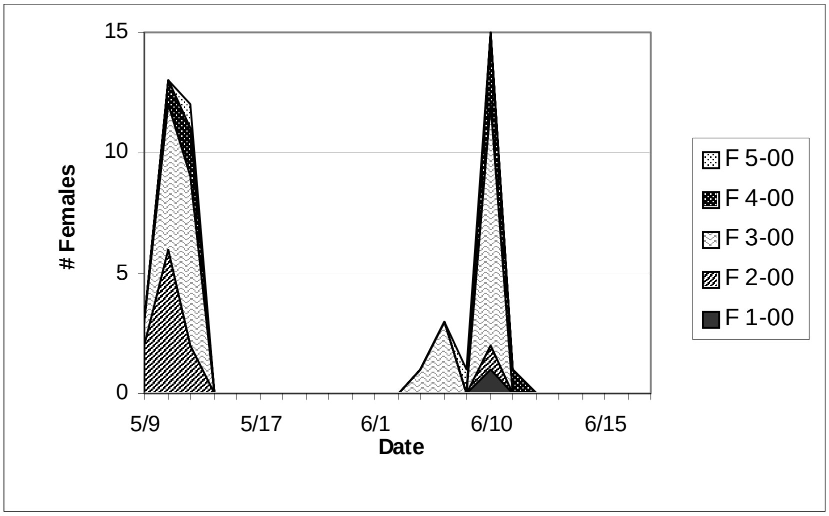

Figure 10. The age distribution over run timing for female eulachon, 2000.

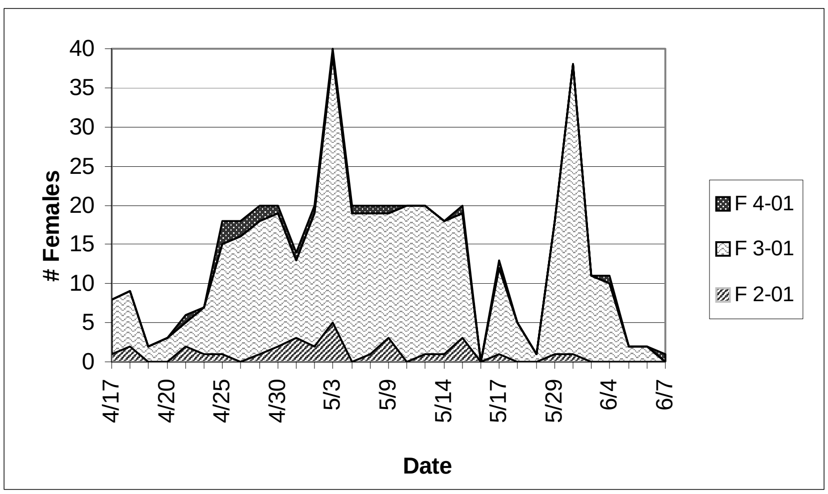

Figure 11. The age distribution over run timing for female eulachon, 2001

Life history

The mean fork length was significantly different (Table 3, $p < 0.0001$) between males and females in 2000. The significant difference (Table 4, $p < 0.0001$) was also seen in 2001 between males and females. Male fish consistently had greater mean lengths than females (Table 5). However, the greatest variation in range was observed for females.

Table 5. Male and female mean, minimum, and maximum fork lengths Twentymile River.

Eulachon Fork Length (mm)					
Year	Sex	*n*	Mean ± SE	Minimum	Maximum
2000	Male	222	215.4 ± 0.9	166.0	242.0
	Female	49	202.1 ± 3.0	143.0	234.0
2001	Male	585	209.1 ± 0.5	100.0	241.0
	Female	425	202.5 ± 0.6	99.0	253.0

The mean weight was significantly different (Table 3, $p < 0.0001$) between males and females in 2000. The significant difference (Table 4, $p < 0.0001$) was also seen in 2001 between males and females. The male fish consistently had greater mean weights than females (Table 6), though the smallest eulachon found were males.

Table 6. Male and female mean, minimum, and maximum weights, Twentymile River.

Eulachon Weight (g)					
Year	Sex	*n*	Mean ± SE	Minimum	Maximum
2000	Male	222	69.9 ± 1.0	26.5	104.0
	Female	49	60.0 ± 2.8	29.0	101.0
2001	Male	585	65.8 ± 0.5	6.0	106.0
	Female	425	60.1 ± 0.5	28.0	122.0

Male and female eulachon showed a significant difference in presence of teeth between sexes in 2000 (Table 3, $p < 0.0001$) and 2001 (Table 4, $p < 0.0001$). During both years of the study, few spawning males had teeth compared with females (Table 7).

Table 7. The percentage of eulachon teeth retention or loss between sexes and years, Twentymile River.

Year	Sex	*n*	Teeth Detected (%)
	Male	222	3.4
2000	Female	49	84.0
	Male	586	32.4
2001	Female	425	96.9

Most fish were age 3 in both 2000 (males, 51%; females, 57%) and 2001 (males, 83%; females, 88%) with ages ranging from 1 to 5 for females and from 2 to 5 for males (Table 8). Average ages of male and female fish were significantly different between 2000 (Table 3, $p < 0.0013$) and 2001 (Table 4, $p < 0.0024$). The age and length were significantly related for males in 2000 (Table 3, $p < 0.0001$) and 2001 (Table 4, $p < 0.0001$). The age and length were significantly related for females in 2000 (Table 3, $p < 0.0001$) and 2001 (Table 4, $p < 0.0001$). The length of the fish increased with age for males and females (Figure 12). The age and weight were significantly related for males in 2000 (Table 3, $p < 0.0001$) and 2001 (Table 4, $p < 0.0001$). The age and weight were significantly related for females in 2000 (Table 3, $p < 0.0001$) and 2001 (Table 4, $p < 0.0001$). The weight of the fish increased with age for males and females (Figure 13).

Table 8. Percentage of males and females by age class, Twentymile River.

	Sex		Age (%)				
Year		*n*	1	2	3	4	5
2000	Male	235	0	9	51	36	4
	Female	49	2	23	57	14	4
2001	Male	585	0	6	83	11	0
	Female	425	0	8	88	4	0

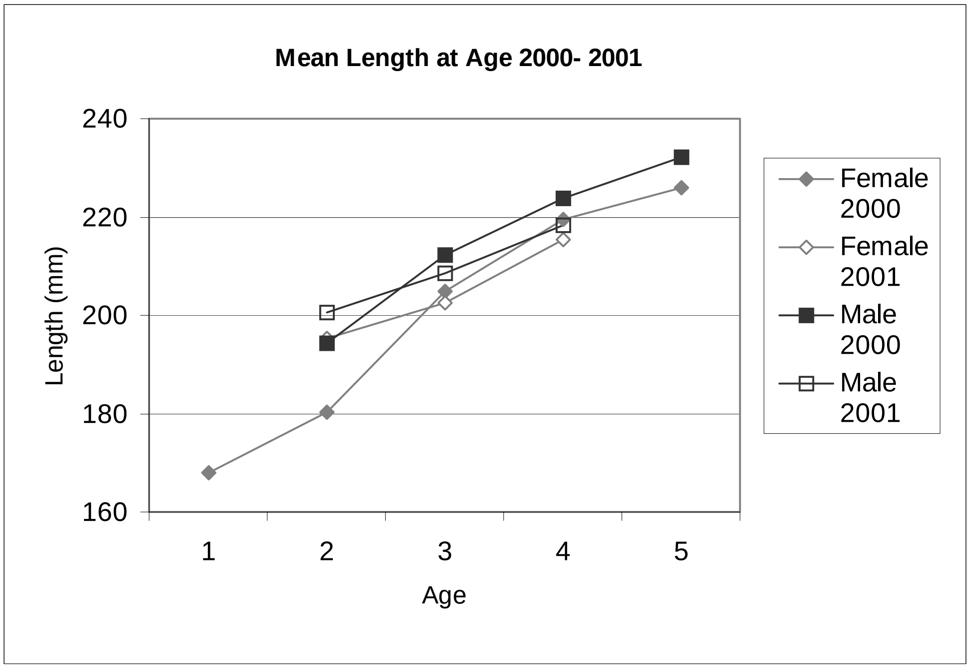

Figure 12. The mean length at age for male and female eulachon, 2000- 2001.

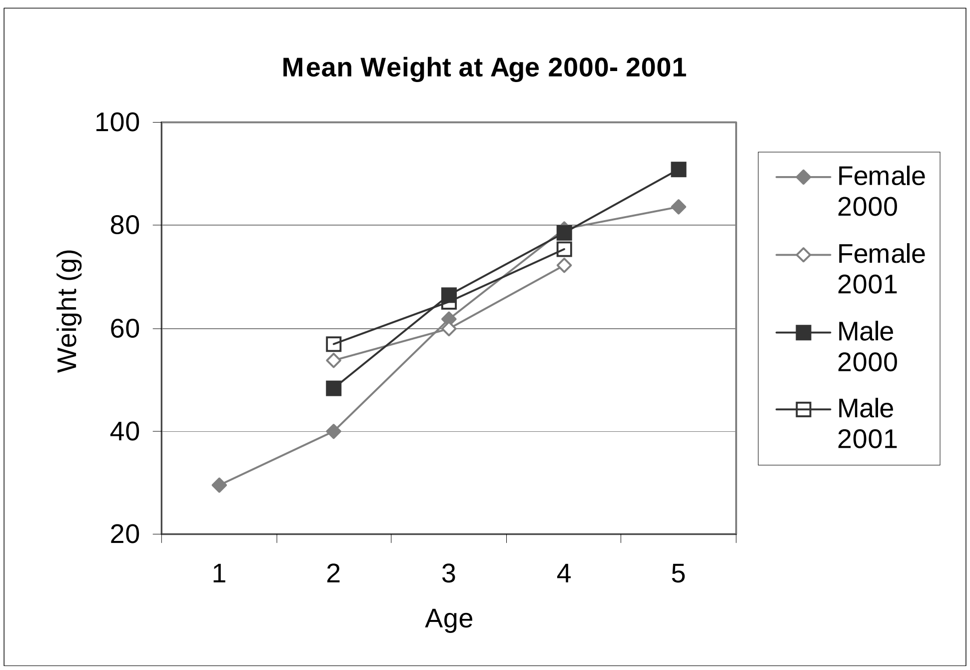

Figure 13. The mean weight at age for male and female eulachon, 2000- 2001.

In 2001, fecundity ranged from 8,532 eggs to 67,507 eggs per female (Table 9). Fecundity was significantly related to age (Table 4, $p < 0.0397$), length (Table 4, $p < 0.0001$), and weight (Table 4, $p < 0.0001$). Females became more fecund with increasing age, length, and weight although weight had the strongest relationship when modeled simultaneously. The high reported standard errors for ages 2 and 4 might be an artifact of small sample sizes.

Table 9. The age and fecundity of females with corresponding mean lengths and weights, Twentymile River.

Age	*n*	Mean # Eggs ± SE	Mean Length (mm) ± SE	Mean Weight (g) ± SE
2	23	29784 ± 1441	198.8 ± 3.7	56.2 ± 2.9
3	330	31377 ± 364	202.6 ± 0.6	60.3 ± 0.5
4	17	35163 ± 2279	214.9 ± 2.4	72.4 ± 2.6

Run strength and environmental factors
Exploratory analysis with adult fish and environmental factors was conducted using a generalized linear model. Catch per unit effort of adults in 2000 (Table 10) and in 2001 (Table 11) was significantly related with day of the year (DY), water temperature (W), tide height (T), river discharge (D), and light intensity (L) in the generalized linear model.

$$\text{Log (CPUE)} = b_o + b_1DY + b_2W + b_3T + b_5D + b_4L$$

Table 10. Adult CPUE compared with environmental factors, 2000.

Environmental Factors	p_{2000}	*n*	β	SE
Day of the Year	< 0.0003	31	-0.0166	0.0046
Water Temperature	< 0.0001	31	-0.3544	0.0478
Tide Height	< 0.0001	31	-0.5530	0.0571

Table 11. Adult CPUE compared with environmental factors, 2001.

Environmental Factors	p_{2001}	*n*	β	SE
Day of the Year	< 0.0001	64	-0.0281	0.0031
Water Temperature	< 0.0001	64	-0.0507	0.0103
Tide Height	< 0.0001	64	-0.2251	0.0255
River Discharge	< 0.0001	64	-0.0185	0.0023
Light Intensity	< 0.0001	64	0.0000	0.0000
Predators	< 0.0001	50	0.0220	0.0009

All variables were positively related to CPUE except for light intensity that had an inverse relationship. During the adult spawning run, water temperatures ranged from 1.6° C to 12.7° C in 2000 and from 0.5° C to 10.7° C in 2001. At the peak of the run, water temperatures were 4.6° C in 2000 and 6.0° C in 2001. High tide heights ranged from 6.86 m to 9.81 m in 2000 and 6.58 m to 9.57 m in 2001. In 2001, the river discharge ranged from 8.16 $m^3 s^{-1}$ to 77.93 $m^3 s^{-1}$ with the greatest CPUE occurring at 21.56 $m^3 s^{-1}$. The light intensity ranged from 0 to 7.4 x 10^4 lumens, with greatest CPUE at low light intensities (< 5.0 lumens) in 2001.

The number of bald eagles (E) was positively related to CPUE of eulachon ranging from 1 to 139 birds with a daily mean of 37 birds (Table 11). The number of bald eagles increased as CPUE increased for eulachon (Figure 14).

$$\text{Log (E)} = b_o + b_1 \text{ CPUE} + b_2 \text{ (DY)}$$

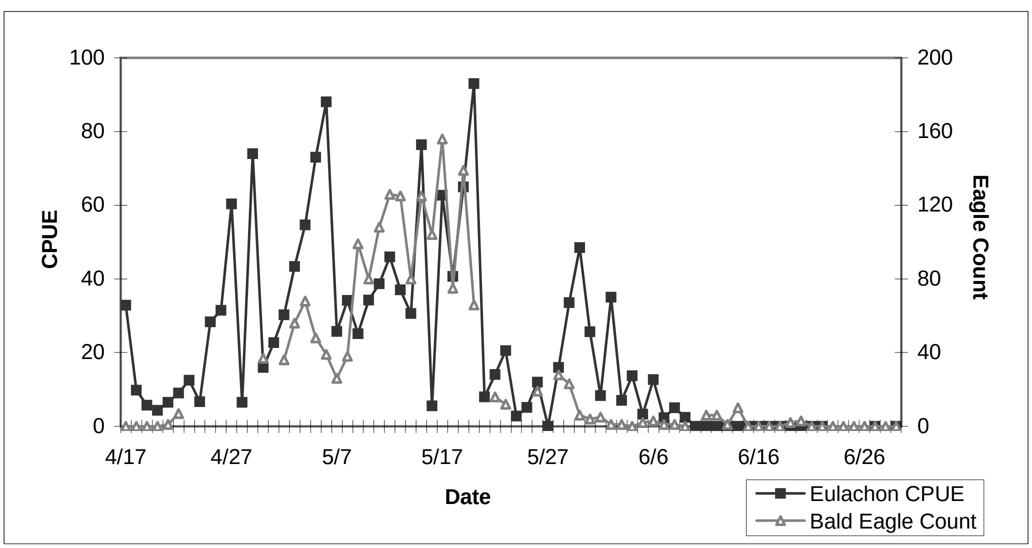

Figure 14. Bald eagle presence compared to CPUE of adults, 2001.

Determine adult migratory behavior and characterize and map upper limits of spawning and critical spawning habitat (2000, 2001)

Tagging procedure

The average insertion length was 4.8 cm (range 4.0 to 6.0 cm). The results of necropsies indicated that the most common errors were puncturing of the stomach followed by insertions that were too shallow. However, after a half hour of practice, technicians were able to insert transmitters correctly. It took an average of 15 seconds to complete the procedure for each fish. Fish were docile enough to conduct work without the aid of an anesthetic.

Radio tag retention test

There was no significant difference between the survival of control and tagged fish (Table 12). When tagged and controlled fish were combined by sex, males had slightly better survival (no mortalities) than females (two mortalities; Table 12). Additionally, observers noted females did not withstand the rigors of the holding tank as well as males following the three-day holding period in the live well. The female fins showed a greater degree of degradation, retained fewer scales, and were less vigorous when handled.

Table 12. Number of mortalities and regurgitated radio tags by treatment and sex for eulachon.

Treatment	Sex	*n*	Mean FL (mm)	Mean weight (g)	Tag weight to body weight (%)	Regur-gitated radio tags	Mortalities
Control	M	7	211	69	N/A	N/A	0
	F	8	198	60	N/A	N/A	1
Tagged	M	9	216	77	1.8	1[a]	0
	F	6	214	79	1.8	0	1

a Radio tag antenna became caught between washers on inside of live well.

N/A = Not applicable

Tracking success

There were a total of 23 eulachon tracked (16 males and 7 females) in 2000, and 108 (54 males and 54 females) in 2001. Of the 23 fish tagged in 2000 we successfully tracked 22 fish (95.7 percent success rate). This fish moved upstream and then had no movement until the life expectancy of the tag was reached. This was likely due to regurgitation of the tag or death. Of the 108 fish tagged in 2001, 93 were successfully tracked and 15 fish moved upstream and then had no movement until the life expectancy of the tag was reached (86.2 percent success rate).

Migratory behavior

The mean and furthest upstream distances were calculated for fish moving upstream and downstream above the initial tagging site (category one) and fish moving only upstream, followed by no movement until the life expectancy of the tag was reached (category two). In 2000, the maximum upstream distance for males was 9,470 m (n = 13; Fig. 15; 2000) and 8,097 m (n = 40; Fig. 15; 2001). The mean upstream distance for males was 3,684 m (n = 13; SE ± 201 m; Fig. 15) in 2000 and 3,688 m (n = 40; SE ± 45 m; Fig. 15) in 2001. Female maximum upstream distance was 6,855 m (n = 4; Fig. 11; 2000) and 7,761 m (n = 43; Fig. 11; 2001). The mean upstream distance for females was 3,919 m (n = 4; SE ± 1006 m; Fig. 11) in 2000 and 2,723 m (n = 43; SE ± 41 m; Fig. 11) in 2001. Males consistently spent more time in freshwater than females (Table 2). These variables were not calculated for categories three (limited movement adjacent to the tagging site) and five (only detected on day of initial tagging) because these movement patterns could be the result of a tagging effect.

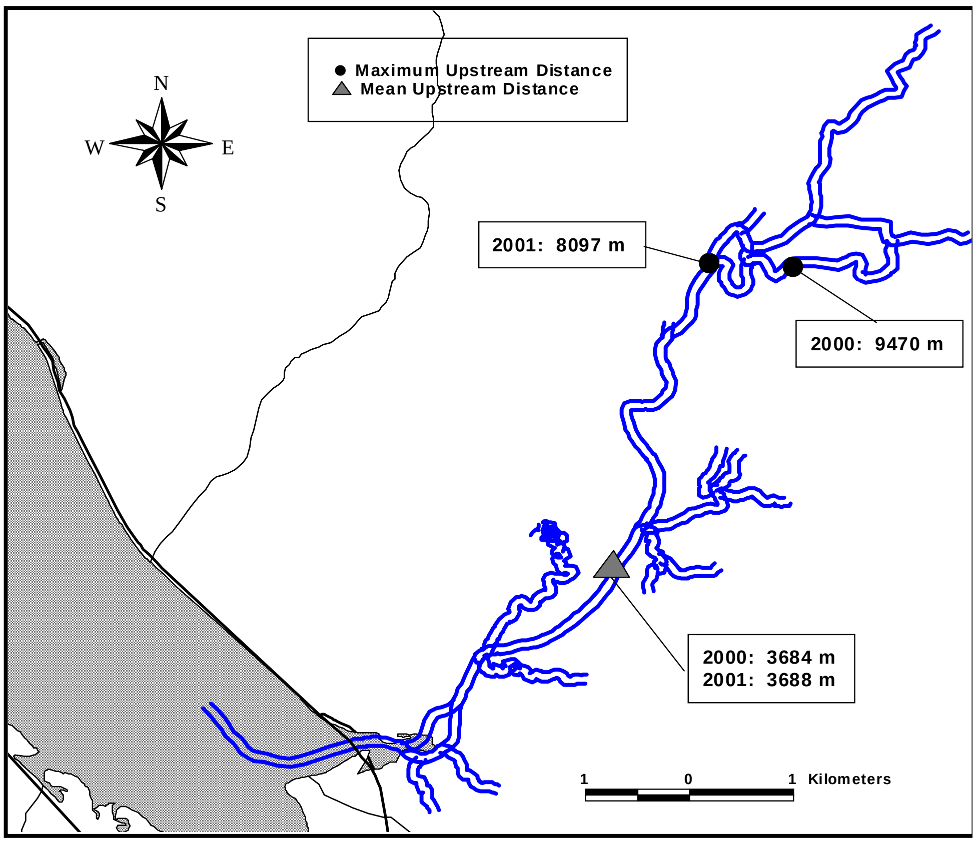

Figure 15. The maximum and mean upstream migration positions for males (2000, 2001).

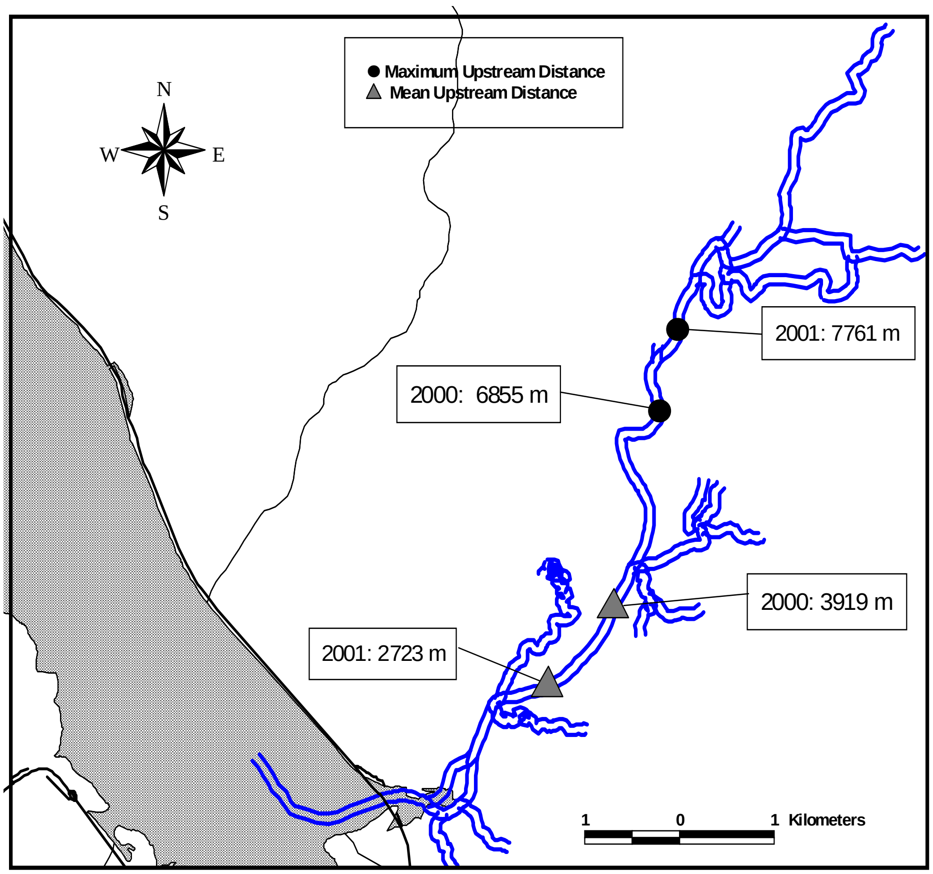

Figure 16. The maximum and mean upstream migration positions for females (2000, 2001).

Table 13. Retention time (days) for category one and four male and female fish. Category one are fish exhibiting upstream and downstream movement above the initial tagging site; and category 4) downstream and upstream movement, but occurring below the initial tagging site.

Year	Sex	Category 1 Fish (days)	Category 4 Fish (days)
2000	Male	4.0	5.0
	Female	2.3	1.5
2001	Male	5.6	4.9
	Female	4.3	3.6

Radio telemetry was not successful in determining the upstream limits of spawning in the Twentymile River. Juvenile fish were detected that are unable to swim upstream were found above the furthest documented location of adult eulachon. However, very few larval fish were caught (3 larvae in 2000 samples; *n* = 55; and 12 in 2001 samples; *n* = 158). when compared with the lower river (617 larvae in 2000 samples; *n* = 60 and 66,519 larvae in 2001 samples; *n* = 765). Therefore, it is reasonable to assume that we captured most of the spawning areas. Larval sampling in the Clear Fork confirmed there were no spawning eulachon as no larvae were detected in either year.

The furthest upstream migration positions identified four possible concentrated areas of spawning in 2000 and five possible concentrated areas of spawning in 2001 (Figures 17 and 18). Four of the spawning sites were similar between years varying in centrums between 24 and 330 m (Table 14). In 2001, there was one additional site located at 4479 m.

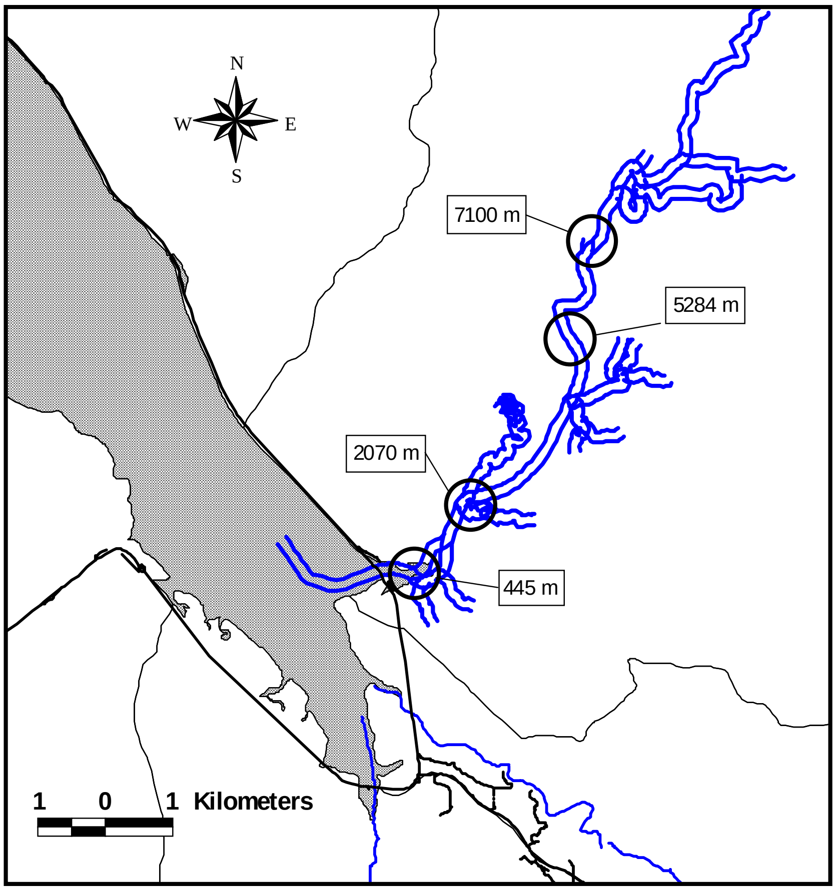

Figure 17. The most common upstream migration areas for eulachon, 2000

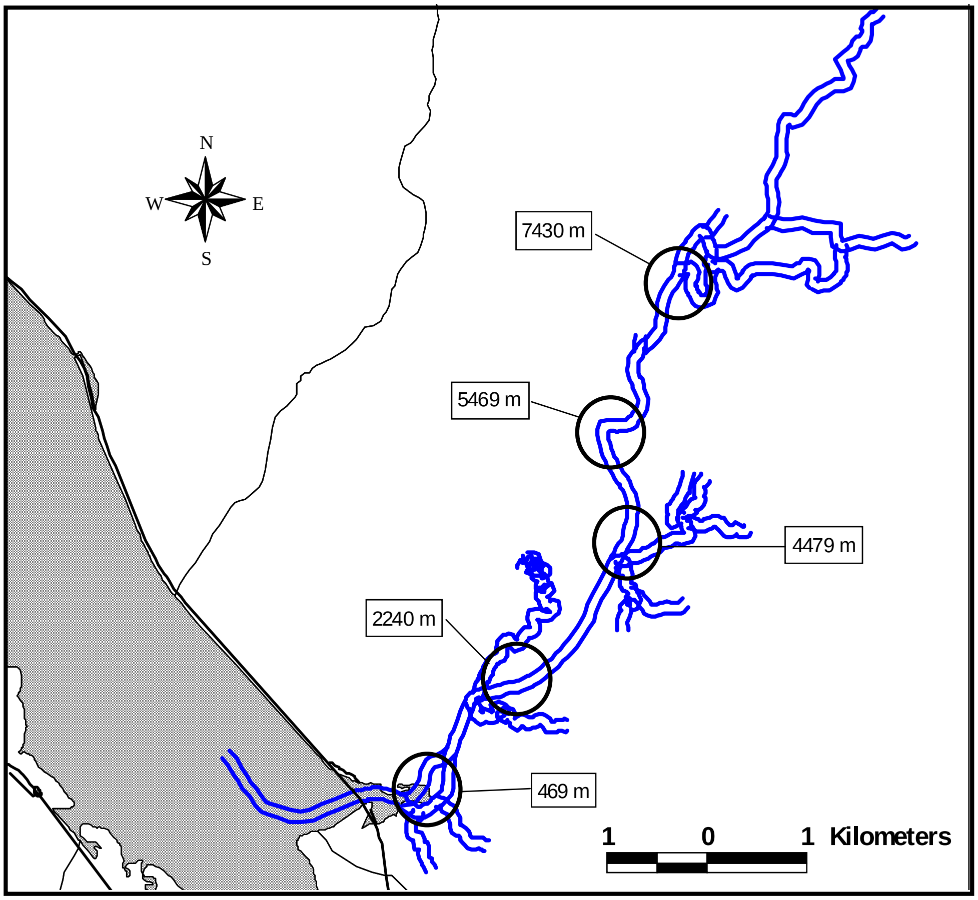

Figure 18. The most common upstream migration positions for eulachon, 2001

Table 14. Concentrated spawning site centrums (meters upstream from initial tagging site) in 2000 and 2001 on the Twentymile River.

Spawning Site #	2000 (*n*)	2001 (*n*)	Difference (m)
1	445 (3)	469 (17)	24
2	2070 (4)	2240 (18)	170
3	(0)[a]	4479 (16)	[a]
4	5284 (4)	5439 (6)	155
5	7100 (3)	7430 (3)	330

[a] no data

Conduct larval and biomass assessments as indices of relative run strength. (2000, 2001)

2000: A stream gauging station was installed to provide instantaneous flow estimates for developing the productivity estimates. Larval sampling methods were successfully adapted for use in small rivers. One site at RM 1.2 was found to be the most stable and repeatable for sampling over the range of flows during out migration. Eulachon egg and larvae samples were collected at six locations in Twentymile River from 21 June to 21 July 2000. Maximum densities of larvae occurred at RM 1.2 (Figure 19).

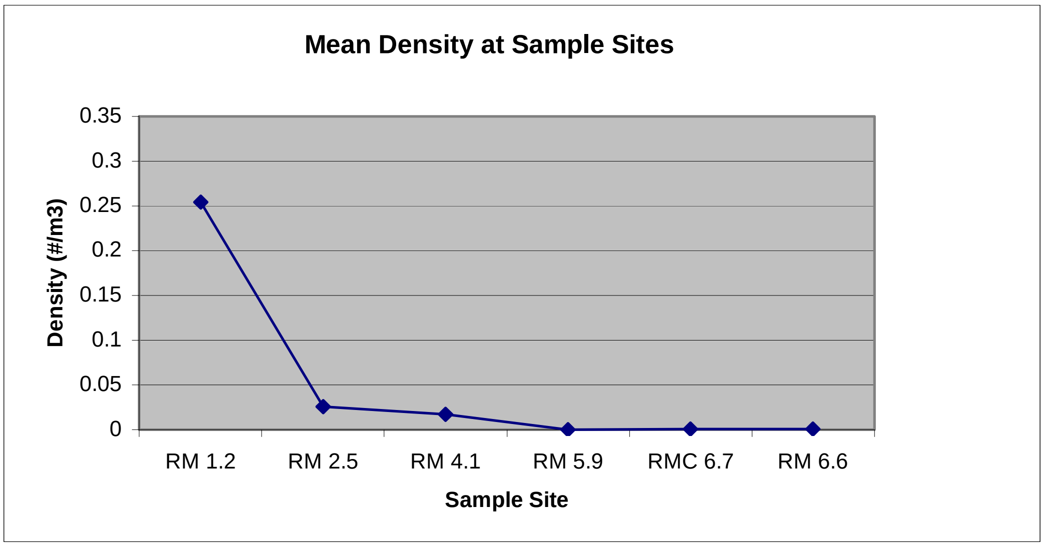

Figure 19. Density at different sampling sites.

2001: Larval fish were detected from 8 May 2001 to 28 August 2001, 113 days. The first larval fish were observed 22 days after the first adults were detected in the system on 17 April 2001. The last larval fish were captured 81 days after the last pre-spawning adults were detected entering the river (Figure 20). The daily mean productivity (P) was 16,947, ranging from 0 to 96,382 larval fish per sampling session. The period of greatest productivity was detected from 17 June to 20 July 2001 with a mean of 42,859 larval fish per sampling session.

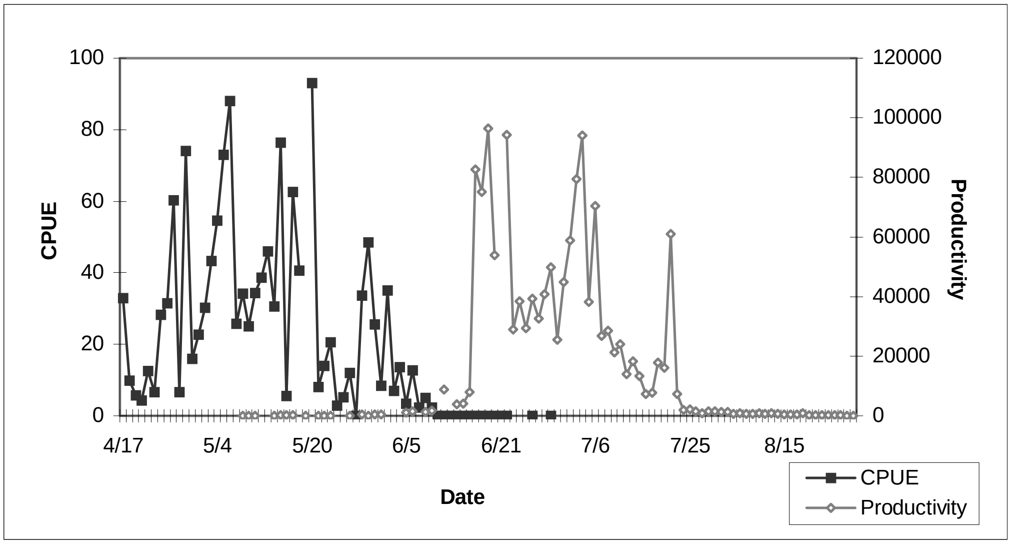

Figure 20. Adult run timing (CPUE) and downstream drifting larval fish (productivity), 2001.

There was a positive trend between productivity of larval fish and decreasing water depth. The bottom of the river had the greatest abundance (mean, 18,790 larvae per sampling session) in larval productivity followed by the mid-water (mean, 14,060 per sampling session) and surface (mean, 10,828 larvae per sampling session; Figure 21).

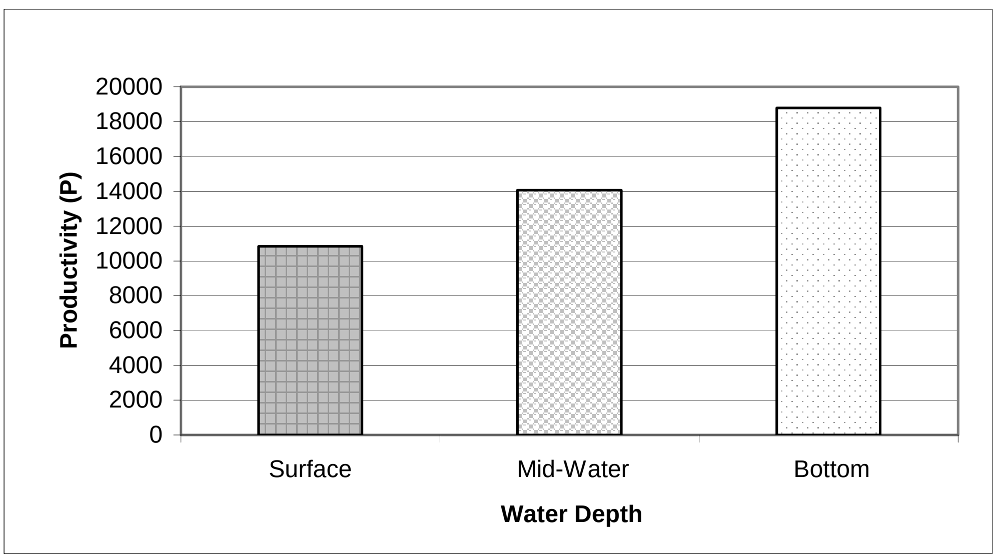

Figure 21. Productivity of larval fish among water depths (surface, mid-water, and bottom), 2001.

Incubation periods were estimated by comparing peaks of adult CPUE and larval productivity (Figure 22). Visual observations of Figure 22 indicated three distinct corresponding peaks between adult CPUE and larval productivity. Each of the corresponding peaks was similar in intensity. The first peak in CPUE was similar in intensity to the first peak in larval productivity. This trend occurred for all three peaks. When comparisons were made between corresponding peaks, the number days were similar at 47, 50, and 47 days. The peak periods were as follows: first corresponding peak period from 5 May (adult) to 20 June (larval), the second corresponding peak from 17 May (adult) to 5 July (larval), and the third peak from 1 June (adult) to 17 July (larval). For each of these three time periods, accumulated thermal units (ATU) were calculated using mean daily water temperatures. The incubation period ranged was from 294 to 321 ATU.

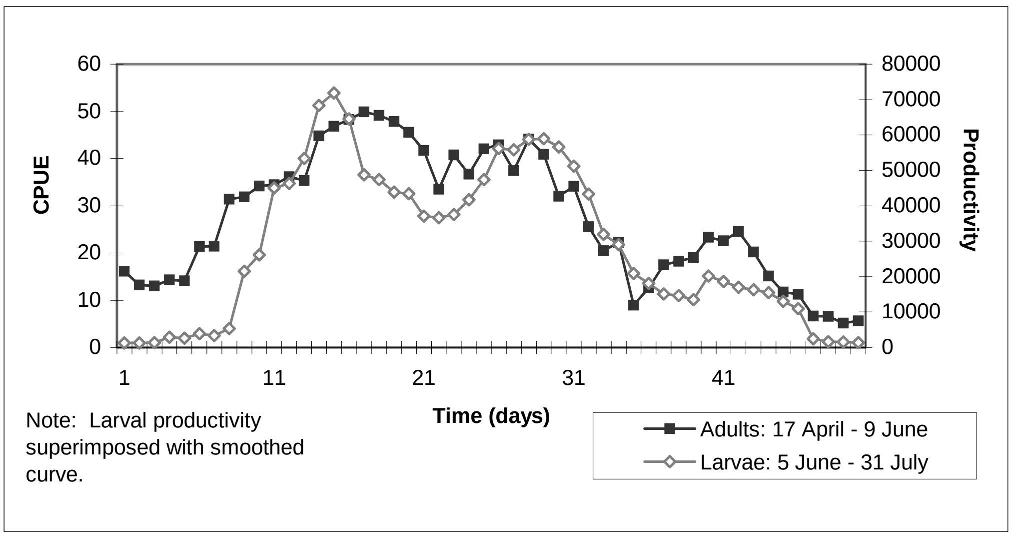

Figure 22. Larval productivity superimposed on adult CPUE, 2001.

Productivity of larvae in 2001 (Table 15) was significantly related with day of the year (DY), water temperature (W), and river discharge (D) in the generalized linear model. There was no significant relationship between tide height and the productivity of larval fish (Table 15).

$$\text{Log } (P_t) = b_o + b_1 DY + b_2 W + b_3 D$$

Table 15. Significance levels between productivity of downstream drifting larval fish and environmental factors, 2001.

Environmental Factor	p_{2001}	n	β	SE
Day of the Year	< 0.0001	73	-0.0493	0.0076
Water Temperature	< 0.0137	73	-0.3472	0.1408
Tide Height	< 0.0897	73	-0.5833	0.3437
River Discharge	< 0.0001	73	0.0586	0.0091
Light Intensity	< 0.0198	4	N/A[a]	7186.06

[a] N/A = not applicable

The water temperature ranged from 4.1° to 9.9° C over the sampling period, but varied less during periods of greatest productivity (5.0° to 6.9° C, mean 6.0° C). River discharge ranged from 15.5 $m^3 s^{-1}$ to 279 $m^3 s^{-1}$ (mean 98.7 $m^3 s^{-1}$) over the sampling period generally increasing as the productivity of larvae increased.

Larval productivity and light were statistically compared for only four paired day and night periods between 2 July to 11 July 2001 when light intensity and tides allowed (Figure 23). The downstream drift of larvae was greater during the "night" than during the "day" (Table 15).

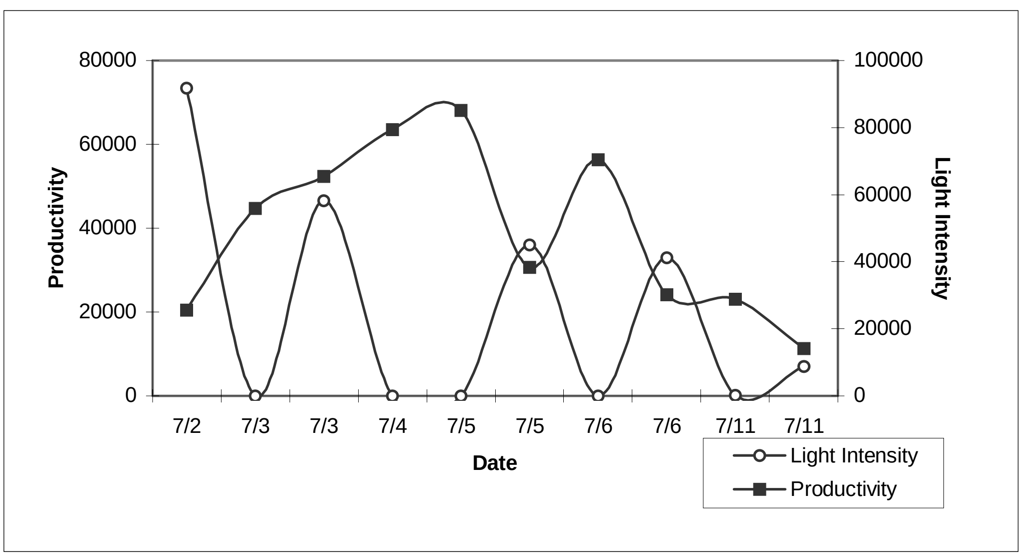

Figure 23. Light intensity compared to productivity of downstream drifting larval fish, 2001

Determine presence/absence of eulachon in the Portage Creek and Placer River drainages. (2000, 2001)

Placer River was sampled twice per week from 5 May through 15 June 2000 and 17 April through 20 June 2001. Eulachon were detected with low catch per unit effort (CPUE) in 2000. The presence of eulachon was not detected in any sampling events in 2001. CPUE was 0.3 fish/ hour in 2000 and 0 fish/ hour in 2001.

Portage Creek was sampled twice per week from 3 May through 14 June 2000 and 17 April through 20 June 2001. Eulachon were detected with low CPUE during both years. CPUE was 0.2 fish/ hour in 2000 (n = 3) and 0.7 fish/ hour in 2001 (n = 18).

Collect samples for larger eulachon study to determine stock composition and interception in the Pacific. (2001)

One hundred samples were sent to Dr. Doug Hay, at the Department of Fish and Oceans, Nanaimo, British Columbia. These data are currently under analyses, but the final product is dependent upon collection of samples from other regions. Therefore the date of completion is unknown.

DISCUSSION:

User demographics and harvest

The eulachon fishery at Twentymile River is an important resource for rural and Anchorage residents. It was particularly surprising that there was the participation by eleven rural communities with residents from as far away as St. Marys, Delta Junction and Talkeetna. Often, residents from these distant rural communities were visiting relatives in Anchorage or other rural communities closer to Twentymile River.

The estimated harvest of 14,941 kg in 2002 is higher than reported by ADF&G for Twentymile River or for any other river with a personal use fishery. From 1977-1997 the estimated average statewide harvest of smelt (eulachon and capelin *Mallotus villous*) was approximately 210,000 smelt (6,930 kg), with 54% taken from the Twentymile River (Mills 1991; Howe et al. 1998). The 2002 harvest in Twentymile River exceeds that of any other harvest of eulachon in the state of Alaska with the exception of the Copper River where annual harvest can be up to 78,300 kg (Moffitt, 2002).

Run timing and life history

The eulachon run lasts over a longer period of time in the Twentymile River than in any other river for which data are available (Table 16). The observed differences among the Twentymile River and other river systems could be due to environmental conditions or to sampling methods. Year-class strength or ocean rearing conditions can also influence the run timing and duration of anadromous fish such as sockeye salmon (*Onchorhynchus nerka*, Gilhousen 1960). Ocean temperature, the temperature gradient between ocean and freshwater, tide height and river discharge can affect run timing and intensity of eulachon (Langer et al. 1977; Groot and Margolis 1991).

Table 16. Geographic studies with run timing, gear type, dates, and duration.

River (Latitude)	Geographic Area	Year	Dates	Duration (days)	Source
Susitna	USA/ Alaska/	1982	5/10 – 6/5	27	Barrett et al.
(61º 16′N	Cook Inlet	1983	5/21 – 6/9	20	1984
150º 30′W)					
Twentymile	USA/ Alaska/	1972	5/20 – 6/4	18	ADFG 1972
(60º 84′N	Cook Inlet/	1973	5/14 – 6/12	30	ADFG 1973
148˚ 99′W)	Turnagain	1974	5/11 – 6/7	28	ADFG 1974
	Arm	1976	5/13 – 6/6	25	Browning
					1976
		1977	4/21 – 6/5	46	ADFG 1977
		2000	5/4 – 6/21	49	Spangler et al.
		2001	4/17 – 6/9	54	2002
Copper	USA/ Alaska/	1998	5/20 – 6/2	14	Morstad 1998
(60º 20′N	central coast				
145º 00′W)	of Alaska				
Nass	Canada/	1970	3/23 – 4/7	16	Langer et al.
(54º 59′N	northern coast	1971	3/17 – 3/27	11	1977
129º 52′W)	of British				
	Columbia				

Sampling techniques may influence results for run timing. Within the Twentymile River, shorter run durations were reported in the 1970’s compared to those in 2000 and 2001 in our study. In these earlier studies ice was more prevalent later into the spring. Eulachon have been reported to migrate under the ice in the Unuk River in southeast Alaska (Tisler and Spangler 2002). Therefore, it is reasonable to assume that if fish were migrating under the ice in Twentymile River, they would have been missed using conventional capture methods. This would have the appearance of shorter run duration.

We observed a one-week lag time between the start of the eulachon run and when dip net fisherman and predators arrived at the river. Data reported in Browning (1976) used creel survey information from dip net fishermen along with the presence of predators as indicators of the run duration on Twentymile River. If indeed this one-week lag period occurred, then the actual run duration would have been longer than reported. Additional bias using creel survey data could occur from fishermen use patterns. Fishermen were more prevalent on days of good weather or on the weekends.

Different environmental conditions in northern latitudes may explain the larger body size of eulachon in the Twentymile and Susitna Rivers than in populations further south (Tables 17 and 18). High latitude ecosystems such as the Bering Sea support some of the most productive and valuable fisheries of the world (Bakun 1996). This is due to the enrichment from seasonal overturns and tidal mixing occurring in shallow areas. Although recent and rapid increases in temperature from global warming and atmospheric oscillations may have caused declines in forage fishes in the Gulf of Alaska (Anderson and Piatt 1999), rearing conditions still may be better than those present in southern latitudes. Although caution must be used when comparing samples between rivers during different years, there was a general trend of smaller and older fish in the Fraser River when compared with fish from the Twentymile River (Tables 19 and 20). This may be reflective of more productive rearing conditions in northern latitudes. Additionally, it is interesting to note, although sample sizes were too small to include in our comparisons, the smallest mean lengths were reported in the southern extent of eulachon range. In California, Russian River males and females had a mean length of only 143 mm (Odemar 1964).

Table 17. Geographic studies (from north to south) with male and female mean length (mm) and mean weight (g).

River (Latitude)	Year	*n*	Mean Length (mm) Males	Mean Length (mm) Females	Mean Weight (g) Males	Mean Weight (g) Females	Source
Susitna (61º 16′N 150º 30′W)	1982	*	213	213	72	72	Barrett et al. 1984
	1983	*	206	206	64	64	
Twentymile (60º 84′N 148˚ 99′W)	1972	155	214	216	72	69	ADFG 1972
	1973	345	222	220	71	74	ADFG 1973
	1976	62	215	211	66	66	Browning 1976
	1977	408	215	210	91	86	ADFG 1977
	2000	287	215	202	70	60	Spangler et.al 2002
	2001	1011	209	203	66	60	
Copper (60º 20′N 145º 00′W)	1998	898	182	176	59	52	Morstad 1998
Fraser (49º 09′N 123º 12′W)	1986	441	181	164	43	33	Higgins et al. 1986
	1995	552	158	156	43	43	Hay et al. 1997b
	1996	459	156	155	41	42	

Table 18. Geographic studies with male and female age and mean length (mm).

River (latitude)	Year	Sex	Age at Length (mm)						
			1	2	3	4	5	6	7
Twentymile	2000	M		194	212	224	232		
(60º 84′N		F	168	180	205	220	226		
148˚ 99′W)	2001	M		201	209	218			
		F		195	203	216			
Copper	1998	M			179	182	183	176	
(60º 20′N		F							
145º 00′W)					181	175	177	186	
Fraser	1954	M			140	143	144		
(49º 09′N		F			156	164	148	151	
123º 12′W)	1986	M				172	183	196	205
		F				158	169		

Table 19. Geographic studies with male and female minimum, maximum, and mean age.

River (Latitude)	Geographic Area	Year	Sex	*n*	Mean Age	Max Age	Min Age	Source
Twentymile (60º 84′N 148˚ 99′W)	USA/ Alaska/ Cook Inlet/ Turnagain Arm	2000	M	168	3.3	5	2	Spangler et al. 2002
			F	49	2.9	5	1	
		2001	M	586	3.0	4	2	
			F	425	2.9	4	2	
Copper (60º 20′N 145º 00′W)	USA/ Alaska/ central coast of Alaska	1998	M	2012	5.0	6	3	Morstad 1998
			F	503	4.5	6	3	
Fraser (49º 09′N 123º 12′W)	Canada/ British Columbia	1954	M	18	3.5	5	3	Higgins et al. 1986
			F	23	3.5	6	3	
		1986	M	10	4.5	7	4	Ricker et al. 1954
			F	10	4.5	5	4	

Table 20. Mean age by geographic area for eulachon

River (Latitude)	Geographic Area	Year	Sex	*n*	Mean Age	Max Age	Min Age	Source
Twentymile	USA/ Alaska/	2000	M	168	3.3	5	2	Spangler
(60º 84′N	Cook Inlet/		F	49	2.9	5	1	et al.
148˚ 99′W)	Turnagain	2001	M	586	3.0	4	2	2002
	Arm		F	425	2.9	4	2	
Copper	USA/ Alaska/	1998	M	2012	5.0	6	3	Morstad
(60º 20′N	central coast		F	503	4.5	6	3	1998
145º 00′W)	of Alaska							
Fraser	Canada/	1954	M	18	3.5	5	3	Higgins
(49º 09′N	British		F	23	3.5	6	3	et al.
123º 12′W)	Columbia							1986
		1986	M	10	4.5	7	4	Ricker
			F	10	4.5	5	4	et al.
								1954

Other researchers have examined the relationship between body size and latitude for other species. Freshwater and marine fish have been documented to be larger in latitudes near the poles and smaller in latitudes closer to the equator for 131 species (Lindsey 1966). The fishes were largest in arctic climates (north of 60° N longitude) followed by cool temperatures (60°N to northern British Columbia) and smallest in northern, warm temperatures (southern British Columbia to California). However, in another study on chinook salmon (*Onchorhynchus tshawytscha)*, there was no such relationship found (Roni and Quinn 1995).

All investigations that have examined the presence of teeth in spawning eulachon in freshwater has documented some level of tooth absence. Our results differ somewhat from the observations of Hubbs (1925), Hart (1973), and Hay and McCarter (2000), who reported that teeth were generally absent on spawning fish. Although we also found edentulous spawning fish, most were males. Although there may be differences in latitude for which we cannot account, all adult eulachon sampled off the coast of British Columbia had teeth before entering streams to spawn (Hart 1973; Hay and McCarter 2000). This suggests that eulachon undergo tooth resorption between life at sea and spawning in freshwater.

The bone, scales, and teeth of teleosts contain high quantities of calcium (Ca) and phosphorous (P; Yamada et al. 2002). These bony formations may provide a reservoir for these ions as demand increases during sexual maturation (Simkiss 1974). The Ca ion is used by the liver to produce Ca-bonded glycolipophosphoprotein vitellogenin that is a precursor to the formation of egg yolk (Carragher and Sumpter 1991). Phosphorous makes up an important element of nucleotides, nucleic acids, and phospholipids used in metabolic processes and is also an important component of vitellogenin (Lall 1989; Yamada et al. 2002).

Most studies on tooth resorption have been conducted on females. This process is less understood for male fish, yet our results indicate a higher percentage of tooth resorption for males when compared with females. First, it is unknown if females have more teeth in the marine environment than males. Second, there may be differences in the timing of sexual maturation between males and females. If females mature earlier when in the marine environment, Ca and P would be more readily available. Therefore, ions stored in bony structures would not have to be mobilized. If males matured later in or near the estuary, needed ions for development of tubercles and sperm would need to be drawn from the bone and muscle tissues. Third, we found males spent more time in freshwater than females. As P is an important element in metabolic processes, more may be needed since eulachon do not feed in freshwater.

Similar to other researchers, we found that male eulachon greatly outnumber females during the spawning run (McHugh 1939; Smith and Saalfeld 1955; Browning 1976; Higgins et al. 1987; ADF&G 1966, 1973, 1974, 1976, 1977, 1978; Morstad 1998). Skewed ratios are also seen with rainbow smelt, always favoring males to females (Kendall 1927 cited in Rupp 1968). The presence of more males may be due to the spawning behavior of smelt. Fertilization success would increase with more available milt in the water increasing the probability of eggs being fertilized. Therefore, the skewed ratio may be a key element to successful spawning (Smith and Saalfeld 1955). However, there is some debate, as little is understood of their spawning behavior. Although it is not known if eulachon are iteroparous or semelparous, we found males to be older than females. If males were capable of spawning multiple years, and if females were limited to one spawning season then the sex ratio would also favor males even after oceanic mortality. Highly skewed sex ratios are often observed with hermaphroditic fish species, but this phenomenon is currently unknown for eulachon (Maynard-Smith 1984).

Previously documented sex ratios may not be true representations of eulachon populations. Errors can result from sampling gear bias, sampling positions in the river, timing of sampling, and misidentification of sex. Sex ratios can vary with different gear types and caution must be used when determining methods of capture (McHugh 1939). In this study, we found differences in sex ratio with sampling gear. Because dip nets are of a fine mesh (5 mm) and the opening of the net was large enough to capture all sizes of fish, we feel this method was not size selective in our study.

The location in the river (across and upstream) at which eulachon were collected has been proposed to cause variations in sex ratio. Males have been reported to occupy areas closer to shore, whereas females remained in the center of the river (Hart and McHugh 1944). This distribution would explain greater percentages of males collected by dip netting from a position standing on the riverbank.

Contrary to other researchers, we found no significant relationship associated with sex ratio and migration time in the Twentymile River in 2001. However, in 2000, we did observe two time periods when females were more prevalent. The run in 2000 was bimodal and females seemed to run at the beginning of each pulse. Some researchers suggest a differential migration timing by sex with the number of males increasing as the spawning run continues over time (Langer et al. 1977; ADF&G 1966; Smith and Saalfeld 1955). Another report suggests the number of males decreases as the spawning season progresses (McHugh 1939). In both of these studies, it was unclear if the counts contained fish that were only in pre-spawning condition. We found higher numbers of males later in the spawning run, but found most spawned out and moving downstream. Therefore, these fish were not counted in our sex ratio estimate. This is similar to the eulachon dip net fishery on the Cowlitz River in Washington where most of the fish caught at the end of the fishing season were males that had spawned (G. Bargmann, Washington Department of Fish and Wildlife, Olympia, Washington; personal communication).

For studies using external visual observation of morphological characteristics to identify sex, misidentification can occur. This is especially true in the later portions of eulachon spawning runs. Females, migrating downstream after spawning look similar to pre-spawning males that lack some of the secondary sexual characteristics such as the presence of tubercles. These well-developed, visible tubercles are also identified on male rainbow smelt (Buckley 1989). Caution should be used in visual sex determinations to avoid over-estimations of males. We found that verifying sex by observing the gonads was the best way to avoid this error.

Adult migratory behavior and spawning habitat

The radio tag retention test successfully assessed the eulachon ability to retain a radio tag after a gastric implant. This success was affirmed in field tests. Although it is difficult to determine whether these tags were mortalities or regurgitated, our success rates were similar to other researchers using gastric tags. For example, success rates reported by Wuttig and Evenson (2002) were the following in the Holitna River, Alaska: adult chum salmon (*Onchorhynchus keta*, 94.0 percent), adult coho salmon (*Onchorhynchus kisutch*, 88.7 percent), adult Chinook salmon (*Onchorhynchus tshawytscha*, 85.5 percent). Similar success rates were also reported for Atlantic salmon varying between 87.5 and 83.3 percent (*Salmo salar L.*; Smith et al. 1998). In a study conducted on juvenile chinook salmon (*Onchorhynchus tshawytscha*), Martinelli et al. (1988) reported a 94.8 percent success rate using a similar tag type and size as in our study. However, these juvenile fish were exposed to different environmental stresses than migrating adult fish.

Males and females respond differently to handling and radio tagging. Females appear to be more sensitive to tagging, as they were the one sex that experienced mortalities. Additionally, females were three times more likely to move upstream, and then show no movement until the life expectancy of the tag was reached suggesting death or regurgitation. Although the ratio of tag weight to body weight was within acceptable levels (2 percent; Winter 1983), females were on average smaller, and therefore the tags made up a greater percentage of body weight than for males. This added stress from transmitter weight might have caused the higher regurgitation or mortality rate.

Males spent more time in the Twentymile River and migrated further than females in this study. The ratio of males to females also increased with distance upriver similar to Langer et al. (1977). Although there little other work on eulachon with which to compare, this behavior has been observed for other species. Although they did not report migration distances by sex, male rainbow smelt (*Osmerus mordax*) did spend approximately twice the time of females in the river (Rupp 1968). On a study of charr, male fish moved nearly twice the distance of females during the spawning run (McCubbing et al. 1998). This adaptive value of this widespread movement of males is uncertain but such movement would allow males to spread their genetic material over more of the population or to find available females.

A portion of the population may be spawning in the estuary. Some fish moved downstream of the tagging site following tag insertion, never to pass upstream. This may have been due to tag effect. However, these fish did not remain stationary and instead moved in and out of this lower section of river. These fish may have been intercepted and tagged at the upper limit of their migration and are spawning in the estuary of Twentymile River. This group of fish had similar residence times within the river to fish that migrated upstream past the tagging site. Rainbow smelt, a similar species, spawns both in the estuary, as well as upriver (Buckley 1989). The estuary is also where the majority of harvest from dip net fishermen occurs. Fish moving in and out of this estuary area may be vulnerable to multiple fishing efforts and as such, this segment of the population could receive a higher proportion of overall fishing effort.

Adult eulachon spent a relatively short period of time in freshwater. This is similar to the retention time of anadromous rainbow smelt (four to ten days; Rupp 1968; Buckley 1989). This short retention time within the river would have several advantages. First, this behavior may be an adaptation to avoid predation. The density of predators is much higher during the eulachon runs than observed for migrations of other fish species such as salmon (R. Spangler, USFS, Glacier Ranger District, Girdwood, Alaska; personal communications). Large aggregations of predators feed on spawning eulachon (Swan 1881; Langer et al. 1977). By spawning quickly in great numbers, eulachon may decrease exposure to predation thereby increasing the opportunity to produce offspring. Second, spending little time in freshwater would allow fish to spend more energy on gamete production instead of using valuable energy reserves maintaining positions in the river when they are not feeding.

Although radio telemetry is a useful tool to study migratory behavior of eulachon, other methods should be used to determine the upper limits of spawning. In both 2000 and 2001, radio telemetry failed to establish the upstream limits of spawning. More tagged fish may have reduced this error, but increasing the number of tags is expensive. Additionally, increasing the number of tags still represents a small percentage of the total spawning population. Larval sampling at an area considered to be the upstream limits of spawning will include all fish passing this location. Additionally, the sampling method is simple and relatively inexpensive when compared to the cost of radio telemetry equipment.

Eulachon appear to be selecting similar areas each year for spawning in the Twentymile River. One spawning area identified by Browning in 1976 on the Twentymile River was confirmed by our work in 2001. This area also was identified in 2000, but was not the most concentrated spawning area. These results suggest that eulachon are selecting certain spawning areas. It is important to realize however, that our observations were made during the day. As spawning behavior has been reported at night (Franzel and Nelson, 1981) our observations may not reflect spawning site selection. Fish could be using the deeper water for cover during the day and using different adjacent areas for spawning at night. Female rainbow smelt have been documented at spawning beds at night and moving back into the estuary during the day (Buckley 1989). However, male rainbow smelt tend to stay near the spawning beds at all times.

Radio telemetry, with acknowledged precautions, is an effective method for evaluating the migratory behavior of eulachon. Procedures were straightforward to implement and success rates were similar to those reported for other telemetry studies. However, there are several precautions that should be taken to accurately characterize a spawning migration. First, it is critical to mark equal percentages of males and females as our study suggests differential movement and retention in the river system between sexes. Second, it is important to be able to successfully identify pre-spawning and tagged fish at the leading edge of the run because of the short fish-residency time in the river. This short residency time also necessitates frequent tracking events. If the researcher tracks every other day, fish may be missed entirely. We recommend tracking at least once every 24 hours in combination with a fixed station operating continuously to detect passage across sites. Third, researchers should be aware that eulachon spend time in the estuary where high salinity levels occur. Some fish spent the entire time there. Salinity affects the ability to receive radio tag signals because of signal attenuation and therefore our ability to track fish is limited to periods of low tide when the salinity is low. To accurately assess movements in the lower river, future studies would benefit from using a new combined acoustic and radio transmitting tag. The combined tag allows monitoring of the migration from freshwater into the marine environment.

Management activities that could adversely affect spawning site conditions in the lower 9.5 km of river should be avoided, as the radio telemetry indicate this section of river is critical spawning habitat. Some spawning occurs above this point, but this was limited in 2000 and 2001. It is interesting to note that in 2002, adult eulachon were observed approximately 1.5 km further upstream than we reported in 2000 and 2001 (A. Eller, USFS, Glacier Ranger District, Girdwood, Alaska; personal communication). Therefore, caution must be used when determining critical spawning habitat because additional areas may be located in the upper drainage.

Another interesting finding was that a segment of the population moved back and forth in the estuary where most of the harvest occurs. Fish that move up and downstream or remain in the area are subject to multiple fishing efforts. Therefore, fish that spawn in the lower estuary may receive unequal fishing pressure when compared with fish that spawn upstream. In this area, one of twenty-three radio tagged fish were caught and returned in 2000 and six of one hundred and eight were returned in 2001. Although the data is anecdotal, there could be greater fishing effort exerted on this segment of the population.

Environmental factors associated with adult and larval migration

The temperature at which eulachon spawning runs commence varies by geographic area. In studies conducted on the Cowlitz River, Washington, between 1946 and 1953, researchers reported temperatures between 3.9° and 6.1° C at the onset of spawning runs (Ricker et al. 1954; Smith and Saalfield 1955). In the Fraser River, B.C., temperatures at onset varied from 4.8° to 7.6° C between 1941 and 1953 (Ricker et al. 1954). Further north in the Nass River, B.C., river temperatures were between 1° and 2° C in 1970 and 1971 (Langer et al. 1977). In the Susitna River, Alaska, temperatures reported at the onset of the run were from 2° to 3° C in 1982 and 1983 (Barrett et al. 1984), while they ranged from 2.8° C to 6.0° C in the Twentymile River, Alaska (ADF&G 1973; this study).

Our results support the findings of other researchers indicating peak migration of adults occurring during periods with high tides and low river discharge (Langer et al. 1977). Because eulachon are considered to be poor swimmers (Langer et al. 1977), upstream movement would be easier and faster during these conditions. Migrating during these times would save energy for spawning and allow fish to reach spawning areas sooner thereby limiting exposure to predators, especially in shallow areas.

High CPUE values of adult eulachon during low light levels may be a behavioral adaptation to escape predation. In Twentymile River bald eagles, gulls, beluga whales, harbor seals, Dolly Varden char (*Slavelinus malma*), and humans were observed preying on eulachon (author's observations). Some predators use visual observation for capturing eulachon, therefore lower light intensities could favor survival. Often eulachon return in such high numbers that it is efficient for predators to focus on this one prey source. An original description in the Nass River (Swan 1881, cited in Langer et al. 1977) notes porpoises, seals, dogfish, ground sharks, halibut, gulls, ducks, and other sea birds accumulate in the immediate vicinity when the eulachon spawning run begins. Here, in excess of 300 bald eagles and thousands of gulls have been reported associated with the eulachon spawning migration. The report indicates the greatest density of predators occurring only one day before the peak of eulachon collected using trawl net tows (Langer et al. 1977). We found the highest counts of bald eagles occurred three days before the peak of the eulachon spawning run.

Our results were similar to other studies indicating that peaks in larvae occur during periods of stable water temperature. In Twentymile River, water temperatures did not vary by more than 1.9º C during peak downstream drift. Variation in water temperature was also relatively small (2.8º C) on the Cowlitz (Smith and Saalfeld 1955), Fraser (Hart 1973), and Nass Rivers (Langer et al. 1977) during peak downstream drift. As eulachon larvae are sensitive to large fluctuations in water temperatures (Blahm and McDonnell 1971), perhaps larvae time movement out of rivers corresponding with periods of stable water temperature to avoid death or adverse metabolic effects.

Our findings support the idea that the number of ATU needed to incubate eulachon eggs increases with latitude (Pedersen et al. 1995). In a northerly direction the order of rivers and the ATU are as follows: Columbia River, 188 (Smith and Saalfeld 1955), Kemano River, 242 (Triton 1990), Kitimat River, 258 (Pedersen et al. 1995), and Twentymile River, 303 (this study). These observed differences may suggest that these fish populations are either from separate stocks or adapted to the local environments. Very little genetic work has been conducted on eulachon. However, in one study conducted on stocks of eulachon from the Bering Sea, Alaska, B.C., Washington, and Oregon, 97 percent of all genetic variation occurred within local populations (McLean et al. 1999), indicating high gene flow among populations from different geologic areas. More research is needed to determine the uniqueness between eulachon populations.

Generally we found that as discharge increased, the downstream larvae increased in number. Eulachon are demersal spawners with the eggs settling on the bottom and adhering to the substrate (Snyder 1970). They spawn on the bottom of a stream or river, typically on substrates of sand, organic demersal debris and small gravel (McHugh 1940; Smith and Saalfield 1955; Samis 1977). As discharge increases, bedload movement and substrate scour are more pervasive. This in turn, has the ability to dislodge fish and eggs from gravel and transport them downstream. Although we did not measure turbidity, we observed lower water visibility during periods of higher discharge. Larvae may also be timing migration with lower water visibility to avoid predation.

We found a two-fold increase in the productivity of larvae at lower light intensities (night) than during periods of high light intensities (day). Although there are no studies reporting predation on larval eulachon, drifting at night would limit predation. This is a common strategy used by other larval fish, such as young of the year sockeye salmon (Egorova 1970).

The results of the exploratory analyses presented here indicate that there are several environmental variables worth considering when developing monitoring programs using larval or adult eulachon. For managers designing monitoring studies, we suggest a year or two of preliminary investigations that include investigating the following variables. For adult fish, environmental factors should include water temperature tide height, river discharge, light intensity, and the density of bald eagles. For monitoring larval fish, environmental factors should include water temperature, river discharge, and light intensity. Calculations of ATU can also help to time the start of larval sampling. By having a better understanding between these variables, monitoring studies can be conducted more time efficiently and cost effectively.

Based on our results, to calculate a reliable population index for the Twentymile River, larval sampling could be reduced to three times per week. In more recent studies, we have also developed a method for reducing the time (by 66%) it takes to sort through larval samples increasing efficiency (USFS, unpublished data). Therefore, we estimate the cost of an annual monitoring program at $35,000. Overall, the larval monitoring process was relatively simple and easy to implement. The only drawback of the current program is the need to conduct some sampling at night, which can be more dangerous for personnel. However, it might be possible to develop a correction factor for the light intensity environmental variable if more data is made available.

Presence and absence in Portage Creek and Placer River

It is unlikely that significant eulachon populations exist in Portage Creek and Placer River. Eulachon were detected only during a few sampling sessions. Times of detection coincided with peak CPUE in the Twentymile River. The close proximity to the mouth of the Twentymile River (all three rivers form confluence at one point) could have resulted in some straying into these systems. Additionally, there could be fish actually spawning below the confluence area as indicated by the radio telemetry data. Some adult tagged fish were spending a large amount of time in this confluence area. However, it is currently unknown if eulachon can spawn successfully in the euryhaline conditions of estuaries.

It is important to realize that just because fish were not detected in the two-year time period, does not preclude their use for spawning in the future. In British Columbia, there is significant variability in the spawning site fidelity of eulachon, and eulachon are known to vary in return strength between rivers sharing a common estuary in Boroughs and Berners Bays, located in southeast Alaska (R. Spangler, unpublished data).

CONCLUSIONS AND RECOMMENDATIONS:

1. Approximately 9% of all fishermen are from rural areas representing 11 different rural communities.
2. To determine proper sampling design for run strength and life history for adult fish, the environmental factors that should be considered include water temperature tide height, river discharge, and light intensity. If resources are severely limited, the presence of bald eagles could be used to determine the start and peak of the eulachon run.
3. There may be a proportion of the adult population spawning in the estuary. Further research is needed to determine if eulachon are capable of spawning in the euryhaline conditions of the estuary. If fish are capable of spawning in the estuary, larval sampling could be missing a segment of the population leading to erroneous results.
4. The larval monitoring index appears to be an effective tool for determining population trends. To develop an efficient and valid sample design, environmental factors considered should include water temperature, river discharge, and light intensity. Sampling should be stratified by depth. Calculations of ATU can also help to time the start of larval sampling and increase sampling efficiency reducing cost. In Twentymile or similar river, cost of larval monitoring is estimated at $35,000 per year.
5. Adult eulachon spend relatively short periods of time in fresh water limiting exposure to harvest. Eulachon do not migrate to spend many days or weeks congregating and spawning as some salmon do.

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