ABUNDANCE AND MOVEMENT OF THE RAINBOW TROUT SPAWNING STOCK IN THE UPPER NAKNEK RIVER, ALASKA

by
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Native rainbow trout *Oncorhynchus mykiss* in the Naknek River of Southwest Alaska attain large sizes and support a popular recreational fishery. I studied the dynamics of the spawning stock during 2000 and 2001. Three methods of capturing spawning fish were assessed; the length structures and sex ratios of spawning fish were described; mark-recapture estimates of the number of spawning fish were conducted; and movements of fish following spawning were determined. I found that drifting gill nets and beach seines were efficient sampling gears, but hook and line was inefficient and biased toward immature fish. Median fork lengths of spawning fish were 640 mm for females and 697 mm for males with fish up to 860 mm in the samples. There were about 3,000 spawning fish in the Naknek River during each year of the study. Eighty percent of radio-tagged fish moved from the river upstream into Naknek Lake following spawning and most of these fish returned to the river in the fall. This information can be used in future monitoring of the spawning stock and assessment of the effectiveness of sport fishing regulations.

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Introduction

Rainbow trout *Oncorhynchus mykiss* have a broad native range in western North America extending from Mexico to the northernmost populations in the southern tributaries of the Kuskokwim River, Alaska (Behnke 1992). The Naknek River of Southwest Alaska is near this northern boundary and supports a natural population of rainbow trout. Naknek River rainbow trout attain large sizes, up to 920 mm TL. Large size is attributed to an abundant food source of sockeye *O. nerka* fry supplied by large escapements from spawning sockeye salmon. Sexually mature rainbow trout in the Naknek River exhibit an allacustrine movement pattern. They move downstream from Naknek Lake to spawn in the upper 14 km of the Naknek River from early April through May, and they migrate upstream into the lake after spawning (Gwartney and Burger 1986). Gwartney and Burger (1986) found that these fish spend the summer in the lake and may return to the Naknek River in the fall. The life history of rainbow trout that spawn in the upper Naknek River is similar to that of steelhead *O. mykiss* in that they attain large sizes and migrate into a large lentic system after spawning. The northernmost steelhead populations are near Port Heiden on the north side of the Alaska Peninsula, several hundred kilometers to the south of the Naknek River drainage (Behnke 1992).

A significant portion of the Naknek River drainage consists of Naknek Lake and the outlet drainage of the Naknek River (Figure 1.1). A large portion of the drainage is in the Katmai National Park and Preserve. Naknek Lake is a large oligotrophic body of water with a surface area of approximately 610 km^2 and a maximum depth of 173 m (Burgner et al. 1969, LaPerriere 1996). The Naknek River flows past the town of King

Salmon into Bristol Bay of the Bering Sea near the town of Naknek (Figure 1.1). The Naknek Drainage supports five distinct spawning stocks of rainbow trout; above and below the falls of Brooks River, Idavain Creek, American Creek, and the Naknek River (Gwartney 1985). Limited seasonal mixing of Brooks River, Idavain Creek, and Naknek River stocks has been documented with Floy-tag data from the 1960s through 1985; however, no mixing of the spawning stocks during the spring has been documented (Gwartney 1985). In addition to rainbow trout, the Naknek River drainage supports populations of five species of salmon: sockeye, chinook *O. tshawytscha*, coho *O. kisutch*, chum *O. keta*, and pink *O. gorbuscha*. Resident sport fish species include: Dolly Varden *Salvelinus malma*, arctic char *S. alpinus*, lake trout *S. namaycush*, Arctic grayling *Thymallus arcticus*, and northern pike *Esox lucius*.

Because the Naknek River flows adjacent to the towns of King Salmon and Naknek it is highly accessible to recreational angling. The first significant angling effort on the Naknek River began in the 1950's when two military recreation camps were established on the river (Gwartney 1985). Lake Camp was near the outlet of the lake and Rapids Camp was 14 km downstream. The two camps were closed in 1974; however, these sections of the river are still locally referred to by the camp names. Angling by civilians increased once the camps were closed and eventually private lodges were created to provide guided fishing. Due in part to its accessibility, the Naknek River sustains over 15,000 angler-days annually, the highest amount of angling of any sport fishery in Southwest Alaska (Howe et al. 1998). Salmon species are the target of most of the angling; however, the Naknek River is world famous for abundant, large rainbow trout (Dunaway and Fleischman 1996).

The Naknek River drainage has been studied periodically by various agencies, particularly the Alaska Department of Fish and Game (ADFG). Physical and chemical descriptions of the Naknek River drainage have been conducted (Buck et. al. 1978, Greenback 1954, Gunther 1992, LaPerriere 1996). From 1956 through 1962 the ADFG collected data through a voluntary creel survey at the two military camps (Paddock 1964). Scale analysis to determine the age of rainbow trout was first done in the 1960s (Redick 1967, Siedelman and Cunningham 1972). Between 1981 and 1985 the ADFG conducted several creel surveys to estimate the numbers of rainbow trout caught and kept in the Naknek River. Age, weight, and length data were collected from rainbow trout retained by anglers (Gwartney 1985). Minard and Dunaway (1991) prepared a compilation of all age, weight, and length data from rainbow trout samples collected in Southwest Alaska for the years 1954-1989 and Riffe (1994) prepared a similar compilation for 1990-1993.

Spawning surveys of rainbow trout in the Naknek River were conducted from the air and on foot from 1982 through 1985 (Gwartney 1986). These surveys identified concentrations of spawning rainbow trout and attempted to count the fish. Aerial and foot counts of spawning rainbow trout were conducted in the 1970's and 1980-1985 with counts varying from 130 to 2,500 fish (Gwartney 1985). In 1993 the ADFG attempted a mark-recapture estimate of spawning rainbow trout in the Naknek River, but they did not obtain enough recaptures to estimate abundance. However, mark-recapture estimates of abundance of rainbow trout spawning aggregations have been made on the Kvichak River in Alaska (Minard et al. 1992). Abundance estimates of rainbow trout have also been accomplished on the upper Kenai River and Willow Creek with a mark-recapture experiment (Lafferty 1989, Hayes and Hasbrouck 1996, Bartlett and Hansen 2000). The ADFG has recently conducted abundance studies of spawning rainbow trout on the middle Kenai River of south central Alaska using similar techniques (Larson and Hansen 2000).

Length frequency and age data were collected from the spring population of rainbow trout in the upper Naknek River in 1981-1985, 1988, 1989, and 1993 (Daniel Dunaway, Dillingham, Alaska, personal communication). Coggins (1994) conducted an in-depth analysis on the precision of aging rainbow trout scales from fish sampled in the vicinity of Bristol Bay. He found that repeatability of age estimates from rainbow trout scales was highly variable among readers (Coggins 1994). In comparison, length data are not influenced in this manner. It has been found that age determined from scales tends to underestimate the age of older fish, such as those in the Naknek River spawning population (Beamish and McFarlane 1987). Gwartney (1985) analyzed age data and found that rainbow trout of the Naknek River are long lived and may live up to 14 years. Gwartney (1985) determined that age is closely related to length for rainbow trout in the Naknek River and concluded that length measurements could detect changes in the population structure. As a result, the ADFG has only relied on length composition data to detect changes in the spawning population of the Naknek River.

The rainbow trout stock in the Naknek River has been managed with special regulations since statehood. Liberal regulations and increasing effort caused declining catch rates and a decrease in the lengths of catchable fish (Minard and Dunaway 1994). A combination of creel surveys and biological data collected in the late 1980’s indicated that anglers were over-harvesting large fish (Minard and Dunaway 1994). Reduced creel limits, as well as length and gear restrictions, were adopted in 1990 (Minard and Dunaway 1994). Sport fishing regulations decree a daily creel limit of five rainbow trout less than 457 mm total length (TL) from 1 November through 9 April and one fish less than 457 mm from 9 June through 31 October (ADFG 2000). Angling is also restricted to single-hook, artificial lures. Additionally, the fishery is managed under the guidelines of the Southwest Alaska Rainbow Trout Management Plan (Minard and Delaney 1989). The plan was implemented to protect the biological integrity of wild trout stocks while maximizing recreational and economic potential. These actions initiated by the ADFG appear to be maintaining a stable trophy fishery.

Rainbow trout fishing takes place upstream of Rapids Camp to the outlet of the lake and has three periods of activity: March to 9 April, 8 June to 30 June, and 15 August until the river freezes in October (Minard and Dunaway 1994). A limited sport fishery that coincides with break-up of ice in the early spring exists on the Naknek River for pre-spawn rainbow trout. The angling pressure in the spring fishery is limited by inclement weather that discourages prospective anglers. Since the 1970's, sport-fishing closures have protected spawning aggregations of rainbow trout. Currently, the section of the river where the majority of spawning activity occurs, i.e., from Rapids Camp upstream to Trefon's Cabin at the lake outlet, is closed to angling from 10 April until 7 June (ADFG 2000). Once the sole province of local anglers, the spring fishery has grown to include more non-local anglers and guided fishing. An unpublished study (George Naughton, Dillingham, Alaska, personal communication) by the ADFG during the spring fishery of 1999 found that 54% of the anglers were not from the King Salmon-Naknek area and

27% of the anglers were guided. Participation by nonresident anglers in the spring fishery has potential to expand.

Potential growth of participation in the fishery and the addition of guide services have sparked controversy and demands for more restrictive regulations. The controversy involves concerns over possible biological impacts on the rainbow trout population, as well as social and allocation issues. These concerns have manifested into regulation proposals to the Alaska Board of Fisheries (ABF) by members of the public. The ABF governs all sport fish regulation changes in Alaska. Proposals to close the spring fishery, reduce the spring fishing season, and restrict guided fishing have been submitted to the ABF.

Rainbow trout angling in the upper Naknek River resumes on 8 June. In early June rainbow trout begin to feed on sockeye salmon smolts migrating downriver from Naknek Lake to Bristol Bay. Angling effort almost exclusively targets these feeding rainbow trout until effort switches to chinook salmon in late June. It is not known if many post-spawn rainbow trout are exploited in this June fishery. Rainbow trout from the spawning population have been shown to move to Naknek Lake for the summer (Gwartney and Burger 1986). These fish have been observed as a portion of the catch in a summer fishery that occurs in an area of the East Arm of Naknek Lake known as Bay of Islands (Figure 1.1). Floy-tagging data in the early 1980s support these movements. In the early 1980s, 14 of 228 Floy-tag recoveries from Naknek River rainbow trout were reported from the Bay of Islands (Gwartney 1985).

The rainbow trout fishery on the Naknek River reaches another peak of angling activity in August when salmon begin to spawn and it continues into October. In 1999 the ADFG collected data to estimate the length composition of catchable rainbow trout from 9 September to 5 October and sampled 289 fish with conventional sport fishing equipment (George Naughton, Dillingham, Alaska personal communication). Large fish became more prominent in the sample as the fall progressed. This observation that larger fish were present in the Naknek River as fall progressed was corroborated by the experience of anglers and guides who participate in the fall fishery. A Floy-tagging study conducted drainage-wide during the early 1980s gave the ADFG limited data on rainbow trout movements. Recaptures indicated that rainbow trout tagged during spring in the spawning area returned in subsequent years (Gwartney 1985). Similar fidelity to spawning location has been found in the Kvichak River through extensive Floy-tagging of a population of rainbow trout with a similar life history (Minard et al.1992). It is unknown if the large fish present in the Naknek River during the fall are from the spawning population and are returning to the river to winter and spawn the following spring.

The ABF has assigned the ADFG the task of developing a management plan for the Naknek River rainbow trout fishery. It is important for the ADFG to assess the status of the spawning population to evaluate the effectiveness of a management plan and current regulations. The ADFG needs a method for monitoring the abundance and length structure of spawning rainbow trout in the Naknek River.

Current regulations in the Naknek River allow for the retention of fish less than 457 mm TL. The intent of this regulation was to provide some harvest opportunity while providing protection of large spawning fish. This length was arbitrarily chosen with the assumption that spawning fish would be protected from harvest. Extensive length data have been collected from the spring population of rainbow trout; however, these data have not been collected in conjunction with the determination of sexual maturity. As a result, the minimum length at which fish become sexually mature is not known. Length data from sexually mature and immature fish in the upper Naknek River during the spring are needed to determine the lengths at which fish become sexually mature and to evaluate the effectiveness of the current length regulation.

Angling closures protect the spawning population in the upper Naknek River during April and May, but it is unknown if this population is susceptible to exploitation by angling through the summer and fall. It has been determined that some rainbow trout migrate to Naknek Lake after spawning, but the proportion of fish that remain in the river when rainbow trout fishing resumes on 8 June is unknown. This date was selected to protect spawning rainbow trout from angling; however, it is unknown if post-spawning rainbow trout make up a portion of this fishery.

A fishery occurs in the fall, and large rainbow trout appear to be more abundant in the upper Naknek River as fall progresses. It is not known if these fish are members of the spawning population that return to the upper Naknek River to spend the winter and if they are available for exploitation in the fall fishery.

My study was conducted during the spring of 2000 and 2001 focusing on rainbow trout in the upper 14 km of the Naknek River. My goal was to assess sampling techniques and provide information needed in the development of a management plan for rainbow trout in the upper Naknek River. My objectives were to determine: (1) the effectiveness of hook and line, gill net, and beach seining for sampling rainbow trout, (2) the potential for using a mark-recapture technique to estimate the abundance of sexually mature spawning rainbow trout, (3) the length composition of rainbow trout $\geq$ 200 mm TL during spawning, (4) the effect of length on sexual maturity of rainbow trout, (5) the proportion of adult rainbow trout that remain in the river or move to Naknek Lake during summer, and (6) the proportion of rainbow trout that moved to Naknek Lake and return to Naknek River during fall.

The objectives are addressed in three chapters. The first chapter addressed objective 1, the effectiveness of hook and line, gill net, and beach seining for capturing rainbow trout. Chapter 2 addressed the abundance estimates and population characteristics, i.e., objectives 2 through 4. The movement objectives, 5 through 6, are addressed in Chapter 3. Management implications of the findings are addressed after the final chapter.

Chapter 1

Evaluation of Gear Types for Assessment of the Rainbow Trout Spawning Stock in the Naknek River, Alaska

Many techniques are available for the capture of fish for biological sampling. Electrofishing was commonly utilized by the Alaska Department of Fish and Game (ADFG) to sample rainbow trout *Oncorhynchus mykiss* until 1988 when research indicated that a large proportion (44 - 70%) of adult rainbow trout captured by electrofishing received spinal injuries and a substantial proportion (14%) experienced short-term mortality (Sharber and Carothers 1988, Holmes et al. 1990). As a result of these findings, the ADFG initiated a moratorium on the use of electrofishing for sampling rainbow trout greater than 400 mm total length (Holmes et al. 1990). Recent findings indicate that electroshocking also reduces rainbow trout growth (Dwyer and White 1995, Dalbey et al. 1996). Alternative capture techniques are needed that can capture large numbers of adult rainbow trout in riverine systems.

The ADFG has used hook and line to capture rainbow trout and this technique has been adequate for length-weight, growth, and body-condition analysis. A benefit of hook and line sampling is that it allows for estimates of population characteristics, such as length frequency distribution, using data obtained by recreational anglers (Minard et al. 1992). The odds of landing fish with hook and line depend on the spatial distribution of the fish, the chance an individual fish will take a lure, and the probability that a take results in a catch (Deriso and Parma 1987). There is an upper limit to the number of fish that may be sampled over a time span regardless of fish abundance due to the time required to retrieve and deploy the lure (Deriso and Parma 1987). Selectivity of hook and line gear is recognized and has been related to lure size (Leclarc and Power 1980). Small fish will be selected against if the lure is too large and large fish may be selected against if the lure is too small to interest them. Also, large fish are less likely to be landed when hooked due the greater force they exert on tackle and their ability to maintain a struggle thereby increasing their chance of escape before landing. Fish may exhibit a learned response from being captured by angling and may not take a lure as readily during another encounter reducing the probability of recapture (Anderson and Heman 1969). This has potential to confound mark-recapture studies where hook and line gear are used to both initially capture and recapture fish.

The ability to capture fish with seines depends on substrate, species of fish, size of fish, and the probability of encirclement and retention (Bayley and Herendeen 2000). Capture efficiency varies by species with benthic species having lower capture efficiencies than mid-water species (Penczak and O'Hara 1983, Lyons 1986, Parsley et al. 1989, Holland-Bartels and Dewey 1997). The capture efficiency decreases for fish of larger sizes as the net is set, but retention is greater for larger fish as the net is hauled (Bayley and Herendeen 2000). Larger fish exhibit greater swimming speed and may escape while a net is set, whereas smaller fish can better escape under lead lines during hauling. Larger seines encircle better, but they also increase contact with snags. Substrate type, such as cobble and boulders, or the presence of snags can reduce the retention of fish while seining (Parsley et al. 1989, Bayley and Herendeen 2000). Few studies have examined the capture of large salmonids with seines in large rivers with substantial current. Beach seines have been used to capture large numbers rainbow trout aggregated for spawning to estimate abundance and stock characteristics in the Kvichak

River of Alaska, although capture efficiency has not been determined (Minard et al. 1992).

Fish captured in gill nets can be gilled, wedged, stuck by the head, or tangled (Hamley 1975, Losanes et al. 1992b, Hubert 1996). The selectivity of a gill net of a certain mesh size can be calculated to determine the modal length of fish of a given species that may be captured (Hamley and Regier 1973, Hamley 1975, Jensen 1995a, Jensen 1995b). This calculation often results in selectivity skewed towards larger fish (Hamley and Regier 1973, Hamley 1975, Losanes et al. 1992a, Losanes et al. 1992b, Jensen 1995a, Jensen 1995b). Fish that are larger than the modal length are captured more frequently than smaller fish. These fish become entangled, held by teeth or maxillaries, or wedged by the head. Factors important for gill-net selectivity include: mesh size; stretching of the net; strength, flexibility and visibility of the twine; shape of the fish; and the way the net is fished (Hamley 1975). Nets made of thinner twine capture more fish due to less visibility and greater flexibility (Hamley 1975, Jensen 1995a). Gill nets of a greater depth resulting in a higher degree of slackness tangle fish more efficiently (Losanes et al. 1992a). These concepts may be applied for the nonlethal capture of adult rainbow trout with actively fished gill nets of mesh size small enough to prevent gilling but allow for capture by the head and entanglment.

Many studies have compared capture techniques for various species (Wiley and Tsai 1983, Elliot and Beamesderfer 1990, Boxrucker et al. 1995, Neumann et al. 1995, Van Den Avyle et al. 1995). These studies often determine that a certain gear captures more fish of a given species and is less selective for other species, suggesting the use of that gear for future sampling of the species. One way of estimating the selectivity of a gear is by comparing catch characteristics with a relatively unselective gear (Hamley 1975, Losanes et al. 1992b). Unfortunately, a reliance on electrofishing has discouraged studies examining other capture techniques for rainbow trout.

I wanted to determine if hook and line, beach seines, or gill nets could be used to sample sexually mature rainbow trout during the spring in order to mark fish for an abundance estimate and to describe the structure of the spawning stock in a large river. My objectives were to evaluate: (1) the effectiveness of each gear by comparing catch per unit effort and (2) the selectivity of each gear by comparing the length distribution, median length, the proportion of sexually mature fish, and the sex ratio of sexually mature rainbow trout in samples captured by each gear.

Methods

Study Area

The Naknek River drainage is in Southwest Alaska. A significant portion of this drainage consists of Naknek Lake and the outlet drainage of the Naknek River (Figure 1.1). The Naknek River flows for approximately 40 km before entering Bristol Bay in the Bering Sea. It is a large clear water river with a maximum width of approximately 100 m and strong flow. The drainage supports populations of all five species of Pacific salmon *Oncorhynchus* spp, and numerous resident fish species, including a population of rainbow trout. Large (up to 860 mm fork length) rainbow trout spawn in the upper Naknek River from early April through May.

The upper Naknek River provided a good site to evaluate the effectiveness of the three gear types in capturing rainbow trout during the spawning period. Rainbow trout concentrate for spawning in the upper 14 km of the Naknek River during the spring and specific spawning locations have been described (Gwartney 1985). The Naknek River is one of the most accessible rivers of Southwest Alaska due to its proximity to the town of King Salmon. Consequently, the river is accessible during the spring when inclement weather prevents access to other rivers.

Design

The study was conducted during 2000 and 2001. During 2000 the study was conducted from 10 April to 14 May, when rainbow trout were concentrated for spawning. The study area in the upper 14 km of the Naknek River was divided into four subareas of approximately equal length (Figure 2.1). The subareas provided insight for future studies as to the effectiveness of each gear in different stretches of the river. Subarea 1 extended 4 km downstream from the lake outlet. This subarea consisted of a slow-moving, wide reach of river with little spawning habitat. Subarea 2 extended 3 km through a narrow, deep stretch of river with relatively few shallow riffles suitable for spawning. Subarea 3 was 3 km long through a wider shallow reach of river with a fair number of riffles for spawning habitat. Subarea 4 was 4 km long over a wide, relatively shallow reach of river with numerous riffles that provide spawning habitat.

The 2001 study occurred from 10 April to 28 April and on a smaller spatial scale to concentrate efforts on large aggregations of spawning rainbow trout as identified during 2000. The 2001 study was reduced to subareas 3 and 4. These subareas contained the majority of spawning areas and the greatest concentrations of fish. Only beach seines and gill nets were used in 2001. Hook and line was not used due to the small contribution that it made to the 2000 sample.

Gear Descriptions

Hook and line sampling was conducted by back trolling with diving plugs and by fly fishing with an assortment of large black streamers. Diving plugs were size 30 non-rattle Hot Shot™ and size 35 rattle Hot Shot™ with a single, Gamakatsu™ siwash size 1 hook. Flies were constructed on size 2 weighted streamer hooks. Back trolling was conducted from a boat with a slow drift controlled by the power of an outboard motor. Diving plugs were fished 5 to 10 m downstream as the boat slowly moved downstream. This was a very effective technique in pools and glides, but not in areas with slow currents, or shallow water. Fly fishing was used to sample fish in areas with low current or shallow water.

The seine was 45.7 m long and 5.4 m deep with 2.54-cm^2 knotless nylon mesh, a double lead line of #65 braided lead core, and a float line. Beach seining was accomplished with two people in a boat and one person on shore. The beach seine was deployed by backing the boat out from shore. The person on shore held one end of the net while a person in the boat held the other end of the net. Once the net was half deployed the boat turned down river creating a “j-hook.” The person on shore walked down river with the shore end of the net as the boat and net drifted down river. The length of the drift depended on the site being sampled. The boat eventually powered the outer end of the seine into shore and the seine was dragged in from each end, corralling fish.

The spring 2000 study began by experimenting with gill nets of various depths, material, and mesh sizes. Nets with greater depth entangled fish the best. Examination of captured fish showed multifilament mesh caused less physical damage than monofilament. Large sexually mature fish were entangled best with 5.1-mm square mesh. As a result of these observations the gill nets used for sampling each year were 15.2 m long and 3.0 m deep with 5.1-cm (bar measure) multifilament mesh of #208 twine, #65 lead line, and a float line. Gill nets were actively fished with three techniques depending on river location: (1) the net was drifted with the current from a boat in wide stretches of the river away from shore; (2) the net was drifted between a boat and a wading technician for near shore situations with deep water; and (3) the net was drifted between two people wading in the river in shallow wide stretches of the river or narrow channels. The nets were hauled into shore or the boat when fish were entangled.

Sampling

All captured rainbow trout were measured for fork length (mm), and subarea and capture gear were recorded. Each fish was categorized as sexually immature or mature. Sexually mature rainbow trout were those fish capable of spawning during the spring of the survey. Visually examining and rating rainbow trout for the following characteristics determined sexual maturity: color, presence of reproductive products, ovipositor extension, kype development, abdomen development, and abdomen hardness (Appendix A). Sexual dimorphism allowed for the determination of sex among sexually mature fish.

Males were dark, had a developed kype, and often exuded milt. Females were silver, had extended abdomens, an ovipositor extended from the vent, and lacked a kype. An individually numbered Floy™ T-Anchor tag, model FS-94, was placed in the left side near the posterior base of the dorsal fin. The hours sampled with each gear was recorded at the end of each day.

Data Analysis

In 2000, a comparison was done with all three gears for subareas 2, 3 and 4. The only gear effective for sampling rainbow trout in subarea 1 was hook and line, but there were no observed spawning locations for rainbow trout in subarea 1. As a result, a comparison of gears was not possible in subarea 1.

In 2001, a comparison was made between beach seining and gill nets. The total number of rainbow trout captured with each gear was computed and catch per unit effort (CPUE; fish/h) was calculated for each gear type. The length frequencies of all captured rainbow trout for each gear was determined, as were the minimum, maximum, and median lengths. Anderson-Darling tests (Scholz and Stephens 1987) were used to assess differences in the length frequency distributions of rainbow trout captured with each gear. The proportion of sexually mature rainbow trout captured with each gear was computed. Possible differences in the proportions of sexually mature captured with each gear were assessed with a Chi-square analysis (Ramsey and Schafer 1997). Similarly, the sex ratio of sexually mature fish captured by each gear type was determined and possible differences were assessed with a Chi-square test. Significance was determined at alpha = 0.05 for all tests.

Results

2000 Survey

The total number of rainbow trout captured with all gears in subareas 2, 3, and 4 during 2000 was 1,103, of which 777 were sexually mature. The number of hours of sampling with each gear was: 76 for the gill net, 33 for the beach seine, and 33 for hook and line. The total number of fish captured, catch per unit effort, and minimum, maximum, and median lengths were determined for each gear (Table 2.1). Rainbow trout captured with hook and line had the smallest median length and fish captured with gill nets had the largest median length.

Length frequency distributions for each gear were computed for all rainbow trout captured (Figures 2.2, 2.3 and 2.4) and for sexually mature fish (Figures 2.5, 2.6 and 2.7). The Anderson-Darling test indicated a significant difference (D=31.42, $n_{H\&L}$=81, n_{seine}=411, n_{gill}=611, P<0.001) in the cumulative length distributions of rainbow trout captured among the three gear types and for rainbow trout captured with the beach seine and gill net (D=27.26, n_{seine}=411, n_{gill}=611, P<0.001) (Figure 2.8), but no significant difference (D=1.04, $n_{H\&L}$=34, n_{seine}=250, n_{gill}=493, P=0.133) in the cumulative length distributions of sexually mature fish was observed among gears (Figure 2.9).

The proportion of sexually mature fish, as well as catch per unit effort, median length, and sex ratio of sexually mature fish captured with each gear were compared (Table 2.2). A Chi-square test for differences in the proportions of sexually mature fish among gears indicated a significant difference (χ^2=80.8, df=2, P<0.001) with hook and line capturing the lowest proportion. Also, a Chi-square test for differences in the proportions of sexually mature indicated a significant difference between the beach seine and gill net (χ^2=48.8, df=1, P<0.001) with a higher proportion for gill nets. Chi-square test for differences in sex ratio of sexually mature fish indicated no significant differences among the three gear types (χ^2=4.7, df=2, P=0.095).

2001 Survey

The total number of rainbow trout captured with both gears during 2001 was 1,031, of which 795 were sexually mature. The number of hours each gear was used was 50 for gill net and 35 for beach seine. The total number of fish captured, and minimum, maximum, and mean lengths were determined for each gear (Table 2.3). Rainbow trout captured with the beach seine had the smaller median length.

Length frequency distributions for each gear were computed for all rainbow trout captured (Figures 2.10 and 2.11) and for sexually mature fish (Figures 2.12 and 2.13). The Anderson-Darling test indicated a significant difference (D=70.78, n_{gill}=489, n_{seine}=542, P<0.001) in the cumulative length distributions of rainbow trout captured among the two gear types (Figure 2.14). No significant difference (D=0.23, n_{gill}=457, n_{seine}=338, P=0.433) in the cumulative length distributions of sexually mature fish was observed between gears (Figure 2.15).

The proportion of sexually mature fish, as well as catch per unit effort, median length, and sex ratio of sexually mature fish captured with each gear were compared (Table 2.4). A Chi-square test for differences in the proportions of sexually mature between gears indicated a significant difference (χ^2=50.3, df=1, P<0.001) with a higher proportion for gill nets. Chi-square test for differences in sex ratio of sexually mature fish indicated no significant differences between the two gear types (χ^2=0.71, df=1, P=0.399).

Discussion

Substrate, water depth, water transparency, and current influenced the effectiveness of gears in the Naknek River as in other waters (Hayes et al. 1996). Subarea 1, a slow-moving, wide reach, proved to be a difficult reach to capture rainbow trout with either a beach seine or gill net. Only 26 immature rainbow trout were captured with the beach seine and no rainbow trout were captured with the gill net in 2000. The ineffectiveness of these gears can be attributed to a combination of clear water, low current velocity, and snags. The low current velocity created very slow drifts enabling rainbow trout to avoid nets. In addition, this stretch of the river contained large rocks, which often snagged nets. Hook and line was the most effective gear in subarea 1, capturing 219 rainbow trout in 2000, the majority of which were immature. The large proportion (71%) of immature fish may be attributed to the lack of spawning habitat in this subarea. Due to the ineffectiveness of all gear types in subarea 1, this subarea was not included in the comparison of gears.

The effectiveness of each gear was affected by habitat, fish behavior, and selectivity (Hayes et al. 1996). Hook and line produced the fewest fish of the sampling techniques and had the lowest CPUE. With angling there is an upper limit to the number of fish that can be sampled per hour regardless of the number of fish present (Deriso and Parma 1987). This limitation is due to handling time, as well as the act of casting and retrieving. In addition, each attempt (or cast) can only result in the capture of a single fish. Hook and line could be used in river locations where netting could not be used due to channel morphology. As shown with subarea 1, hook and line may be used to sample where netting is ineffective.

Hook and line captured a smaller proportion of sexually mature fish than the other techniques. The immature fish were likely to have been feeding, while sexually mature fish may not have been feeding due to spawning activity. Of the sexually mature fish captured with hook and line, a greater proportion were female compared to other techniques. This may be partly due to a propensity for spawned-out females to resume feeding and take lures. As spawned-out females increased in number towards the end of the survey, they were captured frequently on hook and line.

The highest CPUE occurred with beach seines during both years. This can be attributed to the ability of the beach seine to capture a large number of fish with each haul. Up to 62 rainbow trout were captured with a single haul. However, use of the beach seine was limited to eight locations on the river (Figure 2.16). Channel morphology and snags, such as large rocks and woody debris, prevented the use of beach seines in most locations. Catch per unit effort with beach seines was higher during the second year of the study. This can be attributed to experience gained by the samplers during the first year that increased capture efficiency for the second year.

Gill nets could be used in most river locations and were successful at capturing rainbow trout. The short length of the nets made it possible to actively avoid snags by lifting the net over them or moving it around them. The gill nets (5.1-mm bar mesh) selected for relatively large fish, accounting for the higher proportion of sexually mature fish captured with gill nets. The gill nets used for this study appear to select for rainbow trout of the upper length ranges available for capture which consisted largely of sexually mature fish. As a result, there are likely very few rainbow trout greater than 830 mm fork length in the Naknek River.

The wider length range of fish (196–805 mm FL) captured with the beach seine indicated that beach seining was not as selective as gill nets (315–830 mm FL). If greater selectivity is desired, then trammel nets might be used because they have wider length selectivity than gill nets due to a greater incidence of entangled fish (Losanes et al. 1992a). However, if the capture of sexually mature rainbow trout is desired, selectivity was similar for both beach seines and gill nets. The similarities in capture length and sex ratio indicate that the two gears can be used together when targeting sexually mature rainbow trout in the Naknek River.

Both actively fished beach seines and gill nets should be used for future sampling projects on the spawning population of rainbow trout in the Naknek River and similar rivers. Hook and line should be omitted from any sampling regime because of low CPUE and ability to collect only small samples with large proportions of immature fish.

Chapter 2

Abundance Estimates and Population Characteristics of the Rainbow Trout Spawning Stock of the Naknek River, Alaska

Rainbow trout *Oncorhynchus mykiss* have a broad range in western North America extending from Mexico to the southern tributaries of the Kuskokwim River, Alaska (Behnke 1992). The age and growth of rainbow trout populations vary greatly due to genetic and environmental factors. Adult fish lengths can vary from 100 mm total length (TL) in small headwater streams with little production to 800 mm TL in systems associated with large lakes and abundant food. Populations of large, long-lived rainbow trout can occur in large lakes with an abundant source of forage fish (Behnke 1992). Natural populations of large rainbow trout, such as those in Kootenay Lake, British Columbia, co-exist with abundant kokanee *Oncorhynchus nerka*. Similarly, large lakes in Southwest Alaska, such as the Iliamna and Naknek lake drainages, have populations of large rainbow trout associated with an abundance of sockeye salmon *Oncorhynchus nerka*.

Rainbow trout spawning ecology is well described (McPhail and Lindsey 1970, Tautz and Grot 1975, Morrow 1980, Behnke 1992). In general, rainbow trout spawning occurs in flowing waters during spring. Spawning is stimulated by increasing water temperature with spawning occurring between 5.5 and 13^{o}C (Morrow 1980). The age and length at which rainbow trout become sexually mature varies greatly with genetic and environment factors (Morrow 1980, Behnke 1992). Males reach sexual maturity at

2-6 years of age, often a year earlier than females in a population (Morrow 1980, Behnke 1992). Length at sexual maturity ranges from 150 mm TL for fish in small streams to 400 mm TL for fish associated with large lakes (Morrow 1980). Repeat spawning is common in rainbow trout, occurring up to 5 successive years (Hartman 1959). The proportion of repeat spawners in a population ranges up to 57 % with females more likely to repeat than males (Morrow 1980, Behnke 1992). A fish's propensity to spawn in successive years depends on the availability of food and the length of the growing season after spawning (Behnke 1992). Post-spawning mortality can be high with values from 43 to 84% observed for rainbow trout at Loon Lake, British Columbia (Hartman et al. 1962). Increased mortality was correlated with higher numbers of fish on the spawning grounds and was greatest for males (Hartman et al. 1962).

Rainbow trout populations are constrained by spawning, rearing, and overwintering habitat, as well as food availability (Behnke 1992). The number of spawning rainbow trout in a population is similarly limited by these factors. However, populations of large long-lived rainbow trout can compensate for low numbers of spawners with high fecundity. The spawning population of large rainbow trout in the Lardeau River of British Columbia was comprised of 500 to 700 spawners, a relatively low number, yet the population was likely sustained by high fecundity (Hartman 1969).

The Naknek River of Southwest Alaska supports a spawning population of rainbow trout. Large rainbow trout (up to 860 mm fork length, FL) spawn in the upper 14 km of the river from early April to the middle of May (Gwartney 1985). A spring sport fishery for rainbow trout begins with the break-up of ice and extends until a regulated closure of the fishery occurs from 9 April to 7 June to protect spawning fish.

Increased participation in the spring fishery has created public concern regarding the biological impacts of angling pressure on the spawning population of rainbow trout. As a result, the Alaska Department of Fish and Game (ADFG) is developing a management plan for the spring rainbow trout sport fishery in the Naknek River. Monitoring the status of the spawning population will be an important aspect of the management plan. As a result, a method for estimating abundance, length frequency, and proportion of sexually mature fish in the rainbow trout spawning stock is desired.

Estimating abundance of rainbow trout spawning populations has been attempted using several means. The number of rainbow trout ascending the North Platte River from Lake McConaughy for spawning was estimated using a weir (Van Velson 1978) and for Loon Lake, British Columbia using fish traps (Hartman et al. 1962). The Naknek River is large and subjected to periodic ice flows as the lake breaks up preventing the use of weirs and traps. The abundance of Kootenay Lake rainbow trout spawners in the Lardeau River was estimated with visual counts (Cartwright 1961, Hartman 1969). Aerial and foot counts conducted of the Naknek River spawning population in the 1970's and 1980-1985 varied from 130 to 2,500 fish (Gwartney 1985), but these counts probably underestimated the true number of fish. Mark-recapture abundance estimates of an aggregation of pre-spawning rainbow trout in the Kvichak River, Alaska were conducted for several years (Minard et al. 1992).

A mark-recapture technique permits gathering of additional stock assessment data such as length and sex composition. An estimate of the length composition and the proportion of sexually mature fish present in the Naknek River during the spring will be an important aspect for future monitoring of the population. Age, weight, and length data collected periodically since 1966 from the Naknek River have been reported in compilations by Minard and Dunaway (1991) and Riffe (1994), but not in coordination with evaluation of sexual maturity.

My goal was to estimate the abundance, length frequency, and proportion of sexually mature rainbow trout in the Naknek River spawning stock. During the spring of 2000 and 2001, I captured rainbow trout with beach seines, entanglement nets, and hook and line to determine the best capture technique (see Chapter 1). During these years, I made multiple mark-recapture abundance estimates and described results using the different gears. My objectives were to estimate the: (1) abundance of spawning rainbow trout, (2) length composition of spawning rainbow trout, and (3) proportion of sexually mature rainbow trout by length class.

Study Area

2000

In 2000 the study area encompassed the upper 14 km of the Naknek River. This area included all known rainbow trout spawning locations from the outlet of Naknek Lake downstream to Rainbow Bend (Figure 1.1). The study area was divided into four subareas (Figure 2.1). Subarea 1 extended 4 km downstream from the lake outlet. This subarea consisted of a slow-moving, wide reach of river with little spawning habitat. Subarea 2 extended 3 km through a narrow, deep stretch of river with relatively few shallow riffles suitable for spawning. Subarea 3 was 3 km long through a wider, shallower reach of river with a fair number of riffles for spawning habitat. Subarea 4 was

4 km long over a wide, relatively shallow reach of river with numerous riffles that provide spawning habitat.

2001

The 2001 study was conducted on a smaller scale than the 2000 study. This was done to simulate future monitoring when less time would be committed to sampling. The study area was reduced to subareas 3 and 4. These two subareas contain the majority of spawning habitat and few rainbow trout were observed spawning in subareas 1 and 2 in 2000. Subarea 4 was also reduced in length to 3 km by moving the downstream boundary up from Rainbow Bend to the regulatory marker at Rapids Camp (Figure 2.1). This was done because very few fish were sampled and no spawning was observed below the marker in 2001. The mark-recapture survey was reduced to a 3-week period (10 April to 28 April), which encompassed the time of peak spawning observed during the 2000 study.

Methods

2000

A multiple mark-recapture technique was used to estimate the abundance of spawning rainbow trout (Ricker 1975, Otis et al. 1978, Seber 1982). Capture histories of each marked fish were created. This consisted of a row of 1s and 0s where each number represented a sampling period or week. A 1 indicated that an individual fish was captured that week, while a 0 indicated that an individual fish was not captured that week. In closed populations capture histories are modeled in terms of capture probabilities (Nichols 1992). It has been recognized that probability of capture is not equal in most mark-recapture estimates. As a result, a number of models have been developed to estimate abundance when probability of capture is not equal. Otis et al. (1978) developed a model that can account for each of three sources of variation in capture probability: (1) model M_t, variation due to time or trapping occasion, (2) model M_b, variation due to behavioral responses, and (3) model M_h, variation among individual animals or heterogeneity. These three models accounting for unequal probability of capture can be combined creating additional models; M_{tb}, M_{th}, M_{bh}, and M_{tbh} (Otis et al. 1972). In addition, model M_o is available for the rare instances when all individuals exhibit an equal capture probability during the sampling periods (Pollock et al. 1990).

The comprehensive computer program 2CAPTURE was used to provide estimates of abundance from the capture histories (Rexstad and Burnham 1991). The program uses goodness-of-fit and likelihood-ratio tests to assess model assumptions and identify the appropriate model for the data. The original version of CAPTURE (Otis et al. 1978, White et al. 1982) did not provide estimators for models M_{th}, M_{tb} and M_{tbh} due to the high number of parameters in the models. However, adaptions to the program based on the findings of Chao (1992) for the estimation of M_{th} are included in the program 2CAPTURE (Rexstad and Burnham 1991). This version also provides an estimate with model M_t that provides smaller bias and better precision than Darroch (1958) when probability of capture is less than 0.10 (Chao 1989).

The ADFG attempted a mark-recapture estimate of spawning rainbow trout abundance in the Naknek River in 1993. The hook and line capture method did not produce enough recaptures to estimate abundance with acceptable precision (Daniel

Dunaway, Dillingham, Alaska, personal communication). Based on this knowledge, additional capture methods were incorporated for the 2000 abundance estimate. Rainbow trout were captured with beach seines, entanglement nets, and hook and line (see Chapter 1). Sampling was conducted from 20 March to 20 May. Only hook and line was used from 20 March to 9 April to avoid conflicts that netting may cause by disturbing recreational anglers. All three gears were used from 10 April to 20 May.

Each week from 20 March through 20 May represented a separate marking and recapture event. Sampling was conducted at least 5 d each week. A rough estimate of the population of spawning rainbow trout was used to ascertain the number of fish that needed to be marked and recaptured with a desired accuracy for a designated degree of confidence (Robson and Regier 1964). This technique was designed for a 2-event Peterson mark-recapture estimate, but provided insight as to sample sizes required for a multiple mark-recapture estimate. Gwartney (1985) conducted aerial counts in 1983, 1984, and 1985 and estimated 2,500 trout in the spawning area each year. Due to the imprecise nature of counts from the air and the large study area, I assumed an abundance of 3,500 fish when deriving a sampling goal. If this were a two-sample, mark-recapture experiment then a minimum of 867 rainbow trout would have to be marked and examined for marks to estimate abundance within $\pm$25 % of the true abundance 95% of the time (Robson and Regier 1964). This means that during an 8-week multiple-recapture study approximately 109 rainbow trout should be captured and marked each week.

Each captured rainbow trout was measured (FL) and the subarea and gear of capture were recorded. Each fish was categorized as immature or sexually mature. Sexually mature rainbow trout were capable of spawning the spring of the survey. The following characteristics allowed for the determination of sexual maturity: color, presence of reproductive products, ovipositor extension, kype development, abdomen development, and abdomen hardness (Appendix A). Sexual dimorphism allowed for the determination of gender of sexually mature fish. Males were dark, had a developed kype, and often exuded milt. Females were silver, had extended abdomens, an ovipositor extended from the vent, and lacked a kype. An individually numbered Floy™ T-Anchor tag, model FS-94, was placed on the left side near the posterior base of the dorsal fin and the adipose fin was clipped as a secondary mark.

The assumptions necessary to estimate abundance with a closed population model are (Seber 1982): (1) the population is closed with no additions or losses between sampling events (through recruitment, death, immigration, or emigration); (2) all fish have an equal capture probability in the first capture event or in subsequent capture events or marked fish mix completely with unmarked fish prior to subsequent capture events; (3) marking does not affect capture probability in subsequent capture events; (4) marks (i.e., tags) are not lost between events; and (5) all marked fish recaptured during subsequent capture events are correctly identified and recorded. The dates of sampling coincided with the spawning period of rainbow trout in the upper Naknek River (Gwartney 1985) and the study area encompassed all known spawning areas (Figure 3.1). During the study period the rainbow trout spawning stock was likely a closed population as they staged near the lake and then concentrated in the spawning area during the study. Spawned-out rainbow trout begin to leave the river (see Chapter 2) and the proportion of spawned-out fish each week can indicate when fish begin to leave the survey area (Appendix A). Careful handling of all captured fish should have prevented or minimized any sampling mortality. I assumed that any mortality that occurred during the 8-week sampling period was equal between marked and unmarked fish. It is possible that some immigration or emigration may have occurred and that there were losses from mortality. Losses during a multiple-mark recapture study tend to inflate abundance estimates if no additions occur in the population (Ricker 1975). If immigration occurred I expected to see a constant or a declining ratio of marked to unmarked fish among sampling events. Recruitment into the spawning population was not a factor for the abundance estimate of sexually mature fish because the sexually mature rainbow trout would have developed their sexual maturity characteristics prior to the study.

Although tests for closure have been developed (Pollock et al. 1990), these tests generally have low power to reject closure and are confounded with the assumption of equal probability of capture (Otis et al. 1978). The use of three different capture techniques should have minimized differences in the capture probability of rainbow trout (Pollock et al. 1990). However, to aid in determining closure and equal probability of capture over time, I examined the marked to recaptured ratio over time among subareas and by gear. Examination of recaptures among subareas provided insights as to population closure, equal probability of capture, and mixing of individuals among subareas.

Although the third assumption that marking did not affect capture probability during subsequent capture events could not be directly tested, rejecting the hypothesis of equal catchability among capture events could arise from violation of this assumption. Careful and rapid processing when capturing and handling fish was assumed to have minimized stress and possible violation of this assumption. Adipose fin clips were used to test the assumption of no tag loss. Careful examination and recording of each fish that was caught provided an assessment of this assumption.

The length composition of all rainbow trout and the sexually mature portion of the sample from the upper Naknek River were determined. Sample size estimation for a multinomial proportion was used to determine the minimum number rainbow trout to be sampled for length composition. To attain a precision of $\pm$5 % of the sample mean 95 % of the time for length compositions, a minimum of 510 rainbow trout would have to be sampled (Thompson 1987). This goal was easily achieved on the upper Naknek River as all rainbow trout captured were measured. The incremental relative stock density (RSD) of fish captured with each gear and for all gears combined was computed based on proposed quality length classes by Anderson and Neuman (1996) where; stock to quality is 250 to 400, quality to preferred is 400 to 500, preferred to memorable is 500 to 650, and memorable to trophy is 650 to 800 mm TL. FL was converted to TL for RSD computations (Simpkins and Hubert 1996).

Estimating the minimum, mean, and median lengths at which rainbow trout become sexually mature was accomplished by computing the proportion of rainbow trout that appeared sexually mature in 50-mm (FL) length classes.

2001

Data were collected in a similar manner as 2000 with some modifications. Beach seines and entanglement nets were used to capture fish. Hook and line was not used due to the small number of fish captured compared to the netting techniques during the 2000 study (see Chapter 1). A different fin clip, or secondary mark, was used during 2001 to differentiate lost tags from the 2000 survey, and the fin clipped differed for each capture event. The fin clips were: (1) the tip of the left pectoral fin for week one, (2) the tip of the right pectoral fin for week two, and (3) the tip of the left ventral fin for week three. A different secondary mark allowed for the use of recaptures in the abundance estimate in the event of tag loss.

The sample size determination for the 2001 multiple mark-recapture estimate was again based on an estimated population size of 3,500 because this population size falls within the range of estimated abundance for the 2000 population estimate of spawning fish. A minimum of 867 rainbow trout would have to be marked and examined for marks to estimate abundance within ±25 % of the true abundance 95 % of the time (Robson and Regier 1964). This means that during a 3-week multiple-recapture study approximately 289 rainbow trout should be captured and marked each week.

Results

2000

A total of 1,897 rainbow trout were captured at least once between 20 March and 20 May, and 1,037 were sexually mature. Sexually mature rainbow trout that already had a mark or were given a mark numbered 983, and 115 of these fish were recaptured at least once (Table 3.1).

The fork lengths of rainbow trout subsequently recaptured after initial capture were excluded from the length composition estimate, so only one recorded length from each individual fish was used. This yielded a data set of 1,712 samples, 820 immature and 892 sexually mature fish. The fork lengths ranged from 196 to 830 mm FL (Figure

3.2). Memorable to trophy rainbow trout had the highest RSD values of the quality size groups (Table 3.2).

The minimum fork length of sexually mature fish was 425 mm. The proportion of sexually mature fish in the sample increased as length increased (Figure 3.3). Males represented 53% of sexually mature fish sampled. The mean fork length of sexually mature females was 617 mm (SE = 2.7) and sexually mature males was 676 mm (SE = 2.9). The median fork length of females was 628 mm and of males was 685 mm (Figure 3.4).

Abundance Estimate

The amount of effort with each gear to mark and recapture fish each week varied by subarea (Table 3.3). Subarea 1 received the lowest effort and subarea 4 received the most effort each week. Gill nets accounted for the most effort, followed by the beach seine. The number of sexually mature fish recaptured that were marked by a gear type varied among gears (Table 3.4). Fish captured with a beach seine were most frequently recaptured, and fish marked with hook and line were less frequently recaptured. Sexually mature rainbow trout initially captured and tagged with one gear type were recaptured with other gear types; however, recapture was likely to occur with the same gear type (Table 3.5). The cumulative length distributions of sexually mature fish captured with each gear were not significantly different (P=0.133) (see Chapter 1).

There was a significant difference (D=4.72, n_{marked}=838, $n_{recaptured}$=98, P=.004) in the cumulative length distributions between all fish captured and those recaptured during the survey (Figure 3.5).

Mixing of marked and unmarked fish occurred between subareas (Table 3.6); however, the majority of fish were recaptured from the subarea of marking (Table 3.7).

The first recapture event occurred during week 4. The percent of sexually mature fish that were marked increased from 5.6% during week 4, to 16.2% during week 8, but decreased during week 9 to 15.1%. This indicated that immigration from the survey area did not begin until week 9.

Tag loss was encountered seven times during the survey among 140 marked and recaptured sexually mature fish. The number of marked fish included those captured more than once during a capture event (week). This indicated that tag loss occurred among 5% of the marked fish observed during the 9-week study.

Examination of assumptions required to conduct a multiple mark-recapture study resulted in the elimination of some capture data from the data set. All data from subarea 1 was eliminated due to a difference in recapture history for this subarea. Very few rainbow trout were recaptured in subarea 1 due to several factors. Hook and line was the only effective sampling technique in subarea 1. The river in this subarea was characterized by slow flow and greater depth allowing fish to avoid capture by netting techniques. In addition, this subarea had no observed spawning areas for rainbow trout due to a lack of spawning habitat. Despite low catches, some spawning occurred in subarea 2, so the data from subarea 2 were included in the abundance estimate.

Samples collected during week 9 were not included in the abundance estimate since the marked to unmarked ratio decreased during week 9. This was likely a result of immigration out of the survey area. Emmigration can be attributed to an increased proportion of spawned-out fish from 36 to 85% during weeks 8 and 9 (Figure 3.6). The catch of fish in the subareas 3 and 4 decreased dramatically from week 8 to 9. An increasing marked to unmarked fish ratio for weeks 4 through 8 indicated that the capture data could be partitioned into eight capture events. Using only data from sexually mature rainbow trout for the eight capture events, and excluding subarea 1, resulted in a data set of 838 captures and 98 recaptures. Likelihood-ratio and goodness-of-fit tests of the model selection procedure of 2CAPTURE indicated that model M_{th}, which allows for capture probabilities to vary over time and among individual animals, best fit the data. The estimated abundance was 3,258 (SE = 389, 95% CI = 2,608 – 4,143) fish in the spawning population in 2000.

2001

During the 2001 survey a total of 1,031 rainbow trout were captured at least once between 10 April and 28 April, and 804 were sexually mature. Sexually mature rainbow trout that already had a mark or were given a mark numbered 731, and 77 of these fish were recaptured at least once (Table 3.8).

The fork lengths of rainbow trout subsequently recaptured after initial capture were excluded from the length composition estimate, so only one recorded length from each individual fish was used. This resulted in a data set of 890 samples, 229 immature and 661 sexually mature. Fork lengths ranged from 225 to 860 mm (Figure 3.7). Memorable-to-trophy length rainbow trout had the highest RSD values of quality size groups (Table 3.2).

The minimum fork length of sexually mature fish was 424 mm. The proportion of sexually mature fish in the sample increased as length increased (Figure 3.8). Males represented 59% of the sexually mature fish sampled. The mean fork length of all sexually mature females was 630 mm (SE = 3.5) and sexually mature males was 686 mm (SE = 3.7). The median fork length of females was 640 mm and of males was 697 mm (Figure 3.9).

The amount of effort each gear was used to mark and recapture fish in each subarea by week was calculated (Table 3.9). Subarea 4 received more effort than subarea 3 and gill nets accounted for the most effort. The number of sexually mature fish recaptured that were marked by a gear type was similar for both gears (Table 3.10). Sexually mature rainbow trout initially captured and tagged with one gear type were recaptured with another gear; however, recaptures were more likely to occur with the same gear type (Table 3.11). Of fish recaptured with the gill net, 80% were marked with the gill net, and of fish recaptured with the beach seine, 81% were marked with the beach seine. The cumulative length distributions of sexually mature fish captured with each gear were not significantly different (P=0.433) (see Chapter 1).

There was a significant difference (D=4.55, n_{marked}=727, $n_{recaptured}$=77, P=.005) in the cumulative length distributions between all fish captured and those recaptured during the survey (Figure 3.10).

Mixing of marked and unmarked fish did occur between subareas (Table 3.12); however, the majority of fish were recaptured from the subarea of marking (Table 3.13). Of fish marked in subarea 3, 15% were recaptured in subarea 4, and 6% of fish marked in subarea 4 were recaptured in subarea 3. The cumulative length distributions of sexually mature fish captured in each subarea were not significantly different (D=0.38, $n_{subarea3}$=317, $n_{subarea4}$=487, P=0.433).

The first recapture event occurred during week 2. The percent of sexually mature fish that were marked decreased from 14.2% during week 2 to 12.2% during week 3. This decrease appeared to be due to movement of rainbow trout into the study area as indicated by an increase in the number of fish marked from 203 to 257 (Table 3.8). Movement into the study area decreasing the proportion of recaptures was accounted for by program 2CAPTURE and abundance was estimated for the final capture event (i.e., week 3).

Tag loss was encountered three times during the survey among 152 marked and recaptured sexually mature fish. The number of marked fish included those captured more than once during a capture event (week). Tag loss occurred in 2% of the marked fish during the 3 weeks. Different secondary marks identified the capture event of initial marking. As a result, these fish were included in the estimation of abundance.

Likelihood-ratio and goodness-of-fit tests of the model selection procedure of 2CAPTURE indicated that model M_t, which allows for capture probabilities to vary over time, best fit the data. Data from sexually mature rainbow trout for the three capture events resulted in a data set of 727 captures and 77 recaptures. Movement into the study area decreased the proportion of recaptures, which was accounted for by program 2CAPTURE and abundance was estimated for the final capture event (i.e., week 3). Probability of capture among the three capture events was 0.09, 0.11, and 0.14. The estimated abundance was 2,413 (SE = 271, 95 % CI = 1,956 - 3,029) sexually mature rainbow trout.

Discussion

The characteristics of the spawning population of rainbow trout in the Naknek River are similar to other river systems associated with large lakes and abundant forage. Rainbow trout of the Kvichak River, Alaska, spawn at the outlet of Iliamna Lake. Kvichak River rainbow trout recruit into the spring spawning aggregation near 500 mm FL (approximately 6 years of age), but the majority of fish do not show external sex characteristics until 600 mm FL (approximately 8 years of age) (Steven Fleischman, Anchorage, Alaska, personal communication). Rainbow trout from Kootenay Lake, British Columbia, spawn at the outlet of the Lardeau River. The minimum length of a spawning rainbow trout in the Lardeau River was found to be 463 mm FL (approximately 4 years of age) and the majority spawned for the first time at 5 or 6 years of age (Cartwright 1961). The minimum length of Naknek River rainbow trout observed in the spawning population was 425 mm FL, but the majority of rainbow trout are recruited into the spawning population at 551 to 650 mm FL (Figures 3.2 and 3.7). Past Naknek River rainbow trout age-at-length data collected during the spring indicates that 425-mm-FL fish are 5 years old and 600-mm-FL fish are a minimum of 7 years old (Riffe 1990).

The length frequency distributions for all fish captured indicates a clearly defined distinction between sexually mature and immature fish (Figures 3.2 and 3.7). The proportion of sexually mature fish increases between 500 and 600 mm FL among rainbow trout in the upper Naknek River. This length interval represents the minimum length when rainbow trout of the Naknek River begin to recruit into the spawning population, but the length frequency distributions indicate a comparatively low number of fish in this length class than smaller and larger length classes. There may be several possible explanations for this. It may be that these fish are missing from the population due to poor survival for that cohort. If a weak cohort was responsible the trend would be shifted to larger fish in the frequency distribution of the following year. However, this trend was observed in both 2000 and 2001 for the same length classes. Some of these fish were sampled in subarea 1 as immature fish (Figure 3.11), but the majority of fish in this length range may not be present in the river during the spring. The strongest possibility is that there may be a shift in life history from the river to the lake that occurs for fish in this length range as they become sexually mature.

Sexually immature and mature fish appear to be segregated in the river. The proportion of sexually mature fish sampled increased with progression downstream (Table 3.1). This may be due to the availability of spawning habitat by subarea. Subarea 1 had little spawning habitat and immature fish were abundant in this subarea during the spring. Some spawning may have occurred at the lake outlet as indicated by the observation of two redds, but no actively spawning fish were observed. Sexually mature fish were commonly sampled and large concentrations were observed in this subarea during March and early April. Large concentrations of sexually mature rainbow trout stage in several locations near the outlet of the lake. These concentrations disperse down river as spring progresses, eventually arriving at spawning sites. Spawned-out rainbow trout were commonly sampled during mid-May (Figure 3.6). These fish are probably moving upriver from the spawning areas to enter Naknek Lake (see Chapter 3). An explanation for this trend may be the increasing numbers of large spawning rainbow trout down river. These large fish may exclude smaller fish during spawning in April and early May.

Abundance estimates are the number of spawning rainbow trout in the upper Naknek River during spring. An abundance estimate computed for just immature rainbow trout captured during 2000 for weeks 1 through 9 results in the selection of M_t and an estimate of 6,234 (SE = 985, 95% CI = 4,301 - 8167) fish. A sample size of 722 captures including 35 recaptures was used for this estimate. Capture probabilities for this estimate were extremely low ranging between 0.01 and 0.02. Selectivity of the gill net, which excluded the smaller immature fish, and the use of only hook and line to sample subarea 1 where a large number of immature fish were present confound this estimate. It is likely that this greatly underestimates the actual number of immature rainbow trout present in the river during the spring.

Repeat spawning is common for most rainbow trout populations with females more likely to repeat than males (Morrow 1980). This study did not provide an indication of what proportion of the population had spawned the previous year. Floy-tag data indicated that some rainbow trout spawned in consecutive years, however the number of surviving post-spawn rainbow trout from the previous spring was unknown. As a result, the proportion of repeat spawners could not be estimated. The proportion of sexually mature rainbow trout by length class for 2000 (Figure 3.3) indicated that not all large rainbow trout were sexually mature. These rainbow trout that did not exhibit any secondary sexual maturity characteristics were captured in subarea 1 near the lake outlet. It is unknown if these large rainbow trout had been sexually mature and spawned in previous years. These large non-spawning rainbow trout were not represented in the 2001 sample, which did not include sampling in subarea 1.

The sex ratio of fish in the spawning population averaged 56% males over the 2 years. This compares to a sex ratio of 51% for the spawning population of rainbow trout at the outlet of Loon Lake, British Columbia (Hartman et al. 1962). The sex ratio in the Naknek River may be slightly biased by gear in that the netting techniques probably captured higher proportions of males than females due to entanglement by the kype; however, the gear selectivity is unknown (see Chapter 1).

The gears used to capture sexually mature rainbow trout may have biased abundance estimates. Fish were not recaptured with the gears in the same proportion as they were marked, recapture was most frequently by the same gear (Tables 3.5 and 3.11). The beach seine could only be used in certain locations due to channel morphology. As a result, fish marked in that location had a high probability of recapture in that area. The actively fished gill net could sample fish at most river locations and accounted for the most recaptures. Hook and line could be used at all locations, but produced few recaptures (see Chapter 1). During the first 3 weeks of the study, 122 fish were captured with hook and line and marked, but none were recaptured during that time span. Commencement of sampling with the netting techniques during the fourth week immediately produced eight recaptures in 2 d, suggesting fish were not prone to recapture with hook and line after initial capture with the gear. In addition, hook and line only accounted for two of 13 recaptures of fish initially marked with hook and line during the 9-week survey. Use of the three gear types did allow for the versatility required to sample all river locations. For example, hook and line was the only effective gear in subarea 1. Despite potential gear bias the estimates provide an index for future monitoring given that the same gears are used in similar locations.

There was a difference in the cumulative length distributions of sexually mature fish marked and recaptured for each year due to the recapture of large fish. This can be accounted for by the fact that males were more vulnerable to recapture than females. This may be a result of gear selectivity, but the netting techniques captured a similar sex ratio. Higher incidence of male recaptures was likely due to the propensity of males to remain on spawning sites longer than females. Males may spawn with many females as females become ripe over the spawning period. As a result, males remain in shallow riffle habitat much longer than females where they are susceptible to capture. Upon the completion of spawning females appeared to move out of spawning riffles to protected locations of deeper water where they were not as prone to capture.

Tag loss was higher than reported in other studies for rainbow trout. Rainbow trout tagging studies on the Kvichak and Kenai rivers have documented tag loss from 0.0 to 0.012% (Lafferty 1989, Minard et al. 1992, Hayes and Hasbrouck 1996). The increased rates of tag loss in the Naknek River may be attributed to the Floy-tags pulling out as fish struggled in a net, which was observed on several instances. Tag loss was likely higher in 2000 than 2001 due to the longer duration of the study (6 weeks) increasing the odds of fish encountering nets and losing a tag. However, I considered tag loss to be insignificant and not to have biased abundance estimates, although precision may have been reduced (Pollock et al. 1990).

A telemetry study during 2001 allowed for the assessment of the closed population assumption during the mark-recapture estimate (see Chapter 3). From 10

April to 14 May transmitters were implanted in 74 fish, 21 of which were spawned-out rainbow trout tagged during the 3 weeks of the mark-recapture study. Telemetry data indicated that some movement by post-spawn fish did occur out of the survey area during the mark-recapture study. A single fish of 21 fish implanted with transmitters during the dates of the mark-recapture study moved upstream out of the survey area on 27 April, 2 d before the end of the mark-recapture study. In addition the proportion of spawned-out fish increased slightly (Figure 3.12). Immigration is assumed to be similar among marked and unmarked fish; however, movement out of the study area may have resulted in an inflated abundance estimate.

The movement of fish and the different sampling effort between subareas affected the recapture frequency of marked fish among subareas. During 2000 and 2001 fish marked in a subarea were likely to be recaptured in the same subarea (Tables 3.6 and 3.12). This indicated that the probability of recapture of marked fish was not equal among subareas, or that marked fish did not mix completely between subareas. However, some fish were recaptured in subareas other than the subarea of marking, indicating some mixing among subareas (Tables 3.6 and 3.12). The majority of mixing occurred between subareas 3 and 4, with 11% of fish marked in subarea 3 recaptured in subarea 4 and 14% of fish marked in subarea 4 recaptured in subarea 3 during 2000. The extent of movement between subareas during the studies was difficult to ascertain due to different levels of effort among subareas (Tables 3.3 and 3.9). Large numbers of fish were marked and recaptured in subareas 3 and 4, in part due to the large sampling effort in these subareas. In contrast the sampling effort in subareas 1 and 2 were less, in part due to smaller concentrations of fish and limitations of gear. Varying levels of effort made it difficult to ascertain the extent of movement or mixing among subareas.

Post-spawning mortality has been reported to be high for rainbow trout in the Loon Lake drainage, British Columbia (Hartman et al. 1962). Survival in the Loon Lake drainage was higher for unmarked fish than those tagged or fin clipped (Hartman et al. 1962). Tags used in the Loon Lake study were 13-mm Peterson disc tags pinned through the back anterior to the dorsal fin (Hartman et al. 1962). There is no indication whether the Floy-tags used for this study increased post-spawning mortality. However, if mortality were greater for those fish handled and tagged on the Naknek River the estimate of abundance would be inflated.

An abundance estimate for sexually mature fish captured with the same gears and during the same time span of 2000 and 2001 yielded similar estimates. The estimate for 2000, obtained from a sample of 483 captures with 32 recaptures, and using model M_t was 2,484 fish (SE = 429, 95% CI = 1,801 – 3,511). This estimate was similar to the 2001 estimate using M_t, which was 2,413 fish (SE = 271, 95 % CI = 1,956 - 3,029). The cumulative length distributions of sexually mature fish sampled during those abundance estimates were significantly different (D=4.65, n_{2000}=446, n_{2001}=661, *P*=0.005) (Figure 3.13). This difference is attributed to a decrease in the proportion of fish under 700 mm FL and an increase of fish over 750 mm FL in 2001. A similar trend in the RSD values indicated that the proportion of fish in the quality-to-memorable length categories of the spawning stock decreased during 2001, while the proportion of memorable-to-trophy increased. This may represent a combination of poor recruitment at the lower length classes and good survival of large length classes. This could also indicate a potential decline in the spawning population as these large fish perish and there are fewer fish for recruitment into these large length classes. The RSD values were affected by selectivity of the gears (Table 3.2) and future RSD values should be computed for each gear for comparison with the 2000 and 2001 values for monitoring purposes.

The best capture-recapture model selected by program 2CAPTURE to estimate abundance differed between the two years of the study. The mark-recapture data collected during the studies had many variables that caused variation in the capture probability. These variables included; time, gear, river location, length, and sex of fish. The program 2CAPTURE selected the model that best accounted for these variations in capture probability. The model for 2000 was M_{th}, a more complex model than M_t for 2001. This is likely due to a larger number of variables that affected capture probabilities during 2000. The 2000 study was conducted over a longer time span and included an additional capture technique, which likely created greater variation in capture probabilities due to time and heterogeneity. Other models of the program resulted in similar abundance estimates with in each year. This indicated that regardless of the model selected the estimates of abundance were similar indicating relatively high precision among estimates.

Mark-recapture abundance estimates of the spawning aggregation of rainbow trout in an 8-km reach at the outlet of the Kvichak River, Alaska, ranged from 2,038 (SE = 1,252) to 4,461 (SE = 1,141) from 1988 to 1990 (Minard et al. 1992). The number of rainbow trout that spawned at the outlet of Loon Lake, British Columbia, ranged from 3,185 to 7,871 for 1953 through 1955 (Hartman et al. 1962). The number of spawning rainbow trout in the Lardeau River, British Columbia, was estimated with visual counts at

500 to 700 fish (Hartman 1969). The size of the Lardeau River stock was relatively small compared to the Naknek and Kvichak rivers, but their spawning was confined to 1 km of a 300-m-wide river.

This study provides a means of monitoring the spawning stock of rainbow trout in the Naknek River. Sampling in April with netting techniques, while large rainbow trout are concentrated in spawning areas, provided a means of obtaining large samples. Gill nets can be used at all river locations and provided the best means of dispersing effort for an abundance estimate of spawning fish. The beach seine was site selective, but could be used to capture a large sample of rainbow trout of a wide length range during a short time interval. Beach seining could be useful in obtaining samples adequate for length frequency analysis. Abundance, length frequency, and the composition of the spawning stock can be estimated in a similar manner in future years and compared to the stocks assessed in 2000 and 2001 to evaluate temporal trends in the stock.

Chapter 3

Post-Spawning Movement of Rainbow Trout in the Naknek River, Southwest Alaska

Rainbow trout *Oncorhynchus mykiss* spawning ecology is well documented (McPhail and Lindsey 1970, Morrow 1980, Behnke 1992). In general, rainbow trout spawn in the spring between April and June at water temperatures between 5.5 and 13^{o}C (Morrow 1980). Repeat spawning is common in rainbow trout with spawning occurring for up to 5 years in succession (Hartman 1959). The proportion of repeat spawners in a population ranges up to 57 % (Morrow 1980). Migrations to spawning locations are usually upstream movements from a main stem river to tributaries, or from a lake to its tributaries (Northcote 1997).

The Naknek River of Southwest Alaska supports a spawning population of large, migratory rainbow trout (Figure 1.1). Rainbow trout have been found to migrate between the Naknek River and Naknek Lake (Gwartney 1986). Spawning occurs downstream from the outlet of Naknek Lake in the upper 14 km of the Naknek River during April and May. These rainbow trout exhibit an allacustrine movement from the lake to the lake outlet for spawning (Varley and Gesswell 1988). This kind of spawning movement by rainbow trout appears to be relatively rare; however, such movement has been described in other rainbow trout spawning populations (Northcote 1997). The majority of rainbow trout in Loon and Trout lakes in British Columbia spawn in inlet streams; however, some spawn in the outlet of the lakes (Lindsey et al. 1959, Hartman et al. 1962). The rainbow trout that spawn in the outlet of Loon Lake begin to move into the river during March when the lake is still frozen with peak movement occurring in mid April (Hartman et al. 1962). Post-spawn fish returned to Loon Lake during May and June (Hartman et al. 1962). The Kvichak River, which drains Iliamna Lake in Southwest Alaska, also has a spawning population of large rainbow trout that exhibit allacustrine movement for spawning (Minard et al. 1992).

It has been determined that some sexually mature rainbow trout migrate upstream to Naknek Lake after spawning (Gwartney 1986). These rainbow trout appear to spend the summer in the lake and return to the river in the fall and spring. Based on past tag return data (Gwartney 1985), it appears that many of the rainbow trout from the spawning population spend the summer in Naknek Lake. Large rainbow trout appear to be more abundant in the upper Naknek River as fall progresses. Based on limited data from previous studies (Gwartney 1985), it appears that these fish are members of the spawning population that return to the river in increasing numbers as the fall progresses.

The extent of exploitation of the spawning stock by anglers in the Naknek River during the summer and fall is not known. Rainbow trout fishing in the Naknek River takes place upstream of Rapids Camp to the outlet of the lake with three periods of activity: (1) from ice out in March to 9 April, (2) 8 June to 30 June during sockeye salmon *O. nerka* smolt out-migration, and (3) 15 August until the river freezes in October (Minard and Dunaway 1995). The Alaska Department of Fish and Game manages the Naknek River for trophy rainbow trout and protects the spawning population of rainbow trout with an angling closure from 10 April through 7 June. It is not known if post-spawn fish remain in the river when rainbow trout fishing opens on 8 June.

This study was initiated to examine the timing and patterns of movement by the spawning population of rainbow trout following spawning. This information will allow managers to determine if adult fish are vulnerable to exploitation from sport fishing during the three periods of rainbow trout angling. My objectives were to estimate the proportions of radio tagged rainbow trout that leave the upper Naknek River by 8 June, that remain in the river during the summer, or move to Naknek Lake during the summer, and determine if radio tagged rainbow trout in Naknek Lake tend to return to the Naknek River in the fall.

Methods

Study Design

Post-spawning sexually mature rainbow trout were captured with beach seine, gill net, and hook and line in 2001. Seventy-four fish were surgically implanted with high-frequency radio transmitters. Transmitters with frequencies ranging from 152.610 to 153.990 Mhz were manufactured by Advanced Telemetry Systems, Isanti, Minnesota. The transmitters weighed 19 g, had a life span of 1 year, and were equipped with a mortality signal. If movement by a fish ceased for 8 h, the frequency of the signal increased from 55 to 110 pulses/minute.

All fish were captured from a major spawning location in subarea 4 (Figure 2.1). Surgical procedures followed Summerfelt and Smith (1990). The transmitters were implanted with the antenna extended through the body cavity using the shielded needle technique (Ross and Kleiner 1982). Date of implantation, sex, and fork length (FL, millimeters) were recorded for each fish.

Tag weight did not exceed 2% of the fish weight (Winter 1996). A length-weight regression equation from Naknek River rainbow trout sampled in 1993 estimated that a 500-mm FL fish weighs 1,514 g. This is similar to Gwartney (1985) who estimated that a 500-mm FL fish weighs 1,414 g. The smallest sexually mature fish observed in 2000 was 428 mm FL and 83% of sexually mature fish were greater than 550 mm FL. Only sexually mature fish, as determined by the sexual maturity rating (see Chapter 1), were implanted allowing for the use of 19-g transmitters. Sampling during the spring of 2000 yielded a sex ratio of 53% male and 47% female. Based on this sex ratio, transmitters were implanted in this proportion of male and female fish. The distribution of sexually mature rainbow trout receiving transmitters was proportioned out by 100-mm FL classes based on the length frequency distribution of rainbow trout sampled during the spring of 2000.

Sampling intensity during a telemetry study is dependent on the precision of the data desired, as well as cost (Winter 1996). The data desired for this study were essentially a binomial proportion of fish with transmitters that are present in the river or lake. Prior to purchasing transmitters the needed sample size based on a binomial proportion was determined. A scenario where 50% of fish with transmitters emigrate upstream from Naknek River into Naknek Lake by 8 June, where no clear inference from the data can be obtained, was used to determine a sample size. If 50% of the rainbow trout with transmitters entered the lake by 8 June, then 61 fish needed to be marked with radio transmitters to estimate the proportion that emigrate within 12.5% of the true value

95% of the time (Cochran 1977). Consideration of fish mortality or transmitter failure requires additional fish with transmitters. Assuming a loss of 20% of the transmitters due to fish mortality or transmitter failure, a sample size of 74 fish was required to determine the proportion with the desired precision.

Implantation of transmitters occurred in fish that had completed spawning, as determined by the sexual maturity rating. This allowed for the selection of fish that appeared healthy and had successfully endured spawning, minimizing the loss of transmitters due to spawning mortality. Beginning 10 April 2001, 5 weeks were scheduled for capturing fish and performing the surgical implantation of transmitters. The number of transmitters implanted each week was based on the proportion of spawned out fish sampled each week of the 2000 field study. Additional transmitters were implanted the fourth week to ensure that spawned out fish could be captured before they vacated the spawning grounds during the final week. The schedule for transmitters implanted each consecutive week was: 6, 10, 15, 30, and 13 fish.

Data Collection

A fixed station with a receiver and data logger was placed at the lake outlet to monitor the movement of fish from the river into the lake. The fixed station was placed near the regulatory marker on the right bank of the river near the lake outlet (Figure 2.1). Two antennas were used, one directed slightly upstream and the other slightly downstream to detect the direction of movement of radio tagged fish. The fixed station was powered with three gel cell batteries and a solar panel. The receiver scanned continuously for radio signals of the transmitter frequencies. The data from the fixed station were downloaded weekly and batteries were replaced when necessary.

Tracking of the fish with radio transmitters occurred from an airplane at least twice a month from May through December 2001. Airplane telemetry surveys were made at an altitude of 500 m, over both Naknek Lake and the Naknek River. During each tracking event the Naknek River from the mouth of King Salmon Creek to the lake outlet was searched with several passes to ensure that all transmitters in this area were located (Figure 1.1). Occasionally the river was searched from King Salmon Creek downstream to Bristol Bay. This reach of the river is very turbid due to tidal action and provides little rainbow trout habitat. Due to the large area of Naknek Lake (610 km^2, LaPerriere 1996), the search routine for the lake was concentrated along the shoreline and islands. Tracking that followed this search routine took over 3 h of flying. The coordinates of transmitter locations were recorded with a global positioning system (GPS) and the general location was marked on a map of the lake.

Data Analysis

The dates that fish moved from the river to the lake were recorded and the proportion of fish with transmitters that were in the river or the lake upon each survey date was determined. The location of radio tagged trout, as determined by GPS and marked on maps, yielded insight on the summer range of sexually mature rainbow trout that spawn in the Naknek River. The dates that radio-tagged rainbow trout returned to the Naknek River from the lake were recorded. For discrete 2-week periods, the number of rainbow trout with transmitters that moved from the lake to the river, as was the number of rainbow trout with transmitters in the river or lake were determined from August to December.

Results

The radio telemetry study began 10 April 2001. Transmitters were implanted in 74 rainbow trout, 38 males and 36 females. The date of implantation, sex, and fork length of fish implanted with transmitters are in Table 4.1. The mean FL of fish implanted with transmitters was 674 (SE=9) mm for males and 638 (SE=8) mm for females. As of 8 June, 70 fish with transmitters (35 of each sex) were alive and the transmitters were functioning. Of these 70 rainbow trout, 56 (27 males, 29 females) moved from the Naknek River to Naknek Lake by 8 June, and 14 (7 males, 7 females) remained in the Naknek River (see Figures 4.1 and 4.2). Most emigration occurred during the week of 13 May (Figure 4.2). With the exception of one rainbow trout that spent time in the river and entered the lake on 31 August, all the rainbow trout entered the lake by 19 June (Figure 4.2). All of the fish that left prior to 13 May were females. After this date the movement of males and females into the lake was similar. The mean FL at the time of tagging of males that remained in the river for the summer was 635 mm and of those that summered in Naknek Lake was 685 mm (Table 4.2). The mean FL of females that remained in the river for the summer was 592 mm and of those that summered in Naknek Lake was 646 mm (Table 4.2).

The proportion of rainbow trout with transmitters in the lake during the summer was determined from the number of live fish with functioning, locatable transmitters found during each survey event. Sixty-four rainbow trout with transmitters were located during the summer. Of these, 51 (80%) spent most of the summer in the lake and 13 (20%) remained in the Naknek River through the summer.

The number of live rainbow trout with transmitters that migrated to the river from the lake in the fall was determined from 38 fish that could be located as of 1 September. Of these, 21 (55%) were in Naknek Lake on 1 September and 17 (45%) were in the river. Twelve (1 mortality in river before 1 September) of these 17 fish had remained in the river during the summer and five returned to the river after spending the summer in Naknek Lake. An additional 11 of 21 rainbow trout with active transmitters returned to the river from the lake between 1 September and 18 December (Figure 4.3). The mean FL at the time of tagging of fish that returned to the river from the lake for August through December was 682 mm for males and 634 mm for females (Table 4.2). The number of fish with transmitters in the river remained relatively constant from August through December when compared to the number located in the lake, which declined consistently over that time (Figure 4.4).

Nineteen (26%) of the 74 rainbow trout with transmitters died between May and December. Mortality occurred in 12 males and 7 females. The mean FL of mortalities was 666 mm for males and 646 mm for females (Table 4.2). The month with the most mortalities (5) was May (Figure 4.5).

Discussion

Migration patterns within freshwater systems, or potadromy, can vary greatly among salmonids. Our understanding of salmonid movements has expanded from the once widely accepted restricted-movement paradigm of stream resident salmonids (Gerking 1959). Four migration patterns have been identified, including two patterns between rivers and lakes (Varley and Gresswell 1988). Rainbow trout in the Naknek River spawning population tend to exhibit an allacustrine migration pattern with spawning movement from a lake to a river outlet to spawn. Naknek River rainbow trout exhibit similar spawning movement patterns as rainbow trout in Loon Lake, British Columbia. The population in Loon Lake moves from the lake to the outlet to spawn in March and April (Hartman et al. 1962). Similar post-spawning movement to the lake occurs in May and June for each population.

The post-spawning movement of rainbow trout from the Naknek River is likely a feeding migration (Northcote 1997). In 1999 approximately 1.6 million sockeye salmon spawned in the Naknek River Drainage and Naknek Lake provides a large rearing area for juvenile sockeye salmon (Dunaway and Sonnichsen 2001). The post-spawning movement of large rainbow trout in Naknek Lake is likely a response to the presence of a prey base of juvenile sockeye salmon. However, rainbow trout present in the Naknek River aggregate at several river locations to feed on sockeye salmon smolts migrating into Bristol Bay from June through July.

The abundant prey base of the river leads to questions about why large rainbow trout would migrate to Naknek Lake. Another possible explanation is that this movement may be a refuge response to the large influx of salmon, most notably sockeye salmon, into the Naknek River from June through August. Sockeye salmon become very aggressive during spawning, attacking males and females of their own species and fish predators (McPhail and Lindsey 1970, Morrow 1980, Groot and Margolis 1991). Large rainbow trout may have evolved the observed movement pattern as a response to displacement from the river due to the abundance of aggressive salmon.

Refuge responses by salmonids are usually described as movement to a lake for over-wintering (Northcote 1997). Rainbow trout from the Naknek River spawning population use both the lake and the river for over-wintering, but it appears that the river is preferred winter habitat. Over-wintering in rivers before spawning is common in many steelhead *Oncorhynchus mykiss* populations (Withler 1965, Behnke 1992, Begich 1999). Rainbow trout exhibit repeat spawning and many mature fish that spawned during 2000 may have been over-wintering in the river to stage for spawning during 2001. Another possible explanation for the observed fall movement patterns is that large rainbow trout return to the Naknek River in the fall to feed on the flesh of deteriorating salmon carcasses.

Most of the rainbow trout that migrated to Naknek Lake remained there at least through June and July. Rainbow trout are common in a portion of Naknek Lake known as the Bay of Islands (Gwartney 1985) in the east arm of the lake (Figure 1.1). Most of Naknek Lake is glacially turbid during the summer due to the Savonoski River that flows into the southern section of the lake known as the Iliuk Arm. There is no glacial input near the Bay of Islands and a series of islands separate the eastern arm from the remainder of the lake. As a result the water is clearer in the Bay of Islands section of the lake. It has been hypothesized that use of the Bay of Islands by rainbow trout may be due to the clear water that allows them to be more effective visual predators (Gwartney and Burger 1986). The proportion of fish in the lake that were found in the eastern arm of the lake increased from 20% in May to 63% in August.

Post-spawn female rainbow trout initiated movement into Naknek Lake before males. Individual females became ripe over the duration of the spawning period and began to leave the spawning grounds after spawning. As a result, females that spawned early tended to leave the river first. Males may spawn with more than one female, so as one female completes spawning males will locate another female that is ripe. As a result, males were likely to remain on the spawning grounds for the duration of the spawning period. The sex ratio of fish that entered Naknek Lake (28 male, 29 female) and those that remained in the river (8 male, 6 female) was similar. Mean FLs indicated that lengths of each sex that remained in the river were smaller than those that entered the lake (Table 4.2). This may indicate that larger fish prefer some aspect of Naknek Lake over Naknek River, such as abundant prey in the form of sockeye salmon fry or lower energy expenditure due to a lack of current in the lake.

The sex ratio of rainbow trout that moved from the lake to the river in the fall was similar (8 male, 10 female). More males (four) returned from August to mid-September than females (one) (Figure 4.3). From mid-September to mid-October, six females returned but no males. It is difficult to determine if this pattern bears any significance or is just random.

Twenty-six of the 74 rainbow trout implanted with transmitters were confirmed as mortalities between May and December. It is likely that more mortalities occurred and were not located, especially mortalities in deep water of Naknek Lake. A larger number of males (12) than females (7) were documented mortalities. Of the males implanted with transmitters 32% died, but only 20% of the females implanted died. This may be accounted for by increased spawning mortality of males, as documented by Hartman et al. (1962) for Loon Lake, British Columbia. However, I do not think these mortality rates should be considered estimates of post-spawn mortality for Naknek River rainbow trout due to possible reduced survival from the surgical implantation of transmitters.

The results of this study indicate that the majority of spawning rainbow trout from the Naknek River are not heavily exploited by recreational fishing in the river. Spawning rainbow trout are protected with a closure and most of post-spawning rainbow trout move into Naknek Lake before angling resumes in the river on 8 June. Most of the fish that entered the lake remained there during the months of June and July, but from August through the December fish moved back to the river. Fall angling for rainbow trout subsides in early October when the river begins to freeze. The results suggest that more than half of the spawning stock may have been available for exploitation by anglers in the river during September. Some of the rainbow trout did not migrate to the Naknek River during the fall and several returned late in the fall. These fish were not available to the fall rainbow trout fishery.

This study only examined large sexually mature rainbow trout of the Naknek River. Angling and biological sampling data indicate that smaller fish are present in the Naknek River during the summer. These are likely fish that have yet to reach sexually maturity and may be exploited by recreational angling. Future research should be directed towards determining the survival and movements of these immature rainbow trout.

Management Implications

My findings on the spawning population of rainbow trout in the Naknek River provide valuable information for future monitoring of the stock. The capture methods provide a means of capturing a large sample of sexually mature rainbow trout. A means of estimating abundance of the spawning population over 3-weeks was developed. Abundance estimates and length frequency distributions of the spawning stock provide an index for future monitoring. An understanding of the life history of rainbow trout in the spawning population was gained, providing insight on the effectiveness of the current management strategy.

Hook and line has been used in the past to sample rainbow trout in the Naknek River. However, I found hook and line to be an inefficient sampling method. The catch per unit effort (CPUE) and the proportions of sexually mature fish captured were lower, and the sex ratio of sexually mature fish differed, when hook and line samples were compared to gill net and beach-seine samples. The CPUE, length distributions, and sex ratios were similar for sexually mature fish captured with gill net and beach seine. As a result, actively fished gill nets and beach seines should be used for future monitoring of sexually mature rainbow trout in the Naknek River.

Mark-recapture abundance estimates conducted from 10 to 30 April during 2000 and 2001 provided similar estimates of abundance of sexually mature rainbow trout in the Naknek River. All fish included in these estimates were captured with gill nets and beach seines. Gill nets could be used to sample fish in all spawning areas, providing coverage for an abundance estimate. The beach seine was site specific, but could capture large samples of rainbow trout in a short time frame, which may be desirable for attaining a less size selective sample for length distribution analysis. These estimates can provide an index for future monitoring of the spawning stock, given the same gears are used, in the same river reaches, and at the same time.

Catch per unit effort provides an estimate of abundance if a correlation can be made between relative and absolute abundance (Ney 1999). This technique requires that sampling effort is measured precisely and that sampling efficiency is not affected by how a sample was collected. This was very difficult to account for with the gears and techniques used on the Naknek River. The technique used for each gear and the capture success of each gear varied by river location. For example, the gill net was deployed three different ways depending on river location (see Chapter 1). As a result, the gear was not used in a consistent manner throughout the study site preventing a standardization of effort and an estimate of relative abundance.

The length frequency distributions of samples from 2000 and 2001 indicated a high frequency of large (>650 mm, FL) rainbow trout in the Naknek River spawning population. The RSD analysis indicated that the spawning population was comprised of a high proportion of memorable to trophy rainbow trout. This frequency of large fish is rare among rainbow trout populations and provides a unique angling opportunity.

The visual determination of sexually maturity for rainbow trout in the spring appears to be reliable given the guidelines used for this study. This allows for future comparison of the length frequency distributions of sexually mature males and females to 2000 and 2001 samples and a means of evaluating the length structure of the spawning stock.

The length frequency distributions of rainbow trout sampled each year indicated few fish in the 500-600 mm FL range. These fish may not be present in the river during the spring or may be a weak cohort. This makes it difficult to predict future recruitment into the spawning stock. If it is a weak cohort the spawning stock may be severely reduced in subsequent springs. The possible lack of fish near the length of recruitment into the spawning population increases the need for continued monitoring of the spawning stock in the near future.

Given these findings, future monitoring should be conducted between 10 and 30 April when sexually mature rainbow trout are concentrated for spawning and available for capture. These dates provide guidance, but managers should be flexible when conducting future monitoring. The timing of spawning was similar during 2000 and 2001, but may not remain constant for all years. Late springs resulting in cold water temperatures may delay movement onto the spawning grounds making it necessary to delay sampling a week, or extend sampling for an additional week. Sampling should be concentrated where the majority of spawning occurs in subareas 3 and 4. Large numbers of rainbow trout can be sampled during this time span with gill net and beach seine. Future samples and abundance estimates can be compared to the 2000 and 2001 samples.

The findings of my research provide insight as to the effectiveness of current rainbow trout regulations on the Naknek River. The movements of the spawning stock of rainbow trout in the Naknek River currently prevent extensive exploitation by anglers. Based on the proportion of spawned-out fish observed during 2000 and 2001, the majority of rainbow trout did not commence spawning until after the spawning closure on 10 April. In addition, inclement weather and freezing of the river limited anglers from participating in the fishery each year. Telemetry data from 2001 indicated that the majority (80%) of post-spawn rainbow trout moved into Naknek Lake by 8 June when the rainbow trout fishery reopens. Movements by a large proportion of spawning fish in Naknek Lake protected them from exploitation by anglers in the river. These migrating fish remained in Naknek Lake during the summer. While in Naknek Lake these post-spawn fish are susceptible to some exploitation by a fishery that occurs in the Bay of Islands. In August fish from the spawning population began to move back into Naknek River. The majority of this movement occurred after 14 September and extended into December. During the fall these fish are available for exploitation until the river freezes. Periodic surveys of the angling effort during the fall fishery should be conducted to monitor exploitation of rainbow trout.

The area of the spawning closure in the upper Naknek River, from Rapids Camp to Trefon's Cabin, encompasses all spawning areas observed during the study. Gwartney (1985) observed a small number of rainbow trout spawning below the regulatory marker at Rainbow Bend; however, no fish were seen spawning in this area during 2000 and 2001. The section of the river directly below the regulatory markers at Rapids Camp and above the upstream marker provide an opportunity for rainbow trout angling during the spawning closure. Some sexually mature rainbow trout were periodically sampled at these locations during the surveys; however, concentrations were only observed at the upstream marker after the middle of May. These were post-spawn fish moving into Naknek Lake that appeared to stage in subarea 1 near the lake outlet. A combination of low effort and small numbers of fish available outside of the closed area preclude any expansion of the current area of closure.

Rainbow trout in the spawning stock are protected from harvest with the current maximum length limit of 457 mm (18 in) TL and a daily bag limit of one fish. About 2% of all sexually mature fish sampled during 2000 and 2001 were less than 500 mm (19.7 in) fork length. This regulation is applied drainage wide, protecting fish of the spawning stock in Naknek Lake, as well as the river. The harvest of five fish under 457 mm in the winter is allowed; however, this fishery consists of local anglers and harvest is low. This indicates that very little harvest of sexually mature fish occurs in the Naknek River drainage. In addition, current gear restrictions of single hook artificial lures reduce mortality associated with catch and release.

In summary, the population of spawning rainbow trout appears to be relatively large based on abundance estimates for 2000 and 2001. The current management strategy of the ADFG and the seasonal movements of the spawning stock appear to protect the population from excessive exploitation. However, natural fluctuations occur in all populations due to changes in the environment or prey base. The large sizes of fish in this population are likely related to the abundant prey supplied by large escapements of sockeye salmon and low exploitation rates allowing fish to live for up to 14 years. Sockeye salmon escapements in the Iliamna Lake drainage have been severely reduced in recent years; it is unknown how a reduction of sockeye salmon escapement in the nearby Naknek River drainage may affect the rainbow trout population. Routine monitoring should be done to assess changes in abundance and length structure of the Naknek River rainbow trout spawning population that may be due to variation in prey abundance, exploitation by anglers, or other causes.

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Table 2.1. Total number, catch per unit effort (fish/h), and mean, median, minimum and maximum fork lengths (mm) of rainbow trout captured with three gears from 10 April to 14 May 2000 in the Naknek River, Alaska.

	Total captured	Catch per unit effort	Mean length	Median length	Minimum length	Maximum length
Hook and line	81	2.5	506 (SE=7)	475	290	743
Beach seine	411	12.5	545 (SE=8)	604	196	805
Gill net	611	8.0	608 (SE=5)	645	315	830

Table 2.2. Proportion of sexually mature fish, catch per unit effort (fish/h), mean and median fork lengths (mm), and sex ratios of sexually mature rainbow trout captured with three gears from 10 April to 14 May 2000 in the Naknek River, Alaska.

	Proportion of sexually mature fish (%)	Catch per unit effort	Mean length of sexually mature fish	Median length of sexually mature fish	Proportion of males (%)	Proportion of females (%)
Hook and line	42	1.0	641 (SE=8.5)	650	44	56
Beach seine	61	7.6	662 (SE=4)	665	63	37
Gill net	81	6.5	657 (SE=3)	661	59	41

Table 2.3. Total number of fish captured, catch per unit effort (fish/h), mean, median, minimum and maximum fork length (mm) of rainbow trout captured by gear from 10 April to 28 April 2001 in the Naknek River, Alaska.

	Total captured	Catch per unit effort	Mean length	Median length	Minimum length	Maximum length
Beach seine	542	15.5	551 (SE=7)	609	225	841
Gill net	489	9.8	655 (SE=4)	669	280	860

Table 2.4. Proportion of sexually mature fish, catch per unit effort (fish/h), mean and median fork length (mm), and sex ratios of sexually mature rainbow trout captured with three gears from 10 April to 28 April 2001 in the Naknek River, Alaska.

	Proportion of sexually mature fish (%)	Catch per unit effort	Mean length of sexually mature fish	Median length of sexually mature fish	Proportion of males (%)	Proportion of females (%)
Beach seine	62	9.6	664 (SE=4)	671	64	36
Gill net	93	9.1	671 (SE=3)	675	61	39

Table 3.1. Number of sexually mature rainbow trout marked (Mar) and recaptured (Rec) by week and subarea in the upper Naknek River during spring of 2000.

		Subarea 1			Subarea 2			Subarea 3			Subarea 4			Total		
Week		Mar	Rec	Total	Mar	Rec	Total	Mar	Rec	Total	Mar	Rec	Total	Mar	Rec	Total
1	20 Mar-26 Mar	8	0	8	1	0	1	7	0	7	7	0	7	23	0	23
2	27 Mar-2 April	6	0	6	15	0	15	16	0	16	19	0	19	56	0	56
3	3 Apr-9 Apr	8	0	8	4	0	4	14	0	14	17	0	17	43	0	43
4	10 Apr-16 Apr	6	0	6	12	0	12	34	4	38	100	5	105	152	9	161
5	17 Apr-23 Apr	29	0	29	8	0	8	62	7	69	88	11	99	187	18	205
6	24 Apr-30 Apr	3	0	3	8	1	9	86	10	96	56	10	66	153	21	174
7	1 May-7 May	2	0	2	6	0	6	43	17	60	59	8	67	110	25	135
8	8 May-14 May	21	1	22	2	2	4	32	8	40	40	19	59	95	30	125
9	15 May-21 May	20	5	25	5	1	6	14	4	18	10	2	12	49	12	61
Total		103	6	109	61	4	65	308	50	358	396	55	451	868	115	983

Table 3.2. Relative stock density (RSD) of rainbow trout sampled with hook and line, beach seine, gill net, and all gears combined during the spring of 2000 of rainbow trout sampled with beach seine, gill net, and both gears combined during the spring of 2001 from the upper Naknek River, Alaska.

	Gear	RSD				
Year	type	S-Q	Q-P	P-M	M-T	>T
2000	Hook and line	11	28	31	28	2
	Beach seine	22	14	16	42	4
	Gill net	6	11	19	58	6
	All gears	12	19	24	41	4
2001	Beach seine	22	13	14	43	8
	Gill net	2	6	13	66	12
	All gears	12	9	15	54	10

Table 3.3. Effort with each gear for the marking and recapture of sexually mature rainbow trout by week and subarea in the upper Naknek River during the spring of 2000.

		Subarea			
Gear	Week	1	2	3	4
Hook and line	4	3	2	2	1
(hours)	5	3	1	2	2
	6	1	1	2	2
	7	1	1	2	2
	8	1	1	2	1
	Total	9	6	10	8
Gill net	4	10	10	25	40
(sets)	5	5	12	27	45
	6	0	15	28	47
	7	0	10	28	48
	8	0	12	27	50
	Total	15	59	135	230
Beach seine	4	5	4	8	15
(sets)	5	3	5	10	17
	6	0	4	9	18
	7	0	3	11	17
	8	0	5	8	17
	Total	8	21	46	84

Table 3.4. Numbers of sexually mature rainbow trout captured, recaptured, and percent of marked fish recaptured by hook and line, gill net, or beach seine in the upper Naknek River during the spring 2000.

	Gear type		
Total number	Hook and line	Gill net	Beach seine
Total marked	255	419	192
Total recaptured	13	56	46
Total	268	475	238
Percent recaptured	5%	11%	19%

Table 3.5. Numbers of sexually mature rainbow trout captured and recaptured by different gear types in the upper Naknek River during spring of 2000.

Gear captured	Gear recaptured			
	Hook and line	Gill net	Beach seine	All gears
Hook and line	2	20	6	28
Beach seine	4	9	23	36
Gill net	7	27	17	51
All gears	13	56	46	115

Table 3.6. Numbers of recaptured sexually mature rainbow trout originally marked in each subarea and subareas where they were recaptured with designation by gear type during the spring of 2000.

Subarea marked	Gear	Subarea recaptured				
		Subarea 1	Subarea 2	Subarea 3	Subarea 4	All subareas
Subarea 1	Hook and line	1	0	0	0	1
	Gill net	0	0	2	1	3
	Beach seine	0	0	1	1	2
	Total	1	0	3	2	6
Subarea 2	Hook and line	0	0	0	0	0
	Gill net	0	1	5	1	7
	Beach seine	0	0	1	0	1
	Total	0	1	6	1	8
Subarea 3	Hook and line	2	1	5	0	8
	Gill net	0	1	21	3	25
	Beach seine	0	0	7	2	9
	Total	2	2	33	5	42
Subarea 4	Hook and line	3	0	1	1	5
	Gill net	0	1	6	16	23
	Beach seine	0	0	1	30	31
	Total	3	1	8	47	59
All subareas		6	4	50	55	115

Table 3.7. Recapture history by subarea of capture for sexually mature rainbow trout marked in the upper Naknek River during spring of 2000.

Recapture in	Subarea marked				
same subarea	Subarea 1	Subarea 2	Subarea 3	Subarea 4	All subareas
No	103	61	308	396	868
Yes	6	4	50	55	115

Table 3.8. Numbers of sexually mature rainbow trout marked (Mar) and recaptured (Rec) by week and subarea in the upper Naknek River during spring 2001.

		Subarea 3			Subarea 4			Total		
Week		Mar	Rec	Total	Mar	Rec	Total	Mar	Rec	Total
1	10 Apr-16 Apr	69	0	69	125	0	125	194	0	194
2	17 Apr-23 Apr	83	11	94	120	25	145	203	36	239
3	24 Apr-30 Apr	105	18	123	152	23	175	257	41	298
All weeks		257	29	286	397	48	445	654	77	731

Table 3.9. Effort with each gear for the marking and recapture of sexually mature rainbow trout by week and subarea in the upper Naknek River during the spring of 2000.

		Subarea	
Gear	Week	3	4
Gill net	1	35	60
(sets)	2	37	65
	3	38	66
	Total	110	191
Beach Seine	1	10	27
(sets)	2	12	28
	3	10	28
	Total	32	83

Table 3.10. Numbers of sexually mature rainbow trout captured, recaptured, and percent of marked fish recaptured (3 recaptures not included due to tag loss) by beach seine or gill net in the upper Naknek River during the spring 2001.

	Gear type	
Total number	Gill net	Beach seine
Total marked	457	338
Total recaptured	40	34
Total	497	372
Percent recaptured	8%	9%

Table 3.11. Numbers of sexually mature rainbow trout captured and recaptured (3 recaptures not included due to tag loss) by different gear types in the upper Naknek River during spring 2001.

Gear	Gear recaptured		
captured	Gill net	Beach seine	Both gears
Gill net	34	8	42
Beach seine	6	26	32
Both gears	40	34	74

Table 3.12. Numbers of recaptured sexually mature rainbow trout (3 recaptures not included due to tag loss) originally marked in each subarea and subareas where they were recaptured with designation by gear type in the upper Naknek River during spring of 2001.

Subarea marked	Gear	Subarea recaptured: Subarea 3	Subarea 4	Both subareas
Subarea 3	Gill net	23	1	24
	Beach seine	0	3	3
	Total	23	4	27
Subarea 4	Gill net	3	13	16
	Beach seine	0	31	31
	Total	3	44	47
Both subareas		26	48	74

Table 3.13. Recapture history by subarea of capture for sexually mature rainbow trout marked in the upper Naknek River during spring 2001 (3 recaptures not included due to tag loss).

Recapture in	Subarea marked		
same subarea	Subarea 3	Subarea 4	All subareas
No	257	397	654
Yes	26	48	74

Table 4.1. Number of sexually mature rainbow trout by length class (mm, FL), sex, and week implanted with radio transmitters from 10 April to 14 May 2000 in the Naknek River, Alaska.

		Week					
Length class (mm, FL)	Sex	10 April - 16-April	17 April - 23-April	24 April - 30-April	1 May - 7-May	8 May - 14-May	Total
501 - 600	Male	2	0	0	1	4	7
	Female	2	1	1	3	3	10
601 - 700	Male	2	3	4	10	3	22
	Female	0	4	5	12	1	22
701 -800	Male	0	0	3	7	0	10
	Female	0	0	1	2	0	3
	Total	6	8	14	35	11	74

Table 4.2. Number of each sex and mean FL (mm) of rainbow trout with transmitters that spent the summer in Naknek Lake and Naknek River, returned to Naknek River from Naknek Lake, and died during 2001.

		Summered in lake	Summered in river	Returned in fall to river from lake	Mortalities
Number of each sex	Male	28	8	8	12
	Female	29	6	10	7
Mean fork length of each sex	Male	685 (SE=9)	635 (SE=25)	682 (SE=20)	666 (SE=19)
	Female	646 (SE=7)	592 (SE=27)	634 (SE=13)	646 (SE=26)

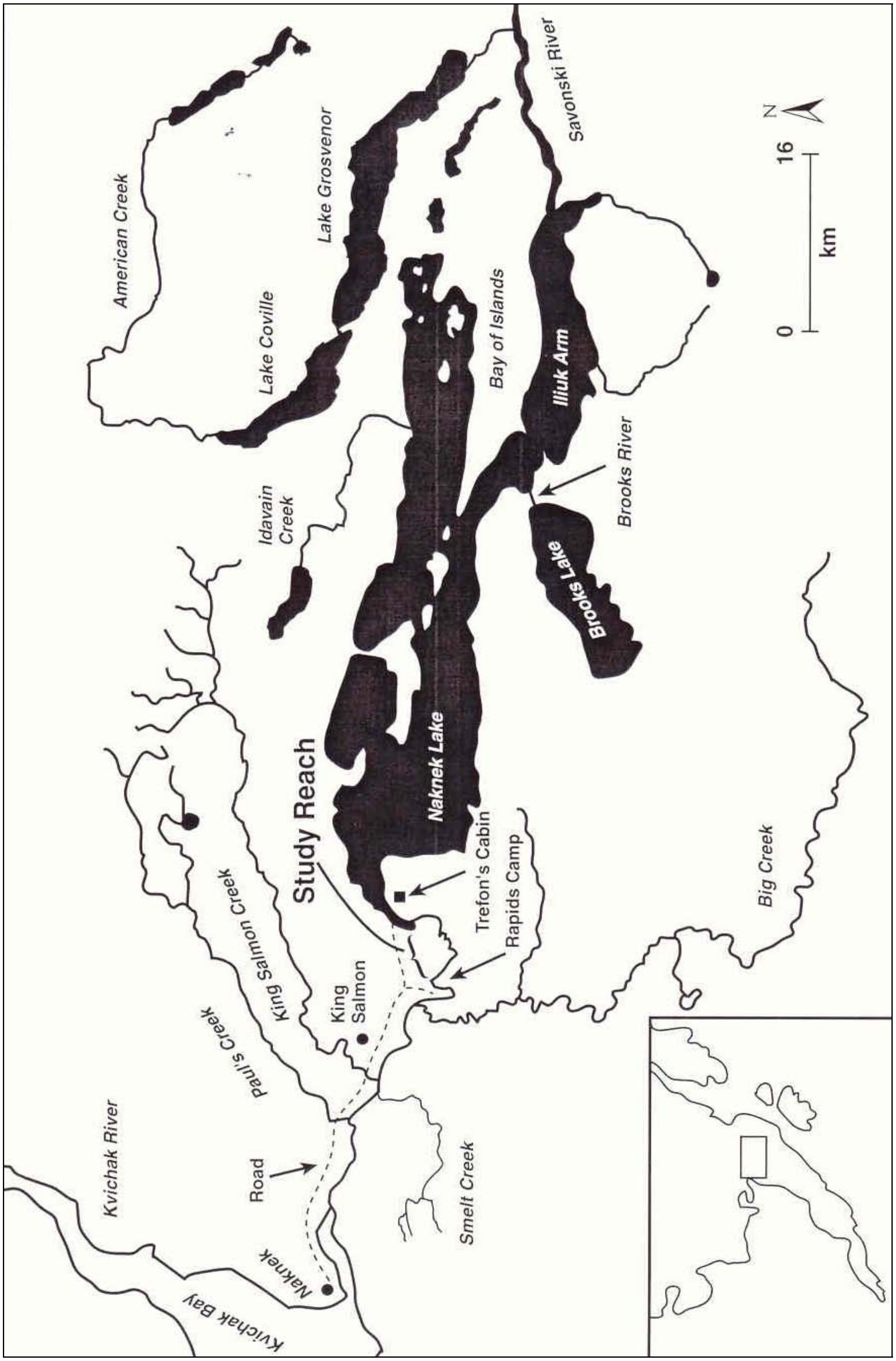

Figure 1.1. Map of study area in the Naknek River drainage, Southwest Alaska.

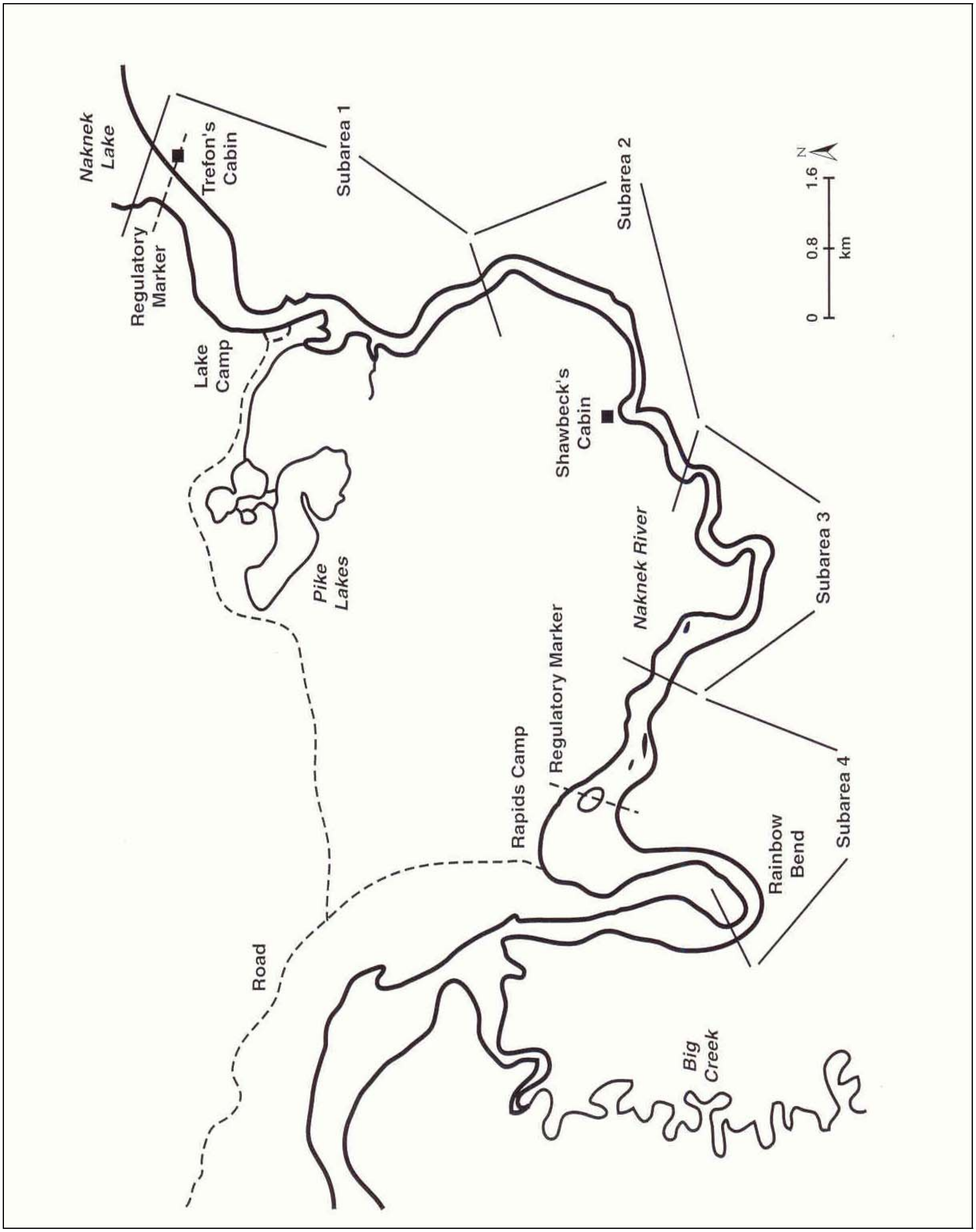

Figure 2.1. Map of study area and subareas in the upper Naknek River, Alaska.

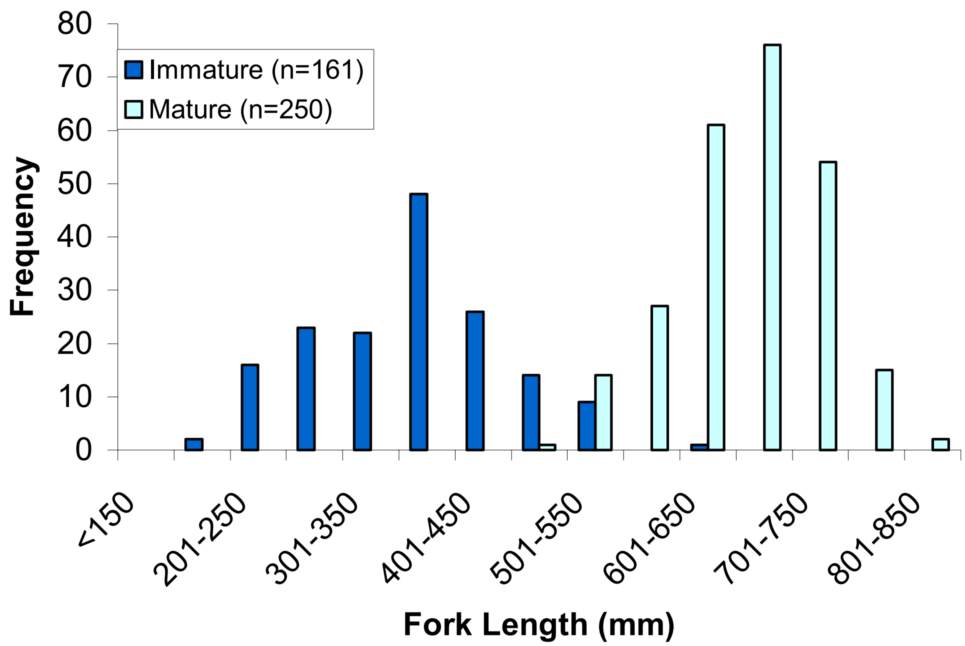

Figure 2.2. Length frequency distributions of sexually immature and mature rainbow trout captured with a beach seine from 10 April to 14 May 2000 in the Naknek River, Alaska.

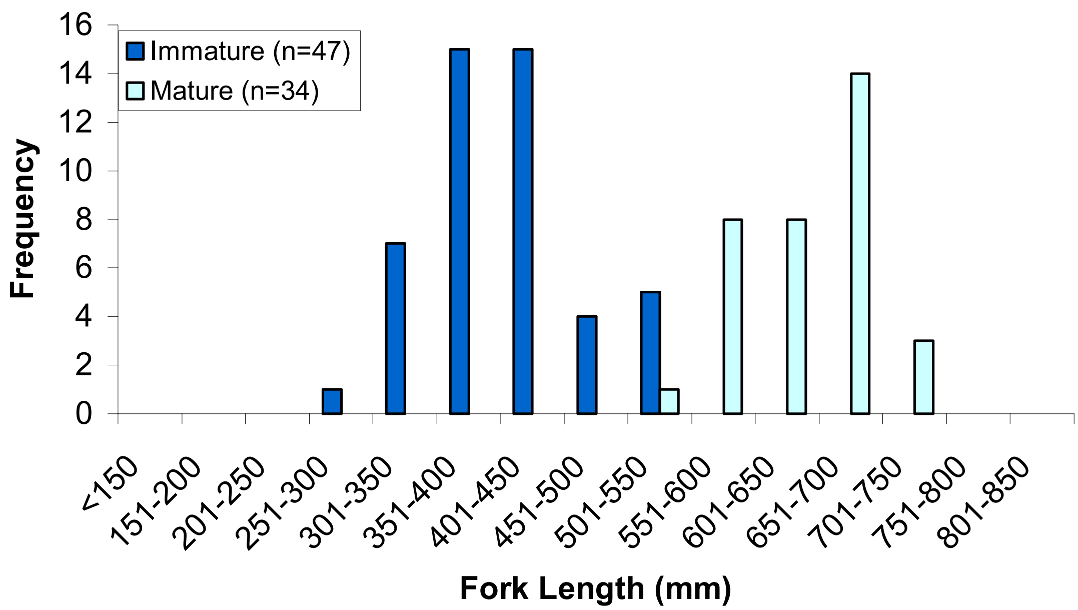

Figure 2.3 Length frequency distributions of sexually immature and mature rainbow trout captured with hook and line from 10 April to 14 May 2000 in the Naknek River, Alaska.

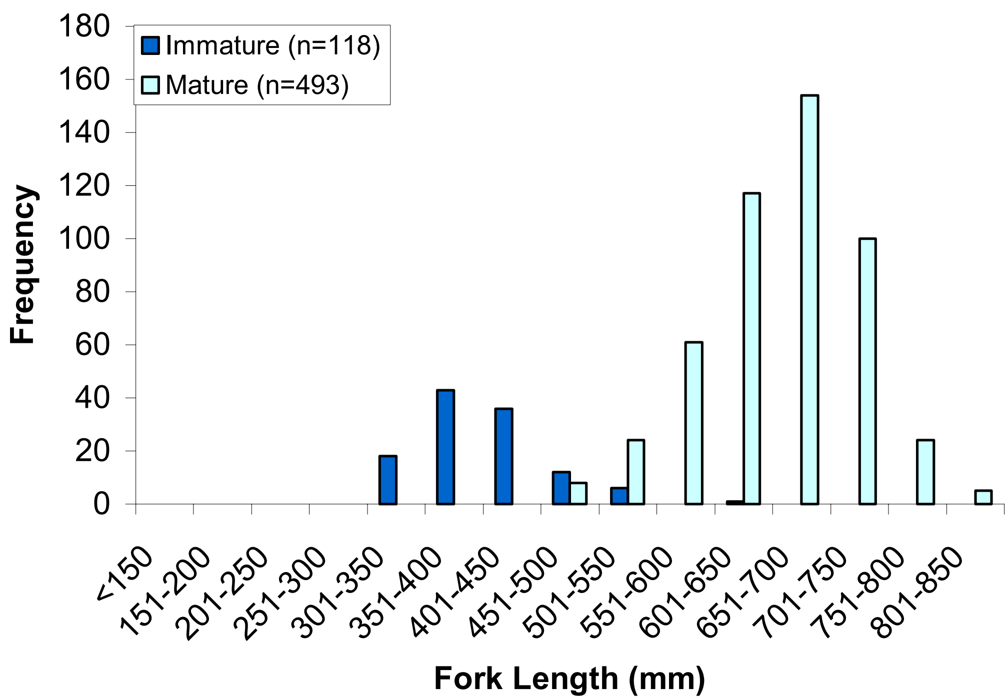

Figure 2.4. Length frequency distributions of sexually immature and mature rainbow trout captured with gill net from 10 April to 14 May 2000 in the Naknek River, Alaska.

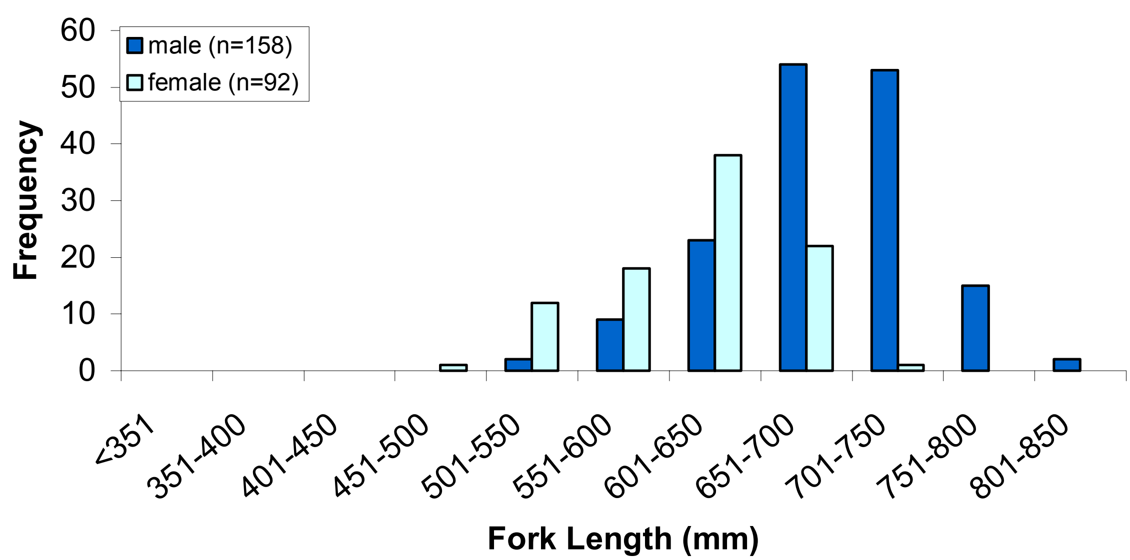

Figure 2.5. Length frequency distributions of sexually mature rainbow trout captured with beach seine from 10 April to 14 May 2000 in the Naknek River, Alaska.

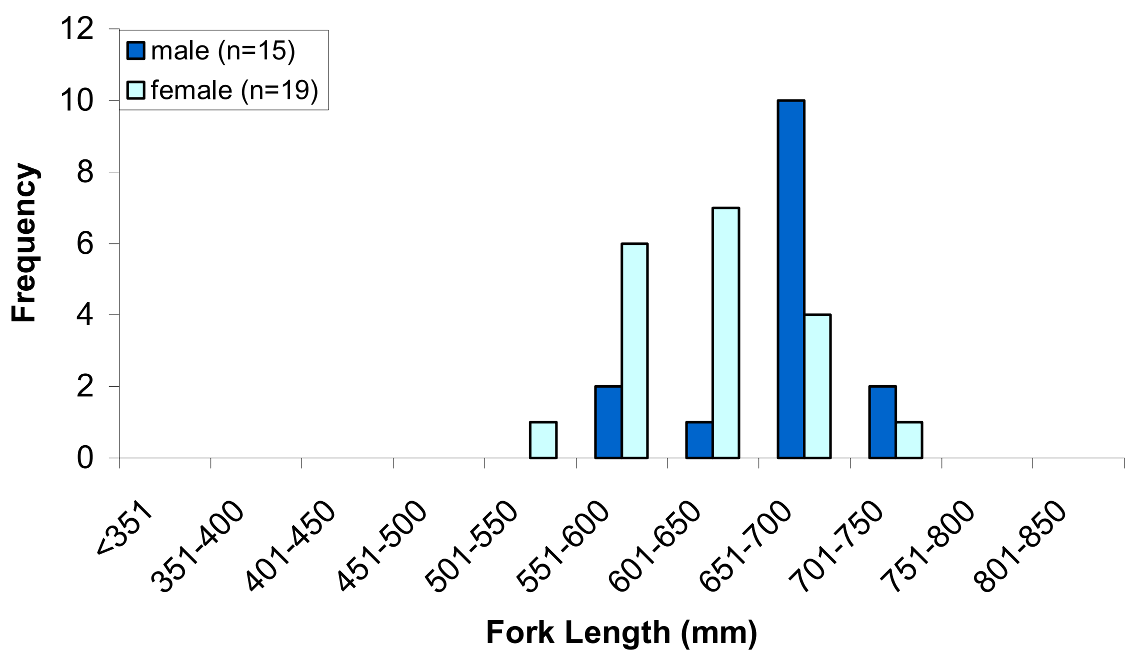

Figure 2.6. Length frequency distributions of sexually mature rainbow trout captured with hook and line from 10 April to 14 May 2000 in the Naknek River, Alaska.

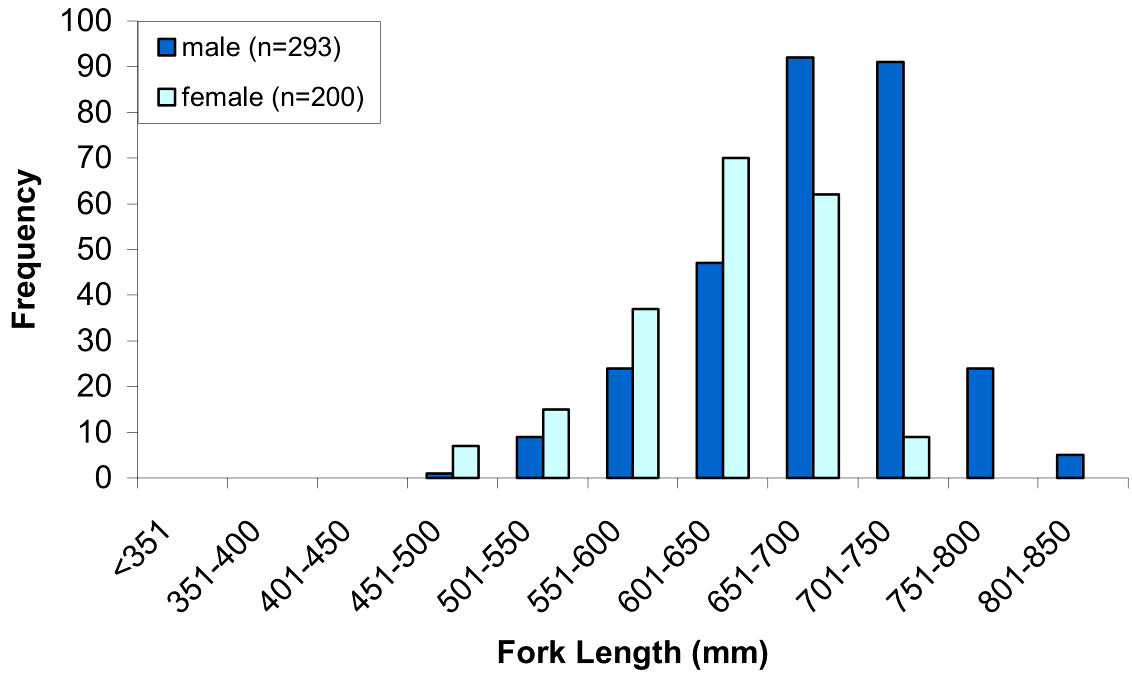

Figure 2.7. Length frequency distributions of sexually mature rainbow trout captured with gill net from 10 April to 14 May 2000 in the Naknek River, Alaska.

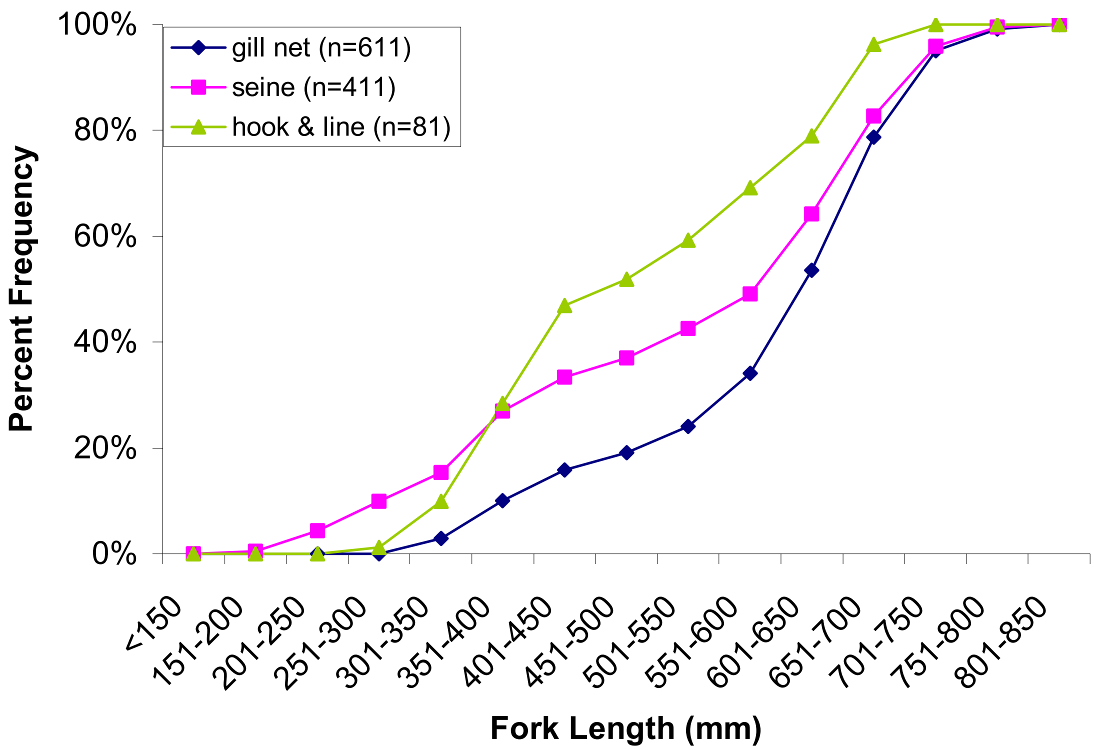

Figure 2.8. Cumulative length frequency distributions of rainbow trout captured with a gill net, beach seine, and by hook and line during the spring of 2000 in the Naknek River, Alaska.

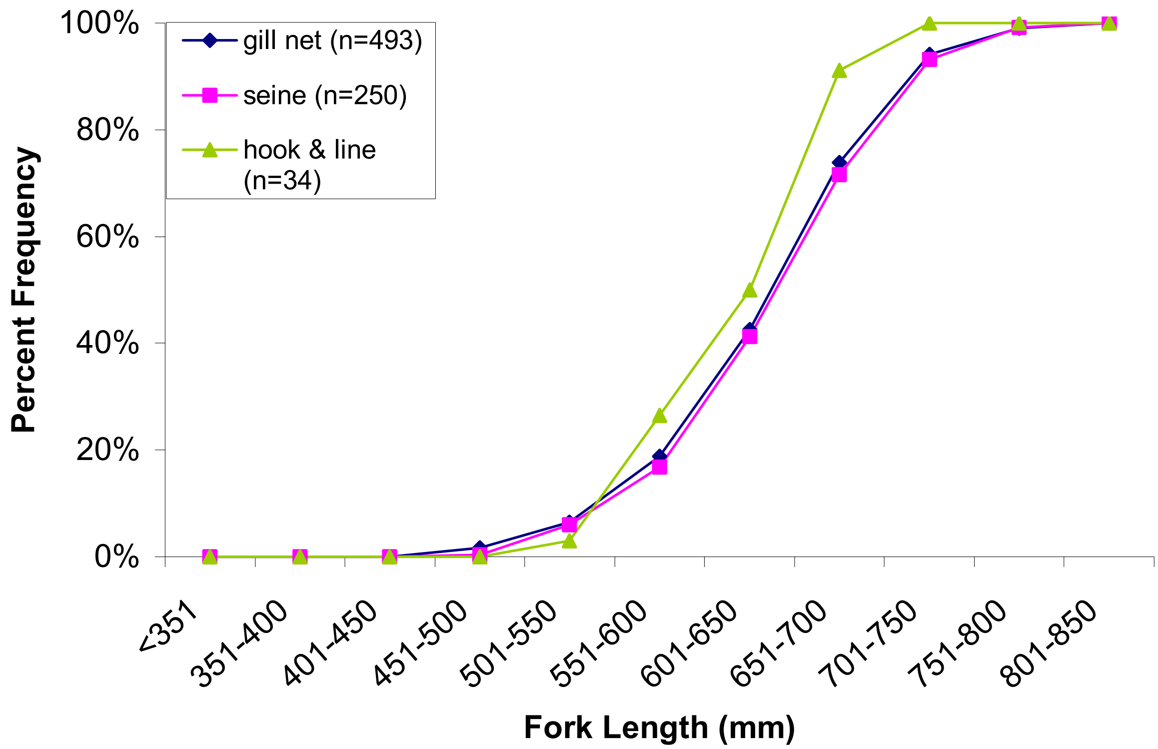

Figure 2.9. Cumulative length frequency distributions of sexually mature rainbow trout captured with a gill net, beach seine, and hook and line during the spring of 2000 in the Naknek River, Alaska.

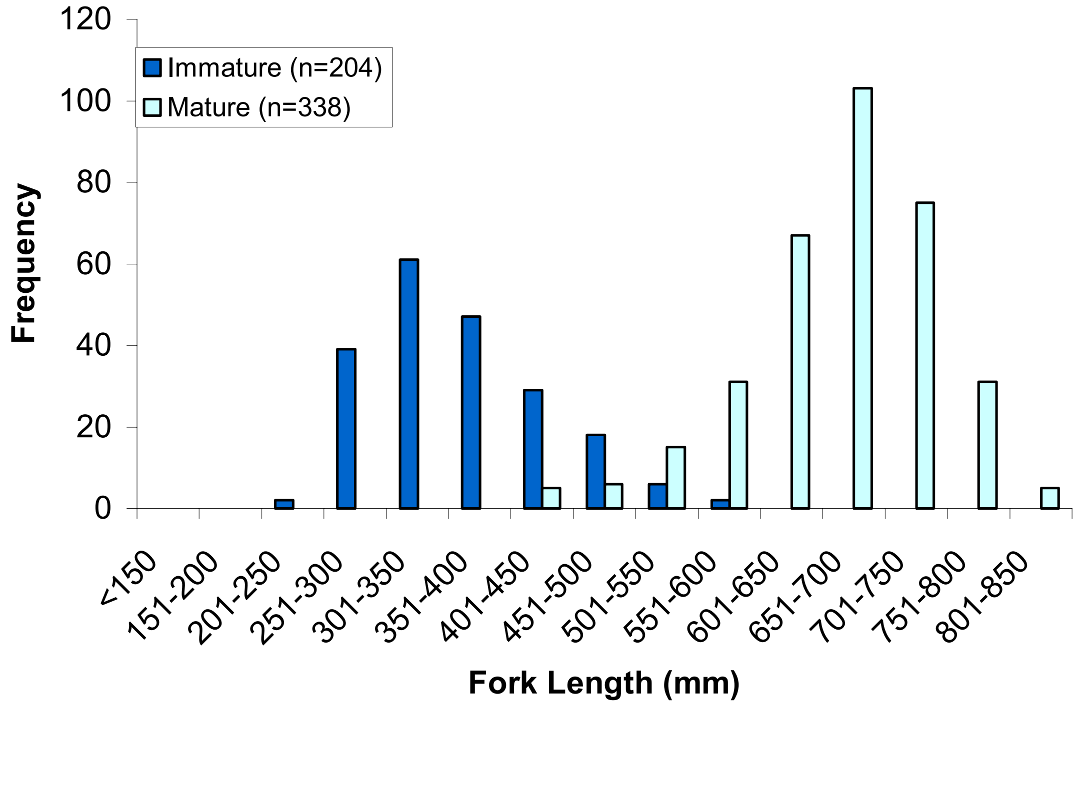

Figure 2.10. Length frequency distributions of sexually immature and mature rainbow trout captured with a beach seine from 10 April to 28 April 2001 in the Naknek River, Alaska.

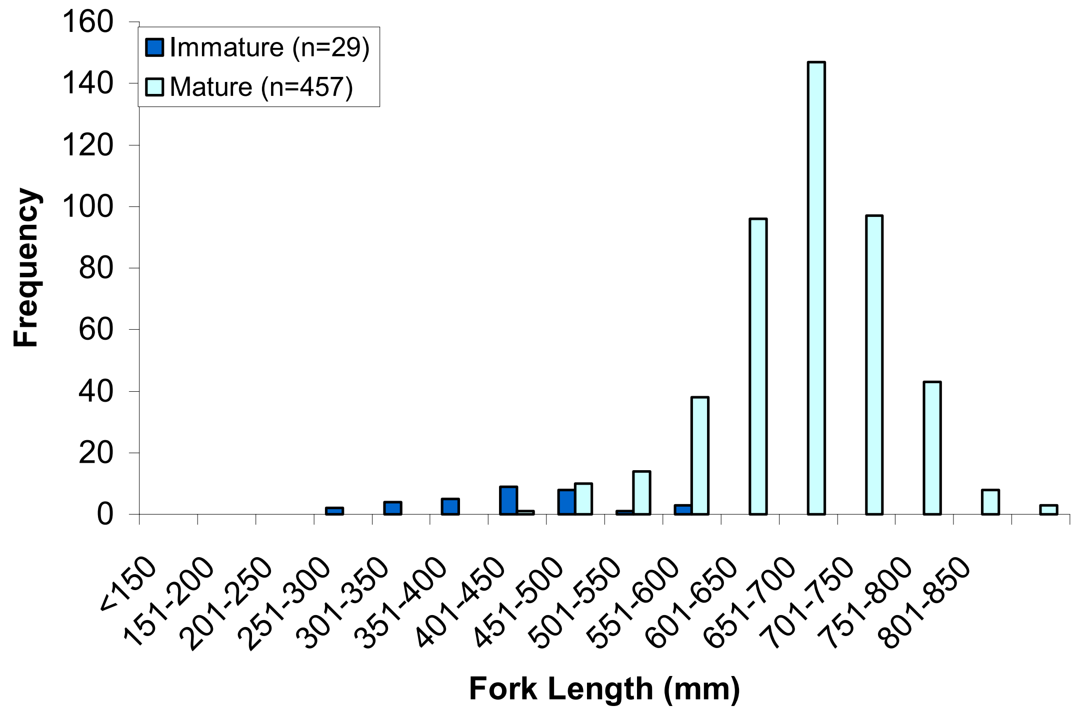

Figure 2.11. Length frequency distributions of sexually immature and mature rainbow trout captured with gill net from 10 April to 28 April 2001 in the Naknek River, Alaska.

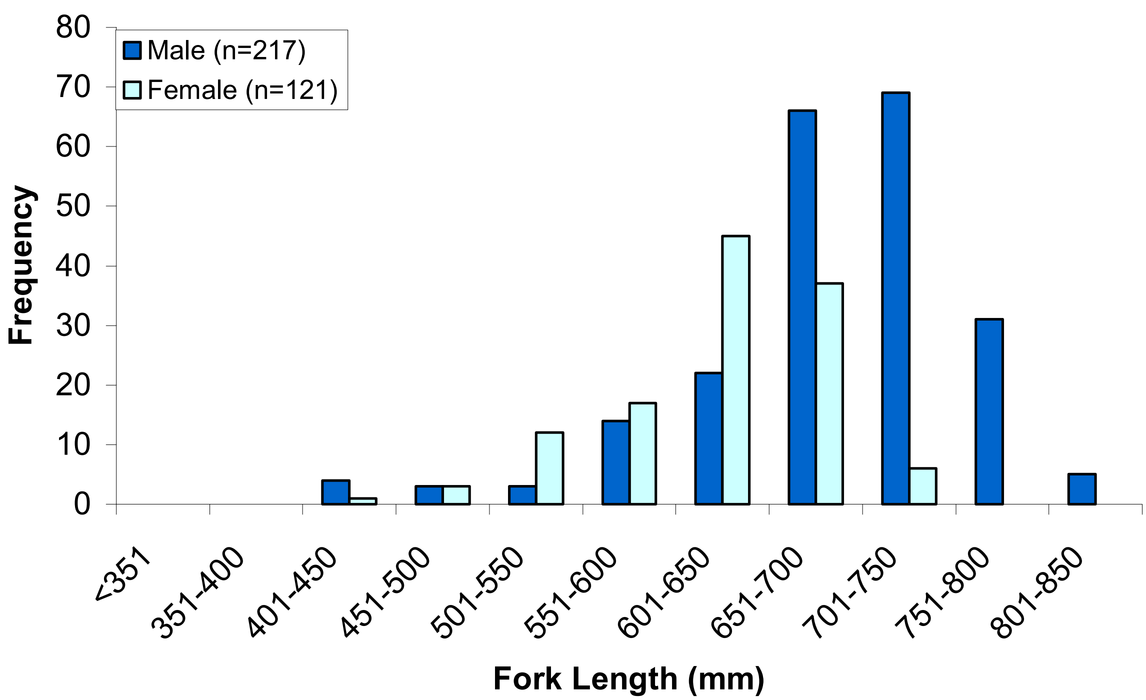

Figure 2.12. Length frequency distributions of sexually mature rainbow trout captured with beach seine from 10 April to 28 April 2001 in the Naknek River, Alaska.

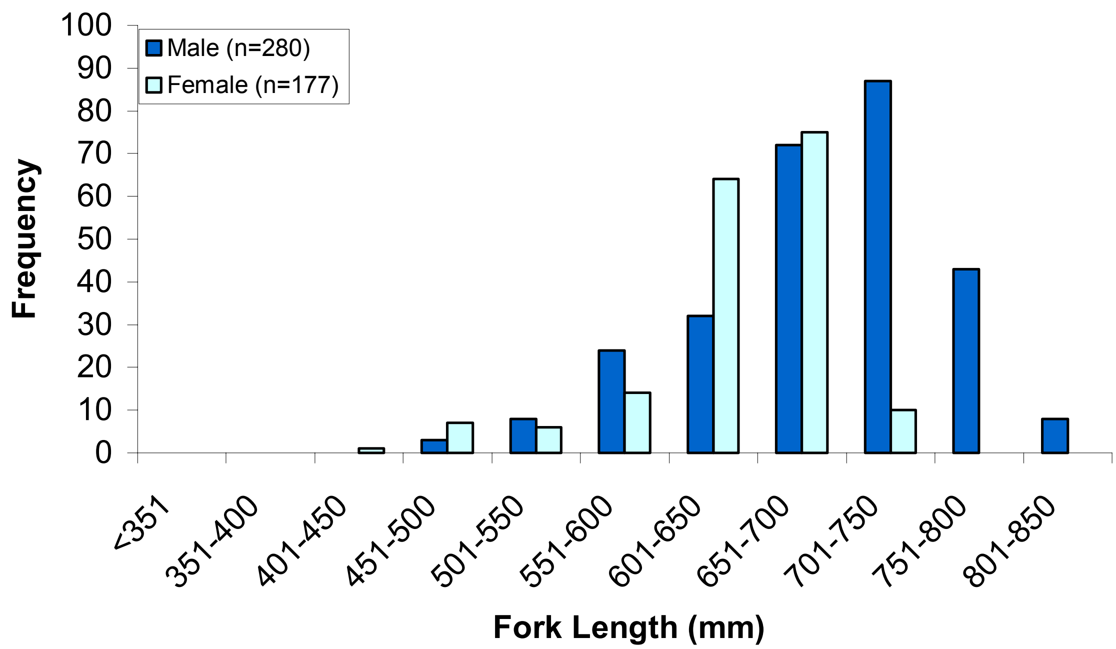

Figure 2.13. Length frequency distributions of sexually mature rainbow trout captured with gill net from 10 April to 28 April 2001 in the Naknek River, Alaska.

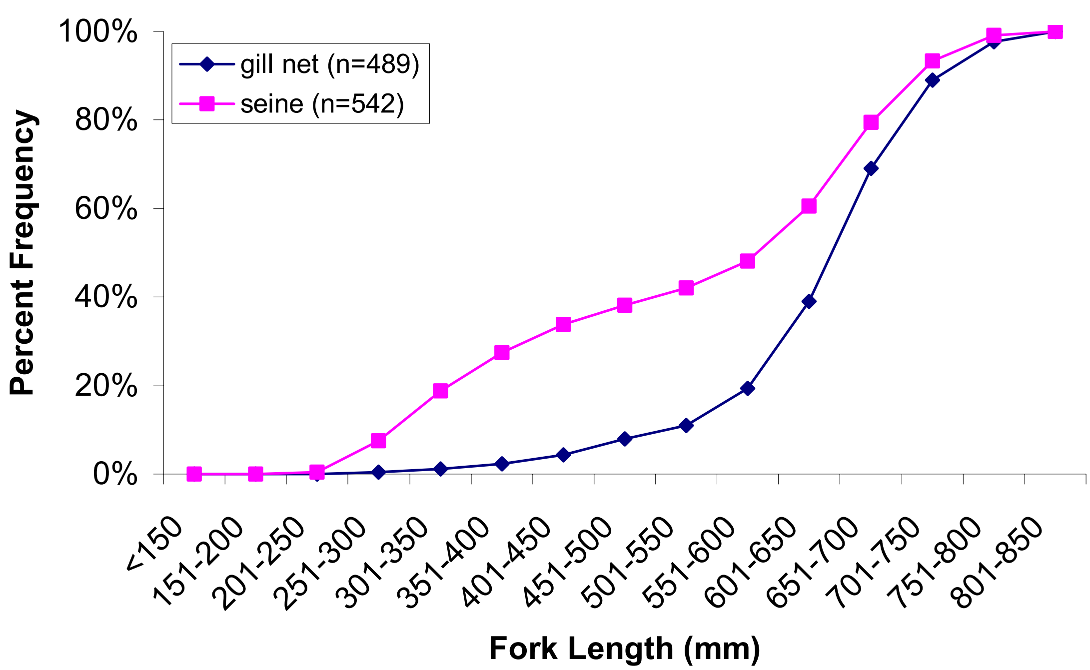

Figure 2.14. Cumulative length frequency distributions of sexually immature and mature rainbow trout captured with gill net, and beach seine during spring of 2001 in the Naknek River, Alaska.

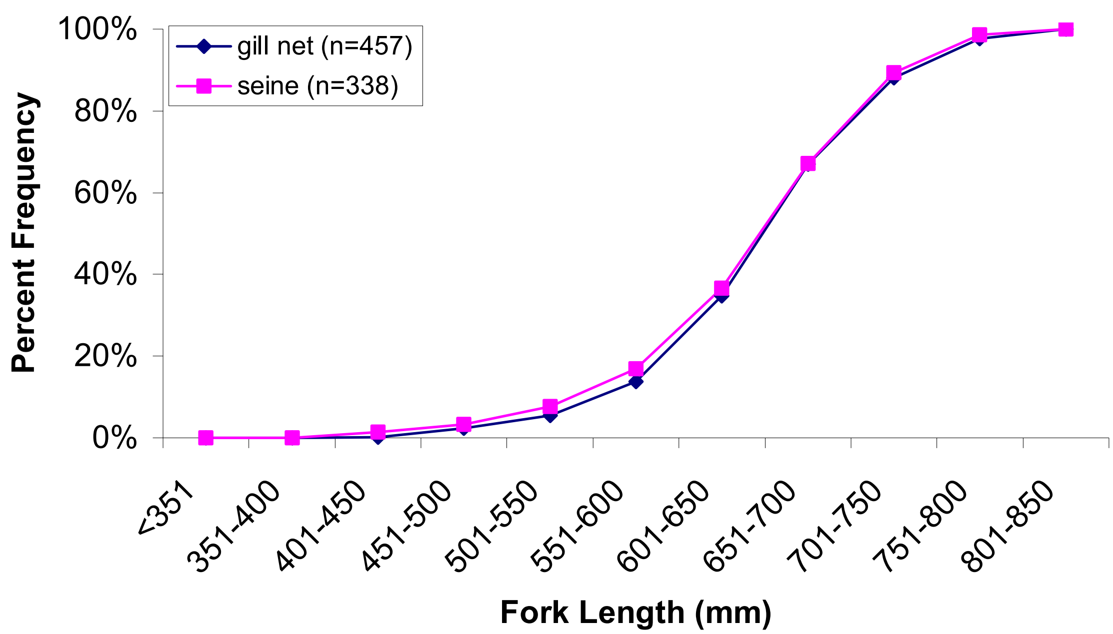

Figure 2.15. Cumulative length frequency distributions of sexually mature rainbow trout captured with a gill net and beach seine during spring of 2001 in the Naknek River, Alaska.

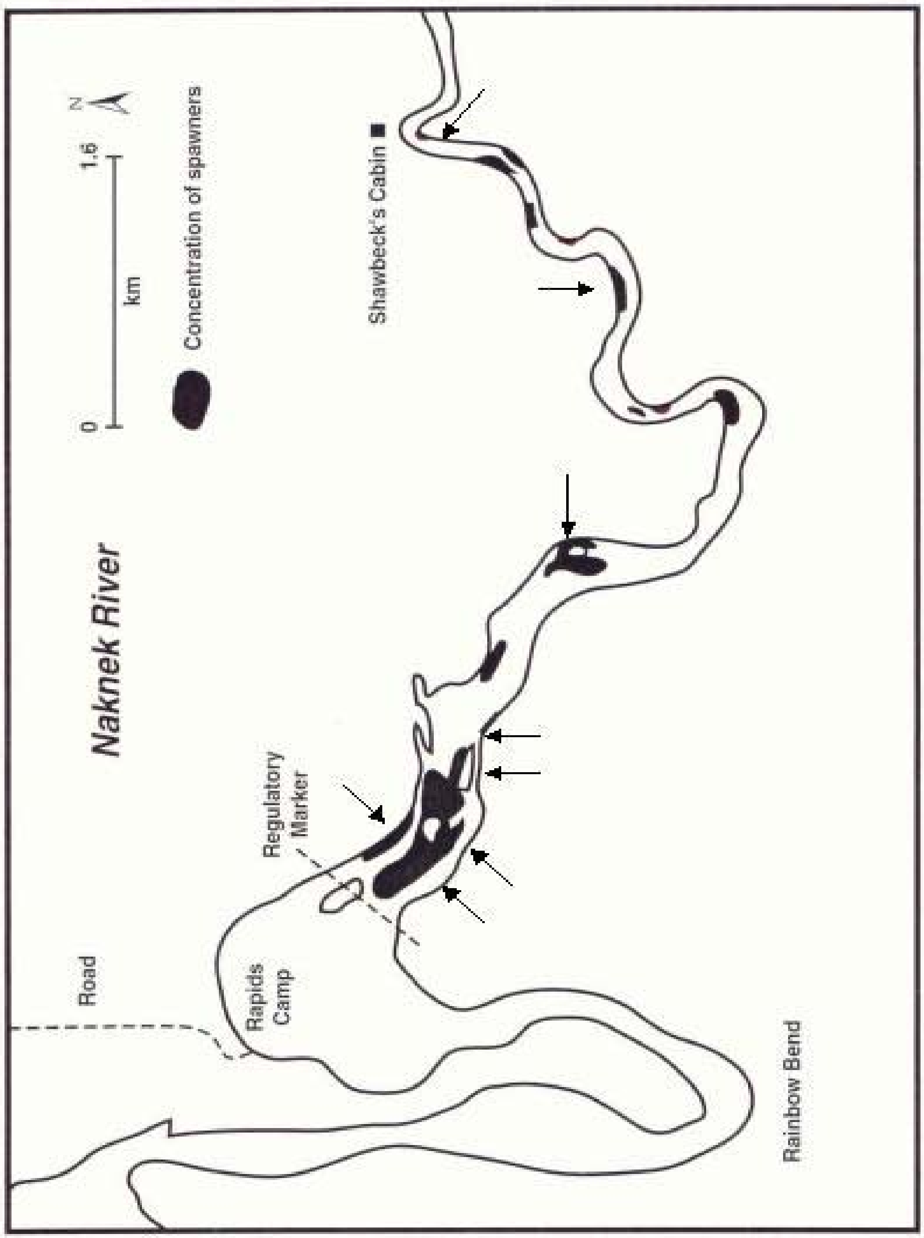

Figure 2.16. Map of eight locations where seining was possible on the upper Naknek River, Alaska.

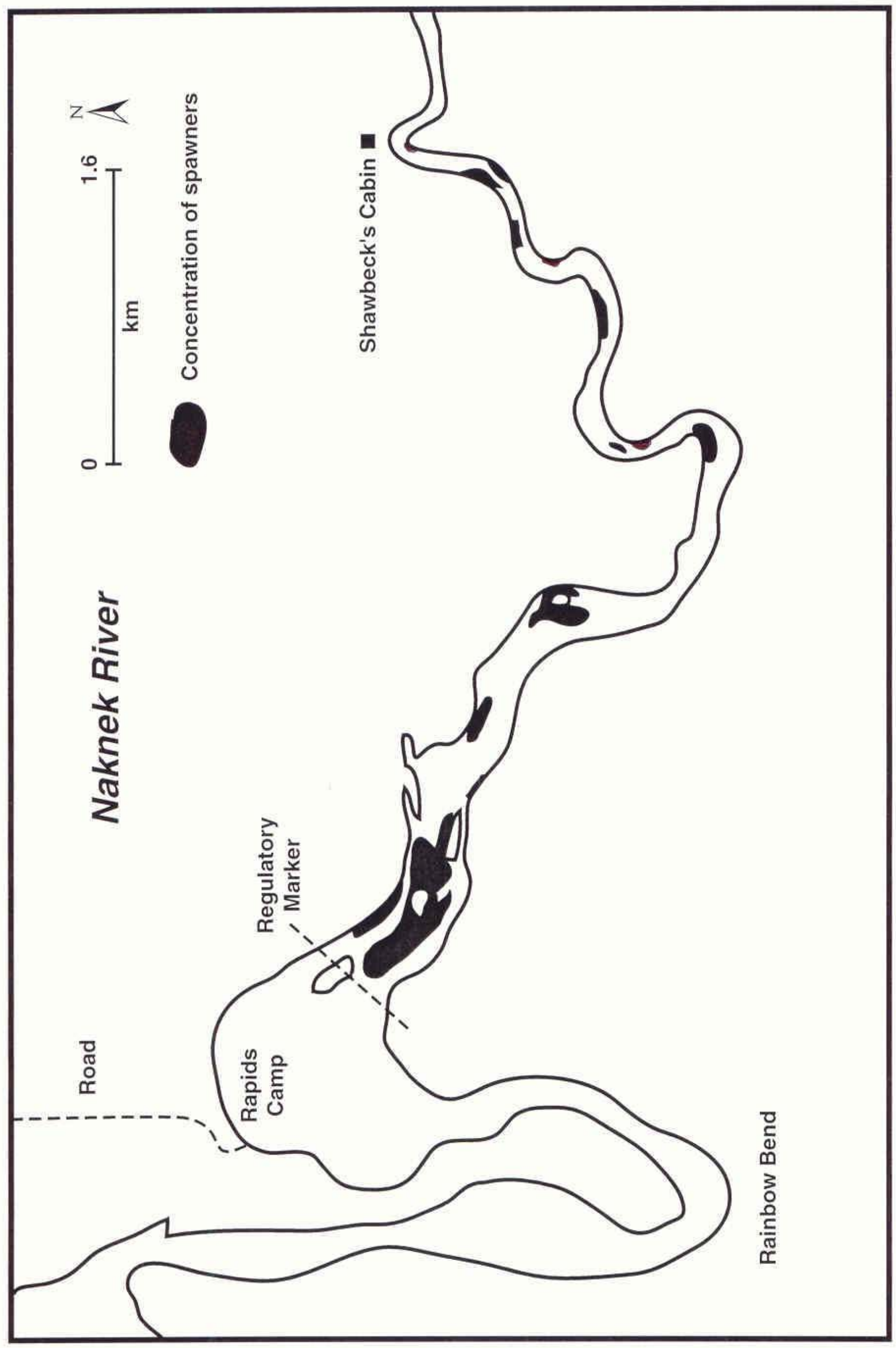

Figure 3.1. Map of all known spawning locations of rainbow trout in the upper Naknek River, Alaska.

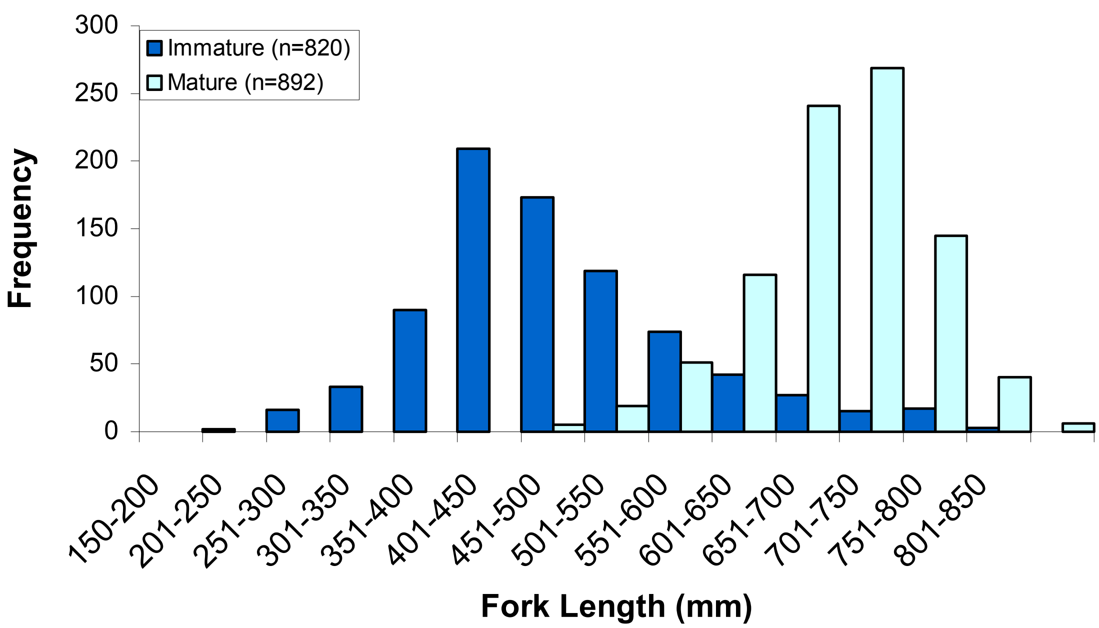

Figure 3.2. Length frequency distributions of sexually immature and mature rainbow trout captured from 20 March to 21 May 2000 in the Naknek River, Alaska.

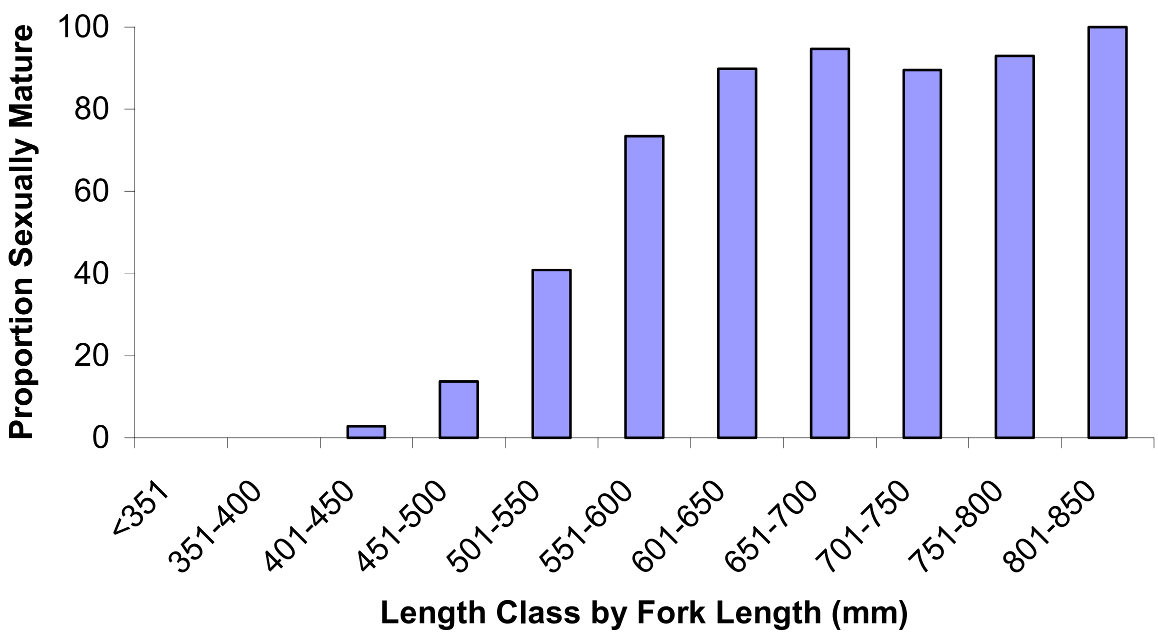

Figure 3.3. Proportion of sexually mature rainbow trout captured from 20 March to 21 May 2000 in the Naknek River, Alaska.

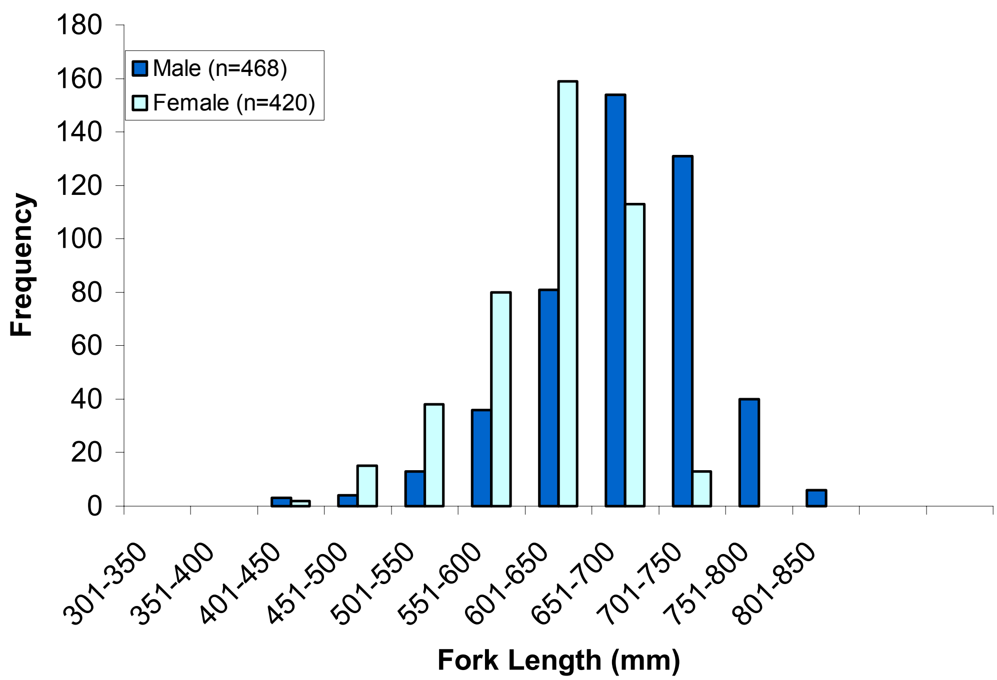

Figure 3.4. Length frequency distributions of sexually mature male and female rainbow trout captured from 20 March to 21 May 2000 in the Naknek River, Alaska.

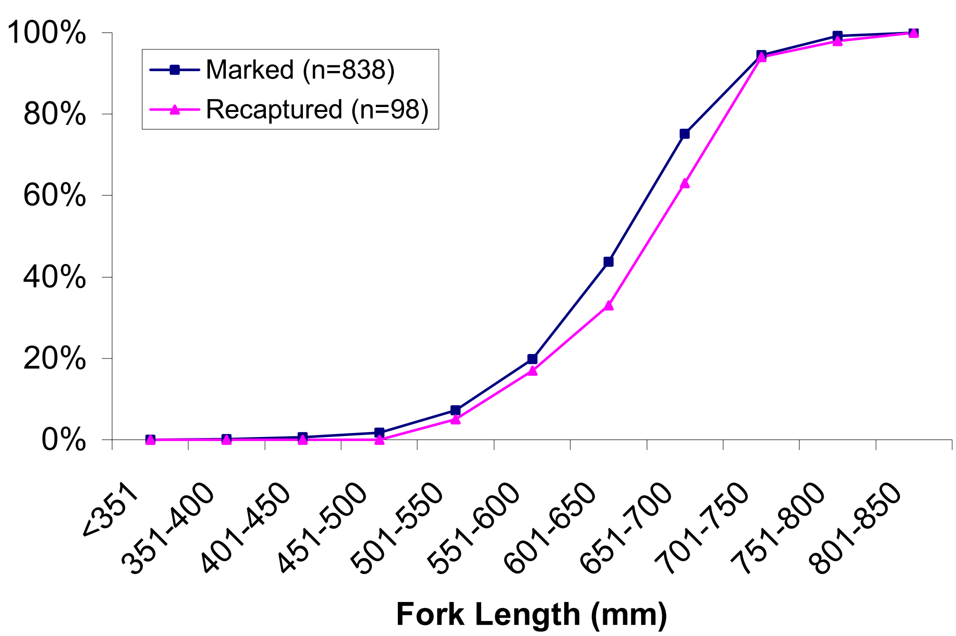

Figure 3.5. Cumulative length frequency distributions of sexually mature rainbow trout marked compared to that of fish recaptured from 20 March to 20 May 2000 in the Naknek River, Alaska.

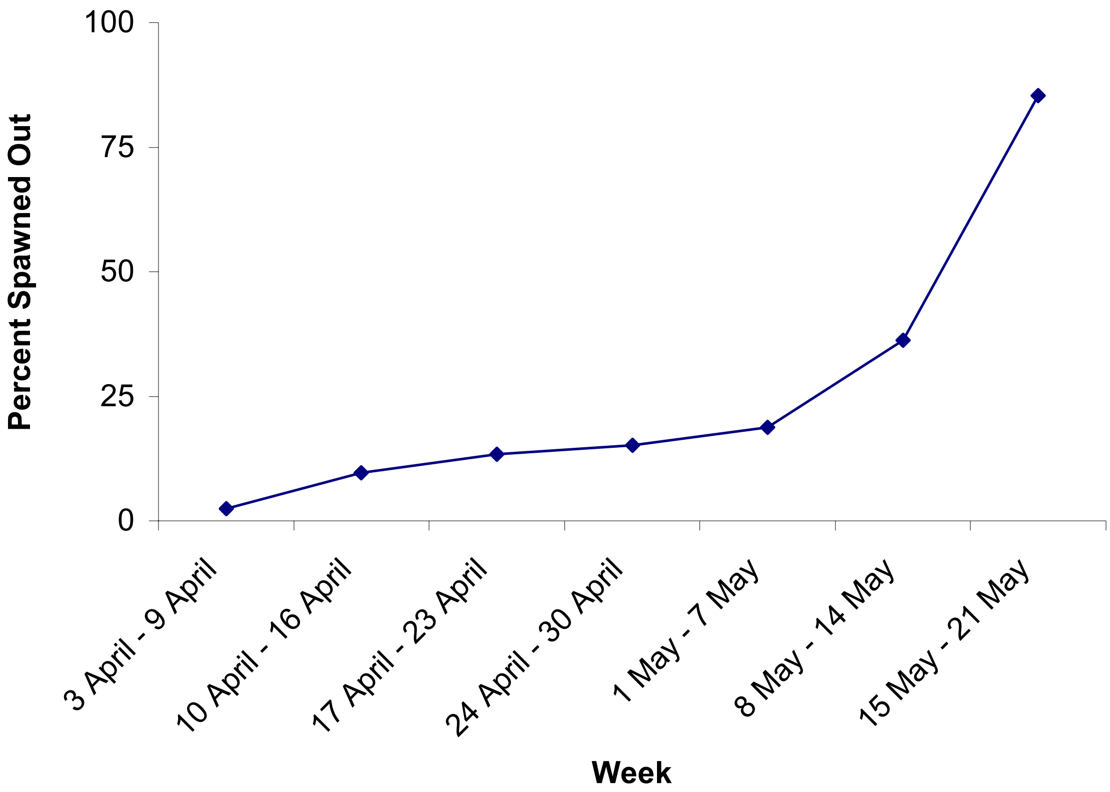

Figure 3.6. Percentage of spawned-out rainbow trout captured from 3 April to 21 May 2000 in the Naknek River, Alaska.

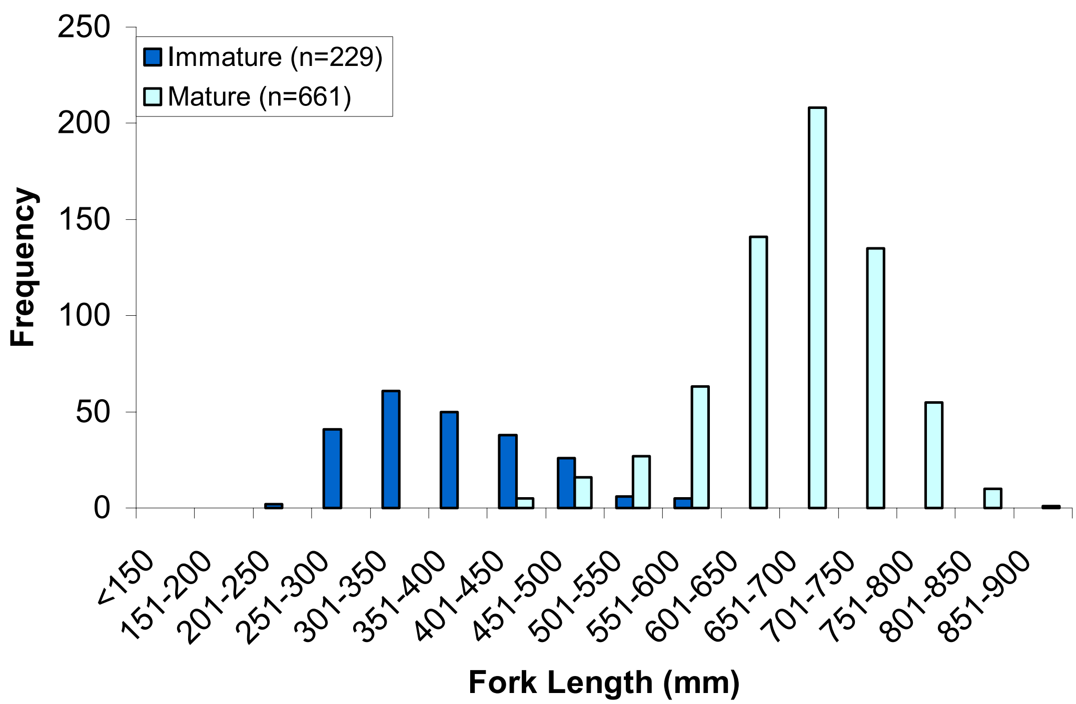

Figure 3.7. Length frequency distributions of sexually immature and mature rainbow trout captured from 10 April to 28 April 2001 in the Naknek River, Alaska.

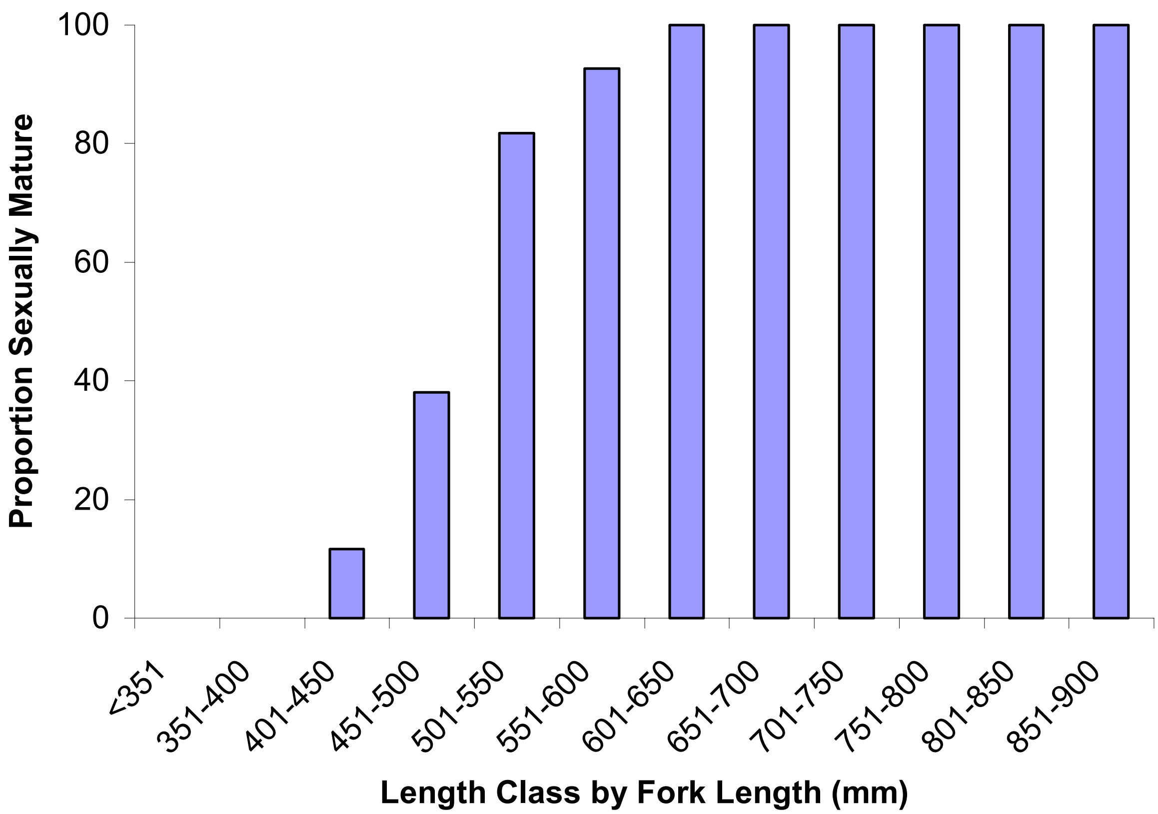

Figure 3.8. Proportion of sexually mature rainbow trout by length captured from 10 April to 28 April 2001 in the Naknek River, Alaska.

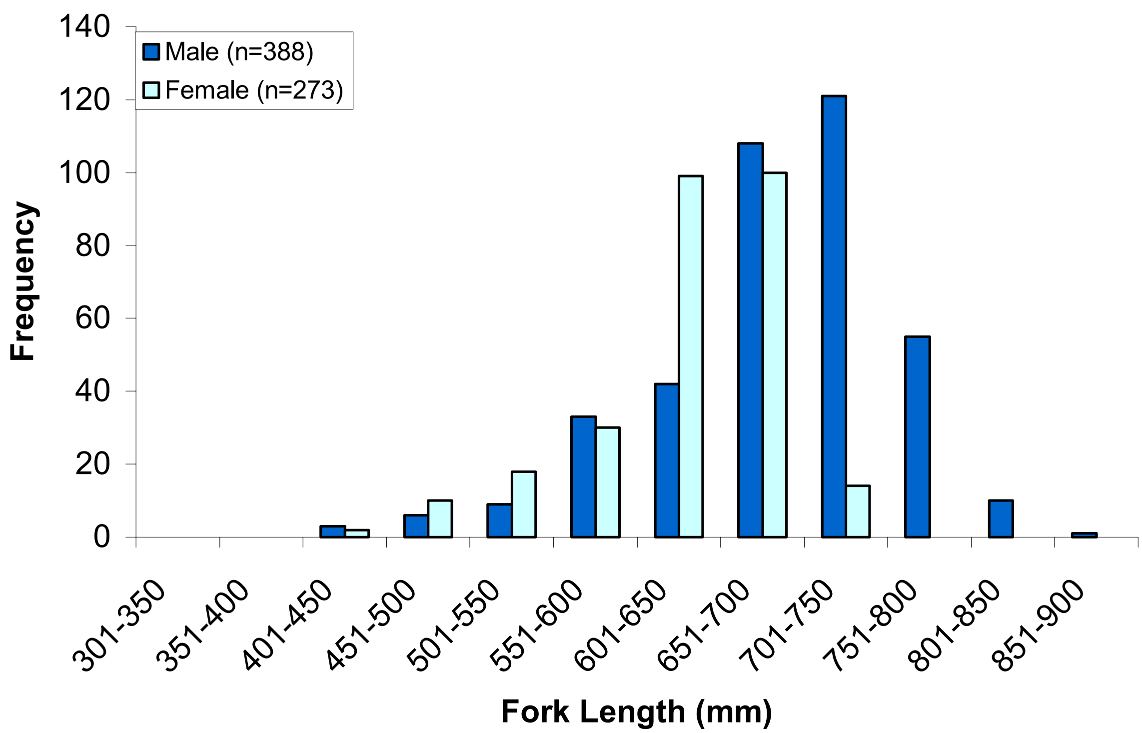

Figure 3.9. Length frequency distributions of sexually mature male and female rainbow trout captured from 10 April to 28 April 2001 in the Naknek River, Alaska.

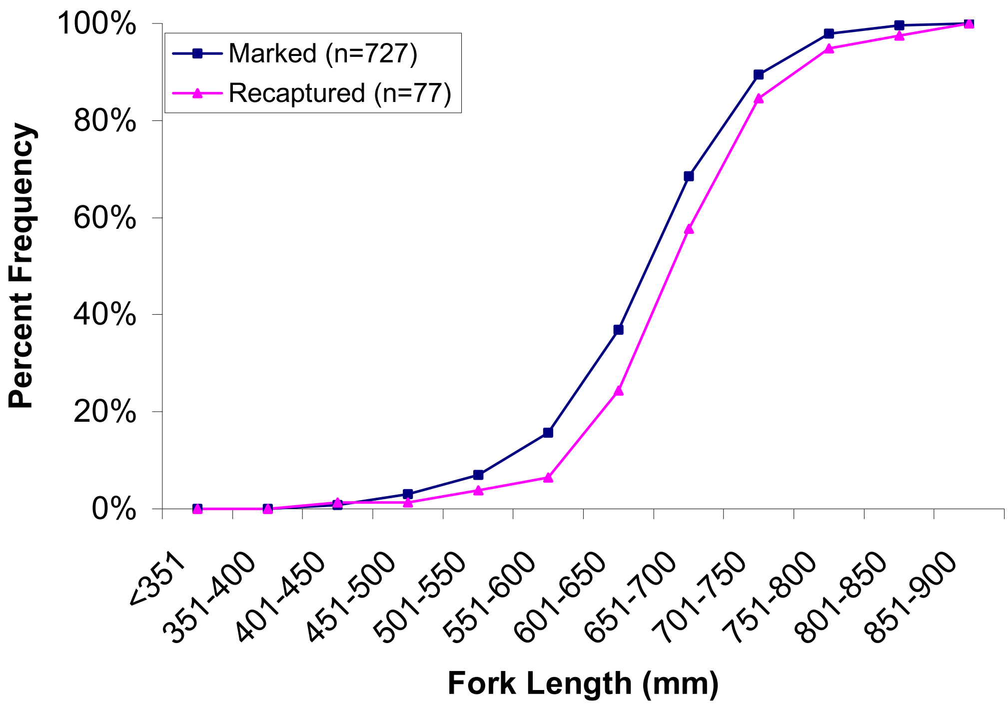

Figure 3.10. Cumulative length frequency distributions of sexually mature rainbow trout marked compared to that of fish recaptured from 10 April to 30 May 2001 in the Naknek River, Alaska.

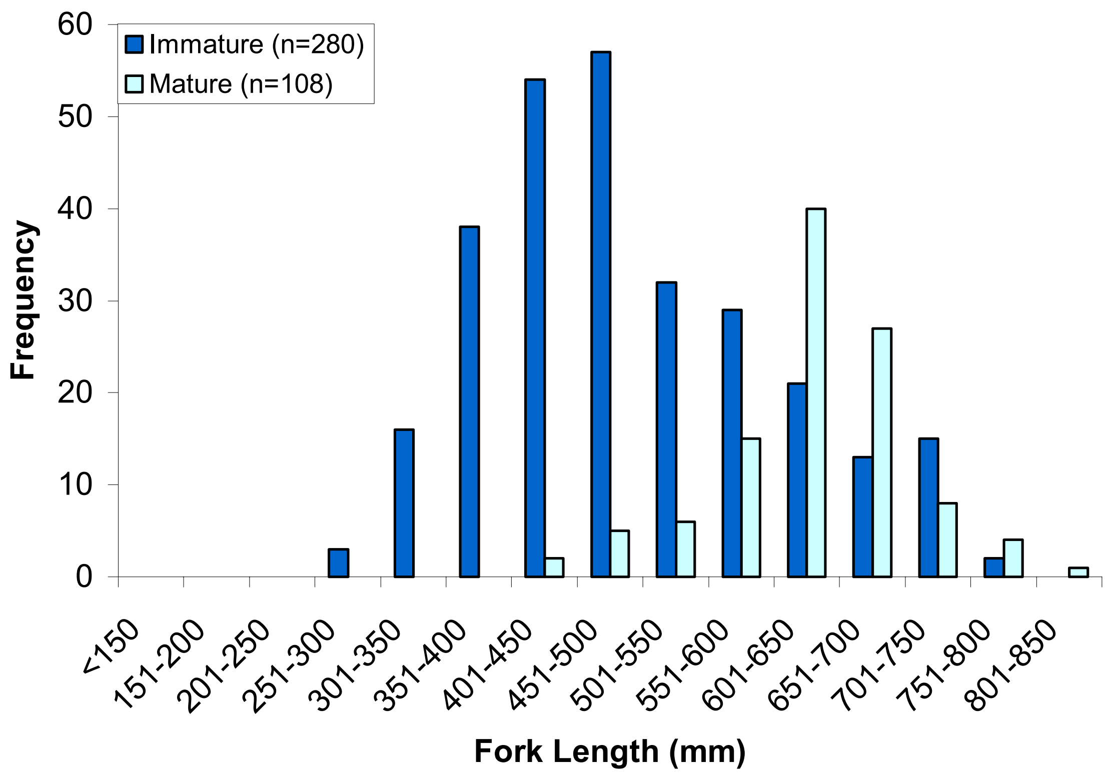

Figure 3.11. Length frequency distributions of sexually immature and mature rainbow trout captured from 20 March to 21 May 2000 for subarea 1 in the Naknek River, Alaska.

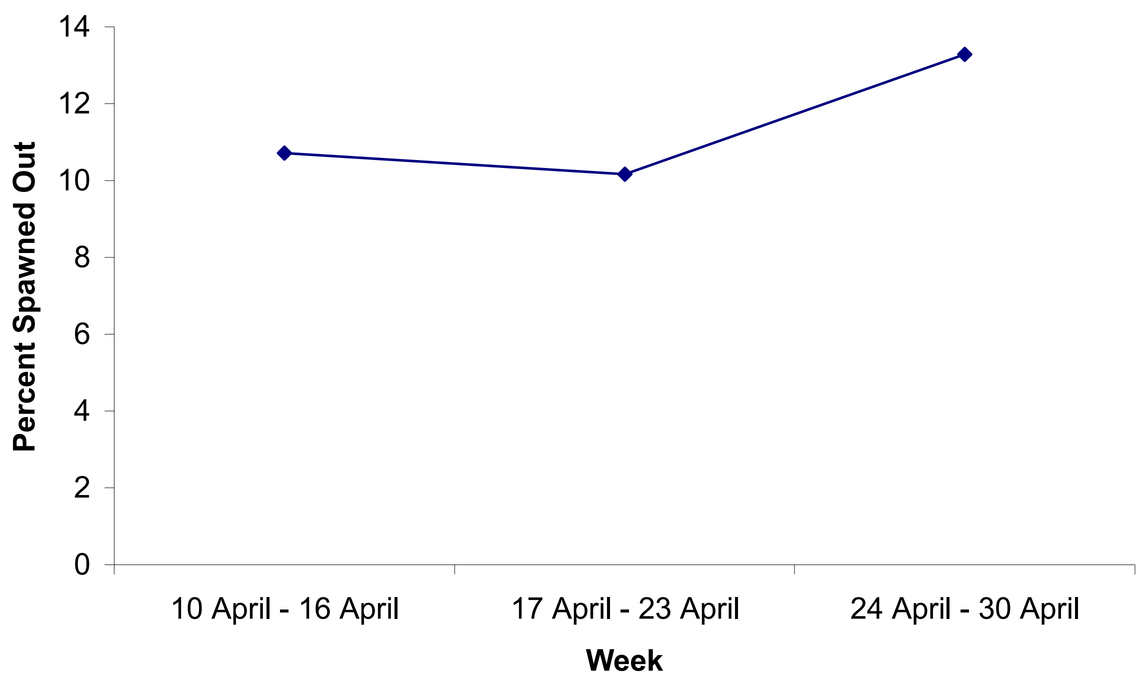

Figure 3.12. Percentage of spawned-out rainbow trout captured from 10 April to 28 April 2001 in the Naknek River, Alaska.

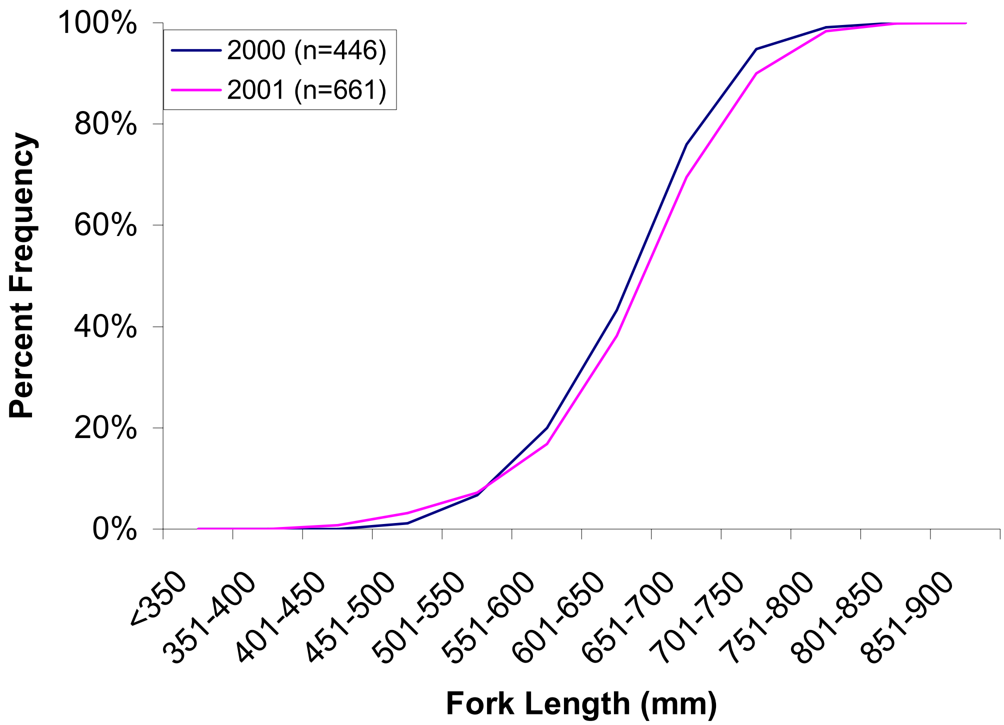

Figure 3.13. Length frequency distributions of sexually mature rainbow trout sampled with gill net and beach seine from 10 April to 28 April 2000 and 2001 in the Naknek River, Alaska.

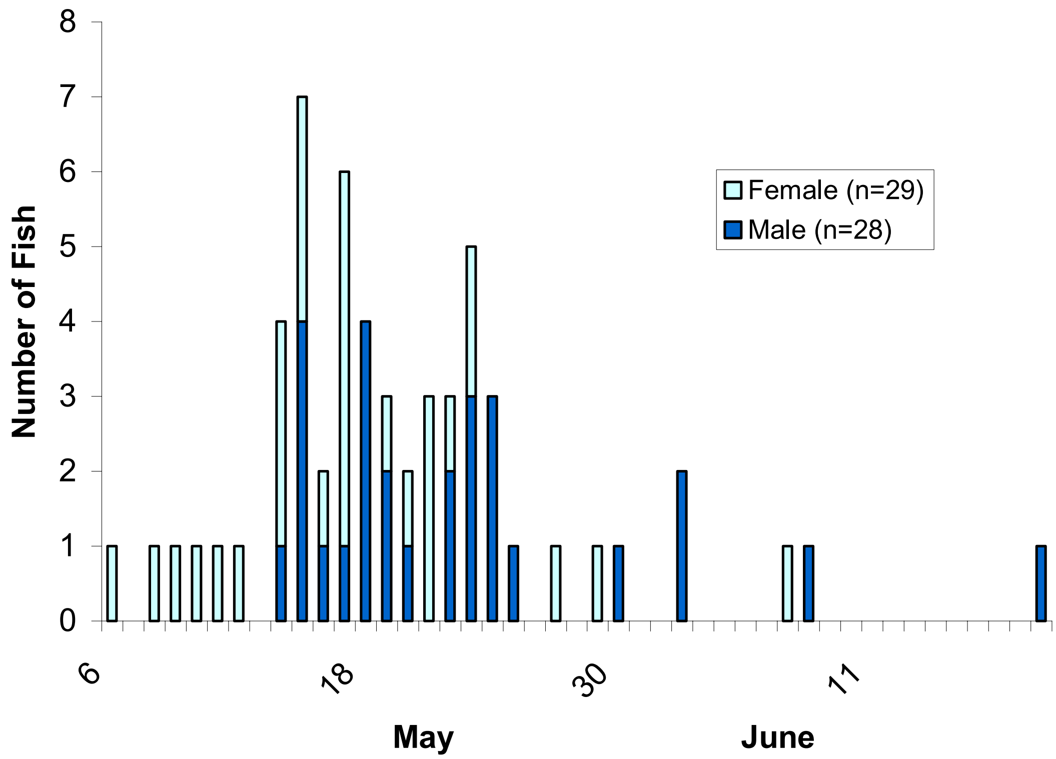

Figure 4.1. Date and sex of rainbow trout with transmitters that migrated from the Naknek River to Naknek Lake during the spring of 2001.

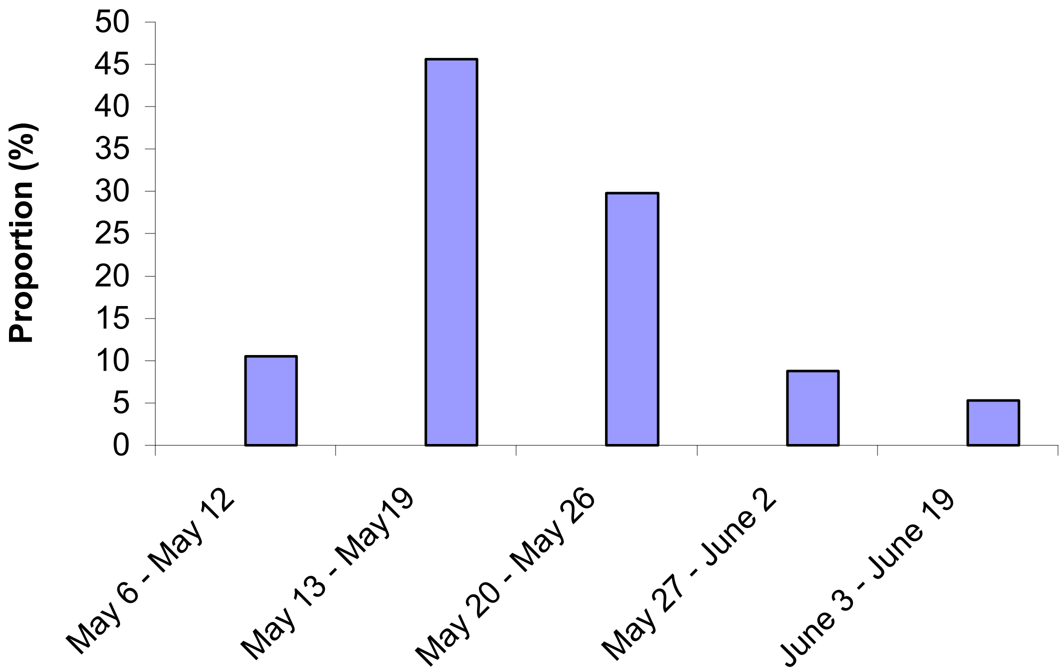

Figure 4.2. Proportion of rainbow trout with transmitters that migrated to Naknek Lake each week during May and June 2001.

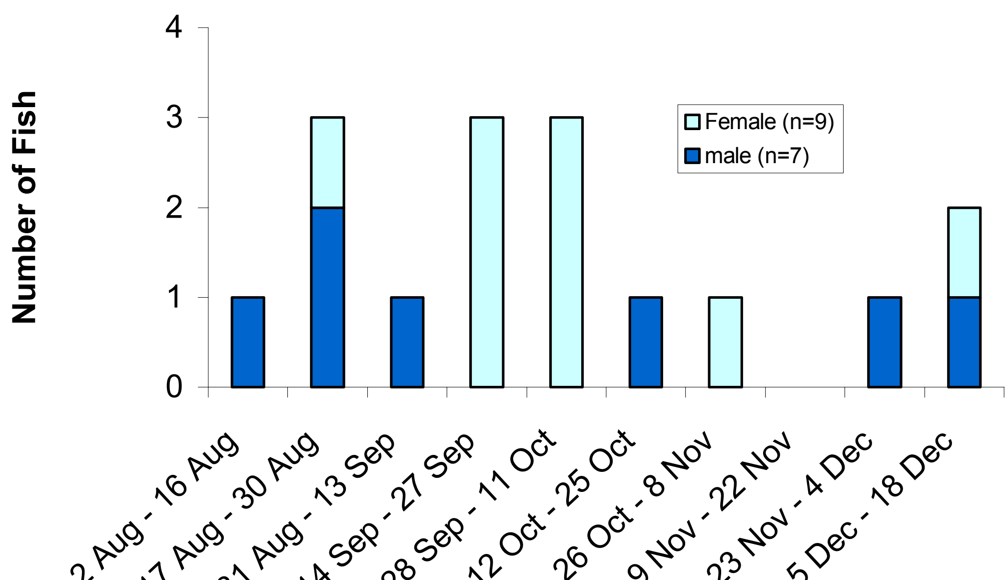

Figure 4.3. Number of rainbow trout with transmitters that returned to Naknek River in 2-week intervals during the fall and early winter of 2001 after spending the summer in Naknek Lake.

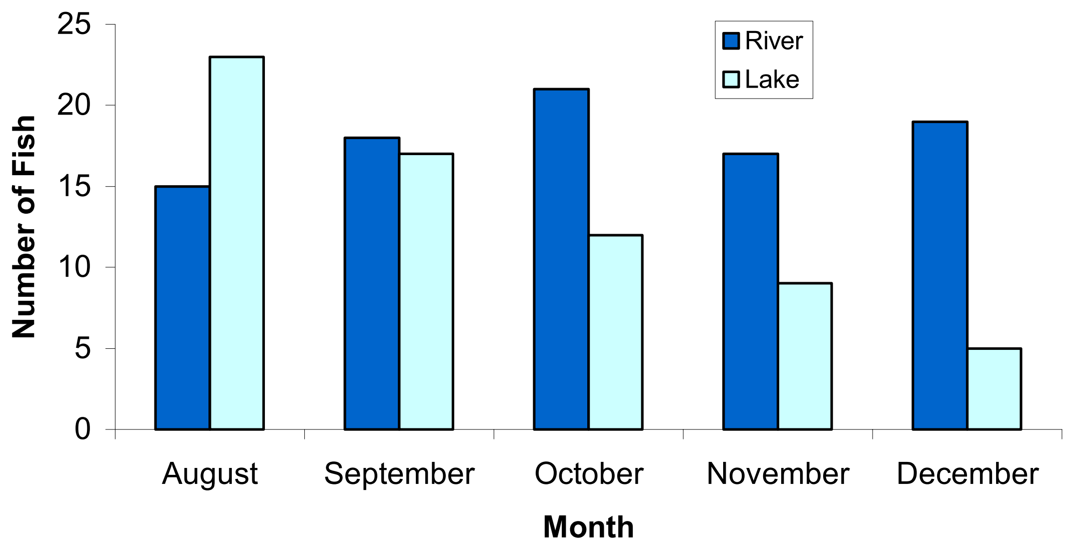

Figure 4.4. The number of rainbow trout located in Naknek River or Naknek Lake from August through December 2001.

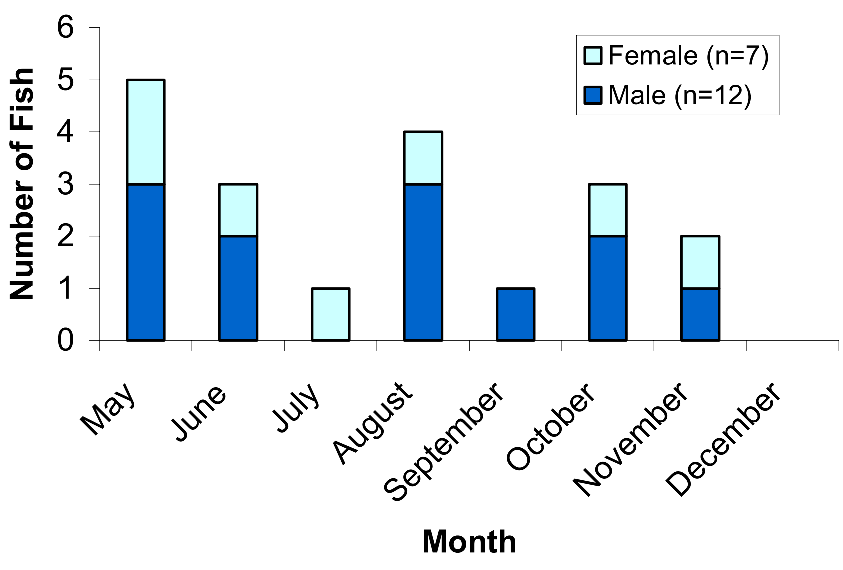

Figure 4.5. The number of mortalities detected during from May through November 2001.

Appendix A. Instructions for rainbow trout sexual maturity rating used in this study of fish from the Naknek River, Alaska.

Immature: describes a fish that is not spawning that spring; silver color, no release of eggs or milt with gentle pressure to the abdomen; ovipositor not protruding from vent of females, kype not developed on males; abdomen not extended on females indicating no development of eggs; and abdomen hard to the touch.

Sexualy Mature: describes fish capable of spawning during that spring; dark coloration for males; silver coloration for females with more pronounced spots than immature fish and a slight red blush to gill plates and side; release of eggs for very ripe females and release of milt on males with gentle pressure; ovipositor protruding from vent of females; kype developed on males; abdomen extended on females due to presence of eggs; and abdomen of intermediate hardness or soft to the touch.

Post Spawn Sexually Mature: describes recently spawned out fish; coloration may still be dark or fading back to silver; no eggs or milt released although water may be released from females; ovipositor may not be protruding from vent of females; kype development still present on males; abdomen not extended and somewhat flaccid on females; and abdomen soft due to flaccidness.

Rating characteristics of fish for sexual maturity determination in the field:

Color:

0 silver; describes an immature rainbow trout
1 medium-green: describes rainbow trout may or may not be capable of spawning
2 green: describes a mature rainbow trout

Sex: Mark only if known

M = male
F = female
U = unknown

Reproductive Products:

M = milt
E = eggs
A = absent

Ovipositor Extension:

Y = yes
I = intermediate
N = no

Appendix A. Continued.

Kype Development:

Y = yes
I = intermediate
N = no

Abdomen Development:
0 = none
1 = developing
2 = fully developed

Abdomen Hardness:
0 = soft
1 = intermediate
2 = hard