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An Age-Structured Stock Analysis of Arctic Grayling in the Delta Clearwater River, 1977 to 1990

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Alaska Department of Fish and Game

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ABSTRACT

An age-structured stock analysis was performed on catch and effort data from the Arctic grayling *Thymallus arcticus* recreational fishery in the Delta Clearwater River during 1977 through 1990. The CAGEAN model was used to estimate abundance, fishing mortality rate, and recruitment of six Arctic grayling cohorts, ages 5-10+. Estimates of abundance ranged from 4,477 fish (SE of 1,766 fish) in 1990 to 12,760 fish (SE of 1,746 fish) in 1983. Estimates of instantaneous fishing mortality rate ranged from 0.32 in 1986 and 1987 to 1.19 in 1978, resulting in an average annual exploitation rate of 37.6 percent. Recruitment in numbers of age 5 fish ranged from 1,085 fish (SE of 694 fish) in 1990 to 7,788 fish (SE of 1,518 fish) in 1983. The modeled increase in catchability during 1989 and 1990 was likely needed because of a 12-inch (305 mm) length limit in that started in 1987 or an increase in fishing mortality as abundance declined during 1989 and 1990. Uncertainty in the number of, identity of, and contributions from parent stocks make choice of an optimal exploitation rate for this fishery complex. Catch sampling of the fishery should continue in concert with radio-telemetry and anchor-tagging to ascertain the number and identity of parent stocks.

KEY WORDS: Arctic grayling, *Thymallus arcticus*, age-structured stock analysis, CAGEAN, abundance, catch, fishing effort, mortality rates, recruitment, Delta Clearwater River.

INTRODUCTION

The Delta Clearwater River (DCR) is a spring-fed tributary to the Tanana River, located 176 km southeast of Fairbanks and 22 km northeast of Delta Junction (Figure 1). The mainstem of the DCR is 22 km long and is formed by two major tributaries, the 11 km long North Fork and 10 km long Sawmill Creek (ADF&G 1993). Arctic grayling *Thymallus arcticus* use the DCR for summer feeding, entering the river during April and leaving the river before December (ADF&G 1993). Recreational fishing for Arctic grayling is popular on the DCR, with an average of 4,637 angler-days of effort expended annually (Table 1). The main feature of this fishery is a high proportion of large (>300 mm fork length) Arctic grayling and pristine water quality (ADF&G 1993). Objectives for management of Arctic grayling in the DCR are to annually provide for: 3,000 angler-days of fishing opportunity, a consumptive catch of up to 3,000 fish, and an average total (consumptive and nonconsumptive) catch of two fish per angler-day (ADF&G 1993). Regulations to ensure these objectives are met (promulgated in 1988) are: catch-and-release fishing during 1 April through the first Sarurday in June, only unbaited artificial lures may be used, a daily bag limit of five fish, and a 12-inch (305 mm) total length limit for retention.

The "stock assemblage" of Arctic grayling in the DCR is thought to be comprised of more than one parent stock (a stock using the same river annually for spawning; Ridder 1991). Likely parent stocks originate in Shaw Creek and the Goodpaster, Volkmar, and Salcha rivers (Ridder 1991). Recruitment or emigration from a "parent river" to the DCR may occur while fish are juvenile (Ridder 1985) or after they have sexually matured (Ridder 1985, 1991). Recruitment to the DCR appears to be permanent, i.e. Arctic grayling that first choose to migrate to the DCR for the summer (post-spawning) months continue to do so reliably and annually (Ridder 1991). The reliability of Arctic grayling to return to the DCR for the summer months permits treatment of the DCR assemblage as a single exploitable stock.

Past stock assessment of Arctic grayling in the DCR has been by creel survey (see Hallberg and Bingham 1991) coupled with age-length sampling and relative abundance estimation of the stock with electrofishing gear (see Ridder 1985). Creel surveys have included estimates of harvest, angling effort, and age-length composition of the harvest. Although these assessments have provided a reasonable measure of the status of the DCR stock, they did not provide managers with estimates of abundance, recruitment, survival rate, exploitation rate, and contribution of parent stocks to the harvest. These quantities are needed to estimate potential exploitation rate of each of the parent stocks (in the DCR and in the parent river) and ensure sustainable harvests from the DCR. This report attempts to synthesize available catch and age composition data from the DCR fishery into estimates of abundance, recruitment, survival rate, and exploitation rate for the period 1977 through 1990. The initial objective of this study was to estimate the harvest of Arctic grayling, greater than 149 mm fork length (FL), by age class in the Delta Clearwater River during 1977 through 1990.

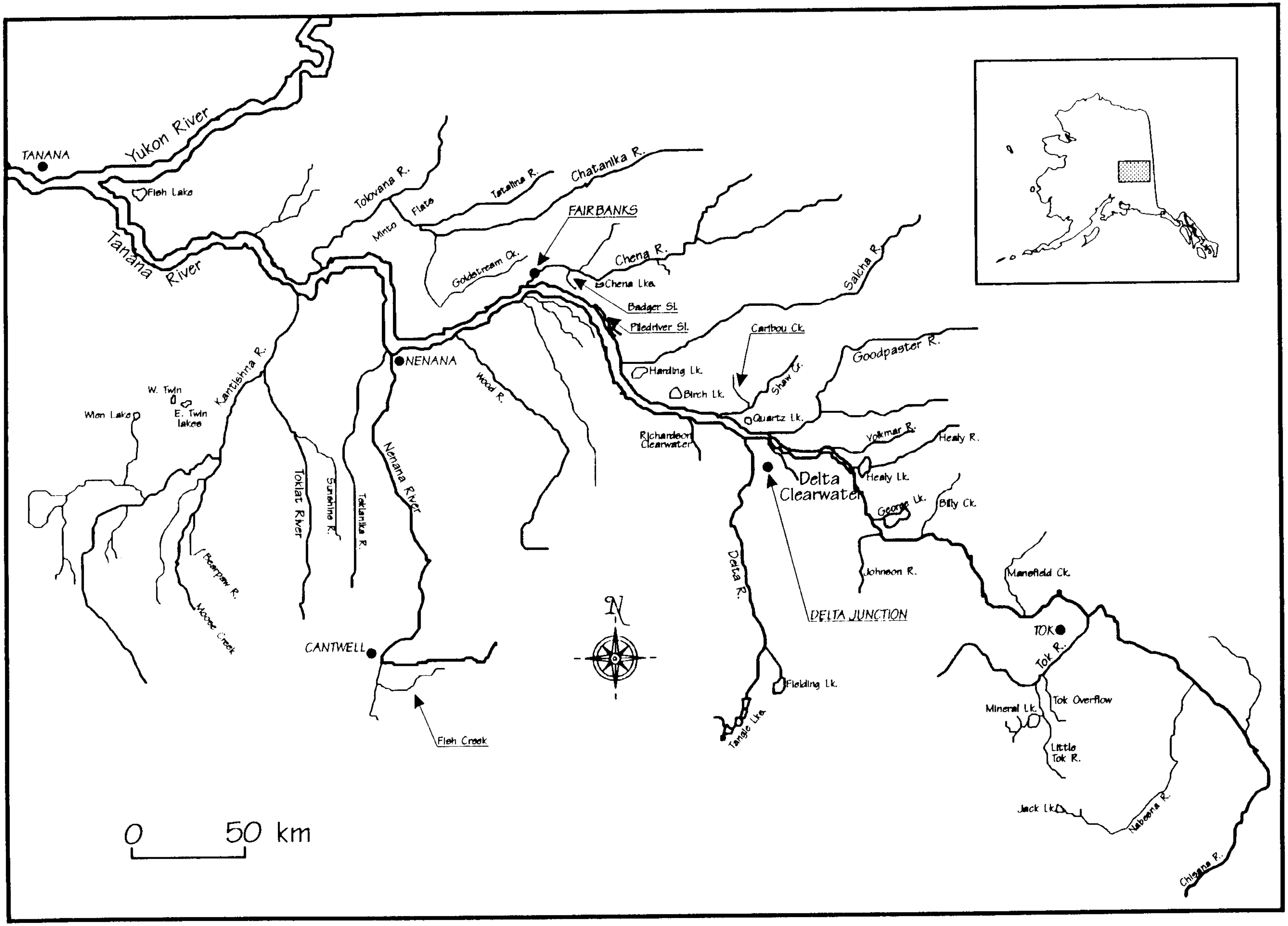

Figure 1. The Tanana River drainage.

Table 1. Estimates of total angler-days, angler-days for Arctic grayling, angler-hours for Arctic grayling, and Arctic grayling harvest and standard error from the Delta Clearwater River, 1977-1990.

Year	Angler-days[a] Total	Angler-days[a] Arctic grayling	Angler-hours[b]	Harvest[c]	SE[d]
1977	6,881	6,798	11,423	6,118	2,962
1978	7,210	6,873	13,400	7,657	3,707
1979	8,398	8,398	11,810	6,492	3,143
1980	4,240	4,173	7,837	5,680	2,750
1981	4,673	4,553	5,657	7,362	3,565
1982	4,231	4,175	10,362	4,779	2,314
1983	5,867	5,698	13,637	6,546	3,170
1984	5,139	3,611	12,706	4,193	2,030
1985	8,722	6,790	12,360	5,809	2,813
1986	10,137	2,867	5,487	2,343	1,134
1987	5,397	3,123	4,483	2,005	971
1988	5,184	3,092	4,440	2,910	1,409
1989	5,368	2,500	6,556	3,016	853
1990	4,853	2,263	2,740	1,772	827
Average	6,164	4,637	8,778	4,763	---

[a] Total angler-days are from Mills (1979-1991); Arctic grayling angler-days are from ADF&G (1993).

[b] Angler-hours are estimates of angler-hours spent fishing for Arctic grayling during May-August as determined by on-site creel surveys (Ridder 1985, Holmes et al. 1986, Clark and Ridder 1987, Baker 1988 and 1989, Merritt et al. 1990, Hallberg and Bingham 1991).

[c] Harvest of Arctic grayling (Mills 1979-1991).

[d] SE is the standard error of estimated harvest. SEs for 1988 through 1990 were estimated by Mills (*Unpublished*); SEs for 1977 through 1987 were estimated from the relation between estimated harvest in 1988 and the estimated SE in 1988, such that the coefficient of variation (CV) of estimated harvest for 1977-1987 was equal to the CV of estimated harvest in 1988 (48.4%). CV's for 1989 and 1990 were 28.3% and 46.7%, respectively.

METHODS

Data Sources

Estimates of Arctic grayling catch and total fishing effort (angler-days) were obtained from the Statewide Harvest Survey for 1977-1990 (Mills 1979-1991). For this analysis, "catch" was defined as those fish caught and kept (also referred to as harvest). Variance of estimates of catch during 1988 through 1990 were obtained from Mills (*Unpublished*). Variance of estimates of catch during 1977 through 1987 were assumed to be proportional to that observed in 1988:

$$\hat{V}\left[\hat{C}_i\right] = \left[\frac{SE\left[\hat{C}_{88}\right]}{\hat{C}_{88}} \times \hat{C}_i\right]^2 \quad (1)$$

where: $\hat{V}\left[\hat{C}_i\right]$ = estimate of variance of catch in year i;

$SE\left[\hat{C}_{88}\right]$ = estimated standard error of catch in 1988;

$\hat{C}_{88}$ = estimate of catch in 1988; and,

$\hat{C}_i$ = estimate of catch in year i.

Age composition of the catch and angling effort for Arctic grayling (angler-hours) were obtained from various creel survey reports (Ridder 1985, Holmes et al. 1986, Clark and Ridder 1987, Baker 1988 and 1989, Merritt et al. 1990, Hallberg and Bingham 1991). Angling effort (angler-days) for Arctic grayling was obtained from the recreational fishery management plan for the DCR (ADF&G 1993).

Catch-at-age was estimated from the proportion of fish at age in the creel survey sample and the estimate of catch for that year from the Statewide Harvest Survey:

$$\hat{C}_{a,i} = \hat{C}_i \cdot \hat{p}_{a,i} \quad (2)$$

where: $\hat{C}_{a,i}$ = estimate of catch at age a in year i;

$\hat{p}_{a,i}$ = estimate of the proportion of the creel sample at age a in year i.

Variance of catch-at-age was estimated from the variance of catch and the variance of proportion at age with Goodman's (1960) formula for the product of two independent estimates (estimates are in Appendices A1 through A14).

Age-Structured Stock Analysis

Abundance, fishing mortality rate, and recruitment of Arctic grayling in the DCR during 1977 through 1990 were estimated using age-structured stock analysis (ASA). This procedure is an extension of virtual population analysis (Pope 1972) that provides estimates of the cohorts still being fished (Hilborn and Walters 1992). There are many different procedures for performing ASA (see Megrey 1989), but the CAGEAN model (Deriso et al. 1985) was used for the

DCR data base. The CAGEAN model allows the incorporation of auxiliary data (such as fishing effort) into the estimation model (Deriso et al. 1985). In the case of the DCR data base of catches-at-age, fishing effort (angler-days for Arctic grayling) was added to the model to aid in the estimation of fishing mortality. The model also allows for a weighting factor (ratio of variances) in the use of fishing effort. The assumptions of the CAGEAN model (and most ASA models) are as follows (summarized from Megrey 1989):

1) the age composition of the stock is not constant from year to year;
2) the age composition data are independent of the total catch estimate;
3) there are errors associated with estimating the total catch;
4) all significant components of mortality are accounted for in F (fishing mortality) and M (natural mortality);
5) M does not vary by age, year, or size of the stock and represents all components of mortality not associated with the directed fishery;
6) F does not vary with respect to stock size;
7) F and M operate concurrently and independent of one another (Ricker's (1975) Type II fishery);
8) M is known or can be estimated independently;
9) F can vary between years and within one year it can vary by age;
10) variation in F can be represented as the product of an age and a year factor;
11) year-specific exploitation can change between years, but not within a year;
12) catchability (q) of the gear is constant and does not vary by age and within a year;
13) there is no gear saturation or competition;
14) the population is closed to immigration and emigration;
15) the fishery operates on a single unit stock over its entire geographic range; and,
16) removals from the population are by fishing only, except for losses due to M.

Mathematical details of the CAGEAN model can be found in Deriso et al. (1985) and Megrey (1989). The operational details of using CAGEAN for the DCR analysis follow.

An initial inspection of the catch-at-age data from the DCR shows that, on average, age 5 fish are fully recruited to the fishable population (Figure 2). This could mean that ages 1 through 4 were present in the stock, but selectivity by the fishery underrepresented these ages in the catch. However, Ridder (1985) found that recruitment of a year-class to the DCR from parent stocks may occur over several years, resulting in full recruitment of the cohort at age 4 or 5. Therefore, availability of age 1 through 4 fish in the DCR was indistinguishable from potential selectivity on these ages. Ridder (1991) found that nearly 100% of fish tagged at the DCR in any particular year, return to the DCR in subsequent years. Assuming that after recruitment to the DCR, fish return to the DCR annually, one could also assume that the unit stock for the purposes of this analysis was "all fish age 5 and older." As a result, modeling with CAGEAN was restricted to fish age 5 and older. Fish older than age 10 occurred in catches from five of the 14 years of data (see Appendices A1 through A14), so that fish age 10 through age 13 were

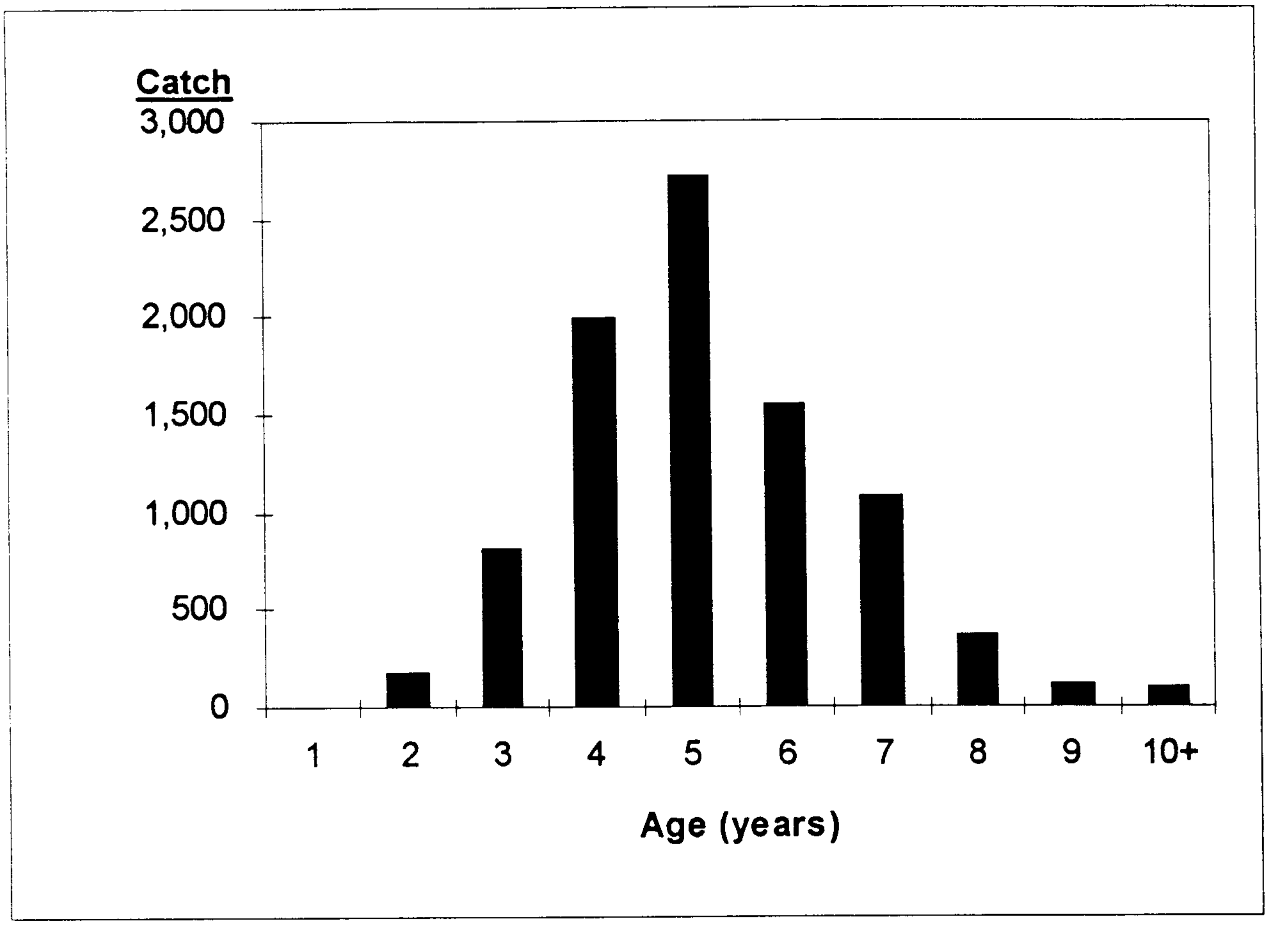

Figure 2. Average catch of Arctic grayling (≥ 150 mm fork length) by age from the Delta Clearwater River, averaged for 1977 through 1990.

pooled into a group called "10+." Fournier and Archibald (1982) recommend pooling older age classes for age-structured stock analyses.

There were no estimates of natural mortality rate from the DCR or any of the supposed parent stocks. Clark (1992) found that instantaneous natural mortality of Arctic grayling in the Chena River averaged 0.31 for fish age 5 and older during a ten-year period. Clark (1994b) also found that average (over five years) natural mortality of the Fielding Lake ($\geq$ 200 mm FL) stock could vary from 0.08 to 0.46. Megrey (1991) compared the residual sum of squares from the CAGEAN model run with varying levels of natural mortality and found similarity between the natural mortality that gave the minimum residual sum of squares and the natural mortality determined from other sources. Natural mortality was varied from 0.08 to 0.64 and the minimum residual sum of squares was found at a natural mortality of 0.20 (Figure 3). Therefore, a natural mortality rate of 0.20 was used in all subsequent modeling with CAGEAN.

Fishing mortality was estimated from the relation between catchability, selectivity and fishing effort:

$$F(a,y) = q(y)s(a)f(y) \qquad (3)$$

where: $F(a,y)$ = instantaneous fishing mortality at age a and year y;
$q(y)$ = catchability in year y;
$s(a)$ = selectivity coefficient for age a; and,
$f(y)$ = fishing effort in year y.

For this analysis, selectivity on Arctic grayling age 5 and older was assumed constant over all ages. Fishing mortality could then be assumed to be a function of catchability and fishing effort ($F(a,y)$ then reduces to $F(y)$). However, fishing effort is often not a reliable measure of fishing mortality and is estimated with error. Program CAGEAN allowed the modeling of the inexact relation between fishing effort and fishing mortality with the use of a variance ratio or "effort lambda" (λ_1 of Deriso et al. 1985). Effort lambda was varied from 0.01 to 1000 (simulating a range of confidence in the effort data from 100 times less reliable than the catch data to 1000 times more reliable than the catch data) and the number of angler-days of fishing effort for Arctic grayling (from Table 1) used as effort in the CAGEAN model. The resultant estimates of fishing mortality by year were similar among the various effort lambdas (Figure 4) so that a value of 0.5 was used for all subsequent modeling with CAGEAN. The disparity in estimates of fishing mortality for 1989 and 1990 with varying effort lambdas necessitated the use of two periods of equal catchability ($q(y)$ in equation 3); from 1977 through 1988 and 1989 through 1990.

As required by the CAGEAN model, catch-at-age data were transformed to the log-normal distribution (Deriso et al. 1985). The CAGEAN model also requires that starting values of the parameters be provided. The starting values needed for the DCR were abundance-at-age in 1977, abundance of age 5 fish for all years, fishing mortality for all years, and catchability for all years. For the DCR analysis, starting values were calculated by performing standard cohort analysis (Pope 1972; COHORT mode of CAGEAN was used) on the catches-at-

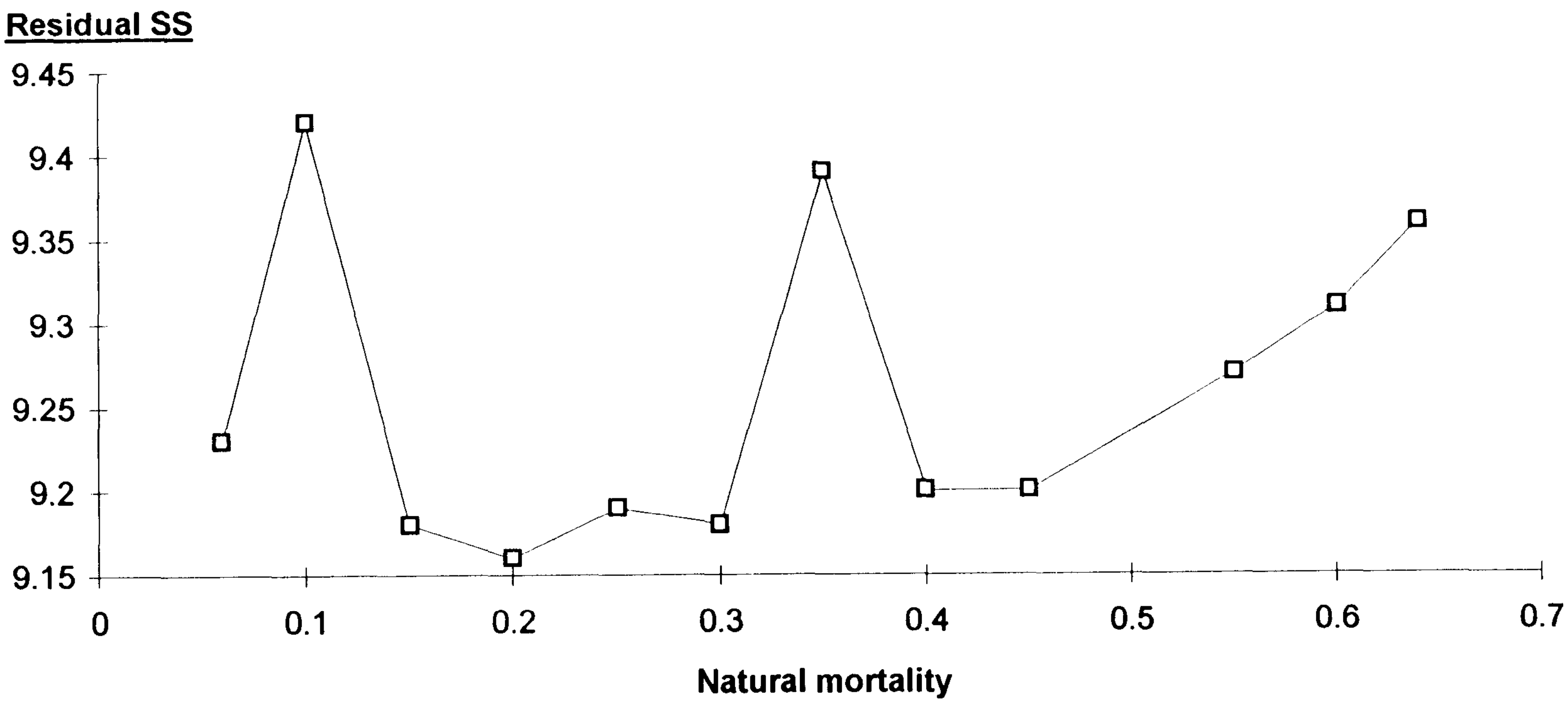

Figure 3. Residual sum squares (SS) from the CAGEAN model for various levels of natural mortality rate, Delta Clearwater River, 1977-1990.

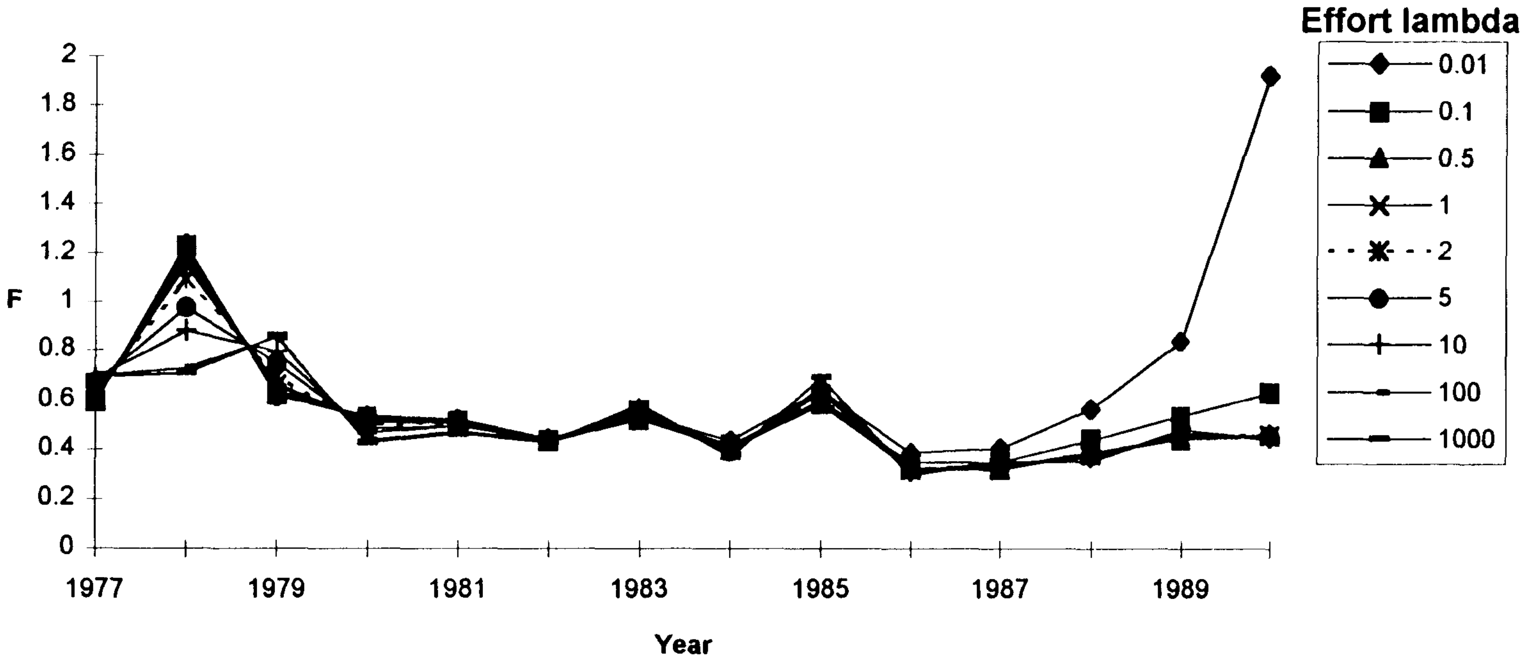

Figure 4. Estimates of fishing mortality rate by year from the CAGEAN model for various levels of effort lambda (assumes natural mortality rate = 0.20), Delta Clearwater River, 1977-1990.

age with natural mortality set to 0.20 and terminal fishing mortality (for age 10+) set to 0.50 (Table 2). Using the bootstrapping procedure in CAGEAN, standard errors of abundance and fishing mortality were estimated from 100 iterations of the model. Systematic departures of the estimates from the input data were investigated by plotting observed and predicted values of total catch and fishing effort by year.

Estimates of abundance calculated from the age-structured stock analysis were compared to two indicators of abundance in the DCR, an index of abundance in the Richardson Clearwater River (a nearby spring-fed river), abundance in two potential parent stocks, and a recruitment index from the Chena River. One index of Arctic grayling abundance in the DCR is angler catch-per-unit-effort (CPUE). CPUE was calculated by dividing the estimate of catch by the estimate of fishing effort for Arctic grayling (Table 3). Another index of abundance in the DCR was the total number of Arctic grayling caught during one complete pass of an electrofishing boat down the mainstem of the DCR (see Ridder 1989, Table 3). Estimated abundance in the DCR was also compared to the total number of Arctic grayling caught during one complete pass of an electrofishing boat down the mainstem of the Richardson Clearwater River (see Ridder 1989, Table 3). Estimates of abundance in the Goodpaster River (Roach 1994) and Caribou Creek (a tributary to Shaw Creek; Ridder *In Preparation*) were also compared to estimates of abundance in the DCR (Table 3). Estimates of abundance of age 5 fish in the DCR were also compared to estimates of abundance of age 5 fish in the Chena River (Clark 1994a and *Unpublished*; Table 3).

RESULTS

Given the starting values for the parameters (Table 2), predictions of catch and effort from the CAGEAN model appear to fit the observed values (Figures 5 and 6). The greatest disparity between observed and predicted catch and effort occurred for the 1978 and 1979 data, suggesting potential bias in estimates of abundance, fishing mortality, and recruitment for these two years. Estimated abundance of age 5 and older fish ranged from 4,477 fish (SE = 1,766) in 1990 to 12,760 fish (SE = 1,746) in 1983 (Table 4). Instantaneous fishing mortality rate varied from 0.32 in 1986 (SE = 0.19) and 1987 (SE = 0.23) to 1.19 (SE = 0.13) in 1978, resulting in annual exploitation rates of 24.8% to 64.4% (Table 4). Recruitment varied from 1,085 age 5 fish (SE = 694) in 1990 to 7,788 age 5 fish (SE = 1,518) in 1983 (Table 4).

The trend in abundance appears plausible, given that other measures of relative abundance follow a similar trend. For example, angler catch rates in the DCR appear to track well with the trend in abundance (Table 3 and Figure 7). Catchability changed after 1987 due to a minimum length limit of 305 mm (12 inch) imposed in 1987. This regulation altered the trend in catchability relative to abundance observed in years before 1987 (Figure 7).

Table 2. Initial values of abundance-at-age in 1977 and recruitment, fishing mortality rate, and catchability in 1977-1990 used in the CAGEAN model of the Arctic grayling fishery in the Delta Clearwater River, 1977-1990.

Year	Age	Abundance[a]	Fishing mortality[b]	Catchability[b]
1977	10+	3	0.77	1.37×10^{-4}
	9	4	0.77	1.37×10^{-4}
	8	54	0.77	1.37×10^{-4}
	7	1,335	0.77	1.37×10^{-4}
	6	4,020	0.77	1.37×10^{-4}
	5	4,890	0.77	1.37×10^{-4}
1978	5	3,385	1.83	1.37×10^{-4}
1979	5	5,395	0.88	1.37×10^{-4}
1980	5	3,530	0.54	1.37×10^{-4}
1981	5	6,984	0.94	1.37×10^{-4}
1982	5	4,814	0.47	1.37×10^{-4}
1983	5	8,588	0.49	1.37×10^{-4}
1984	5	5,210	0.82	1.37×10^{-4}
1985	5	5,308	0.51	1.37×10^{-4}
1986	5	2,905	0.30	1.37×10^{-4}
1987	5	3,028	0.31	1.37×10^{-4}
1988	5	4,157	0.38	1.37×10^{-4}
1989	5	1,512	0.45	2.00×10^{-4}
1990	5	1,024	0.50	2.00×10^{-4}

[a] Abundance at age 10+ is abundance of fish age 10 and older. Abundance at age 5 is recruitment.

[b] Fishing mortality and catchability for 1978-1990 is applied to all ages (5-10+).

Table 3. Auxiliary abundance (age 5 and older) and recruitment (age 5) data used for comparison with estimates of abundance from the CAGEAN model of the Delta Clearwater River, 1977-1990.

Year	DCR CPUE[a]	DCR EB Index[b]	RCR EB Index[c]	GPR abundance[d]	Caribou abundance[e]	Chena age 5[f]
1977	0.55	33	ND[g]	4,200	ND	10,010
1978	0.74	15	ND	2,004	ND	7,116
1979	0.48	62	ND	ND	ND	5,403
1980	0.56	66	138	1,534	9,820	12,983
1981	0.81	32	145	ND	9,927	15,652
1982	0.66	21	266	2,240	5,332	8,311
1983	0.87	38	177	ND	4,780	14,789
1984	0.92	63	128	3,918	2,340	8,137
1985	0.65	22	135	11,768	8,237	15,652
1986	0.67	5	61	3,071	7,623	5,542
1987	0.55	7	99	1,598	ND	2,369
1988	0.83	25	163	5,359	ND	9,423
1989	0.92	ND	ND	2,169	ND	2,563
1990	0.67	ND	ND	1,245	ND	2,429

[a] Catch from Mills (1979-1991) divided by angler-days of effort for Arctic grayling (ADF&G 1993).

[b] The total number of Arctic grayling (age 5 and older) caught during one complete pass of an electrofishing boat down the mainstem of the Delta Clearwater River (Ridder 1985 and *Unpublished*).

[c] The total number of Arctic grayling (age 5 and older) caught during one complete pass of an electrofishing boat down the mainstem of the Richardson Clearwater River (Ridder 1989).

[d] Abundance of Arctic grayling (age 5 and older) in the lower 53 km of the Goodpaster River (Roach 1994).

[e] Abundance of Arctic grayling (≥ 270 mm fork length) in Caribou Creek (a tributary of Shaw Creek; Ridder *In prep.*).

[f] Abundance of age 5 Arctic grayling in the lower 152 km of the Chena River (1977-1985 is from Clark (*Unpublished*); 1986-1990 is from Clark 1994).

[g] ND = no data.

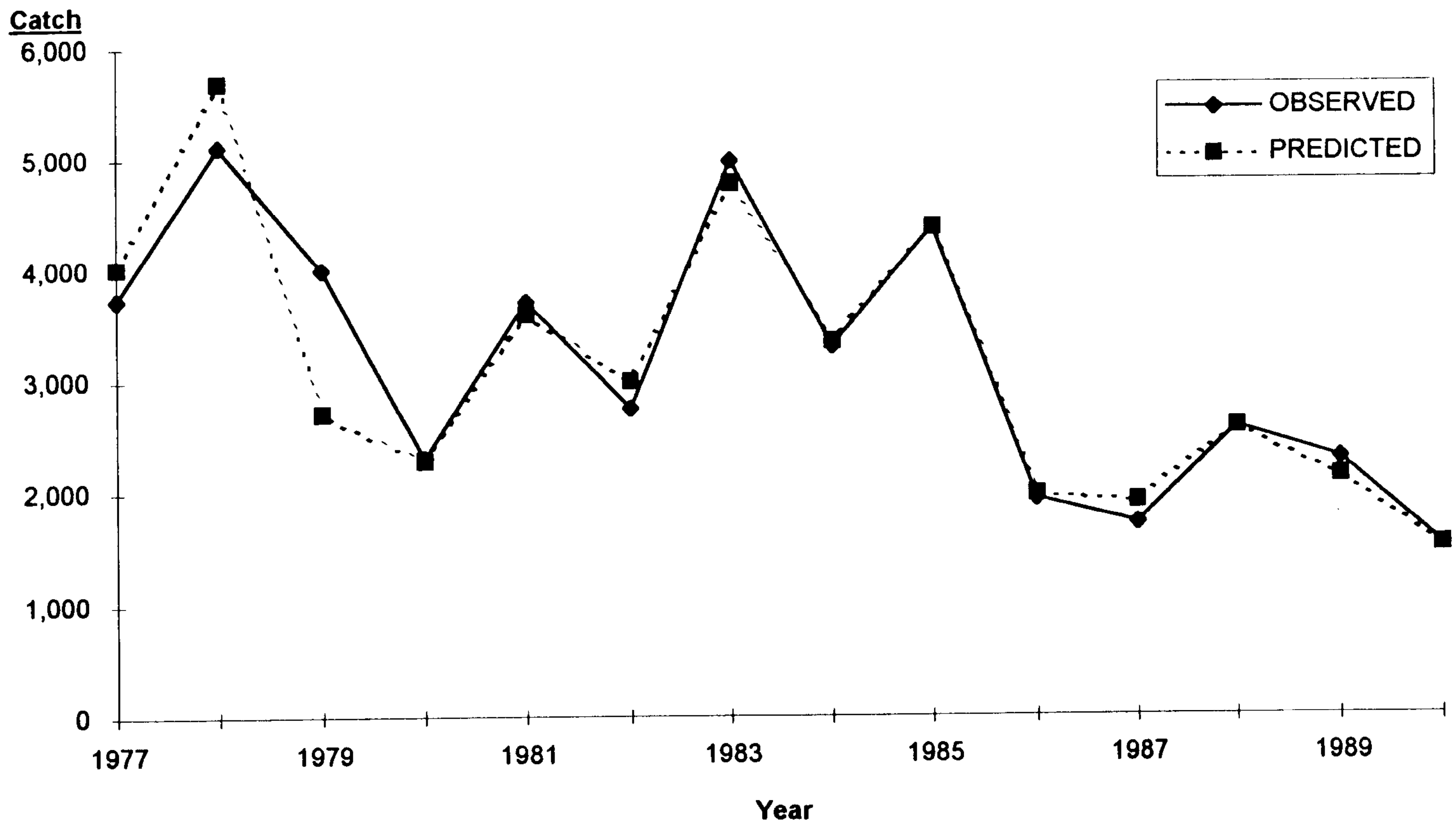

Figure 5. Comparison of observed catch with catch predicted from the CAGEAN model, Delta Clearwater River, 1977-1990.

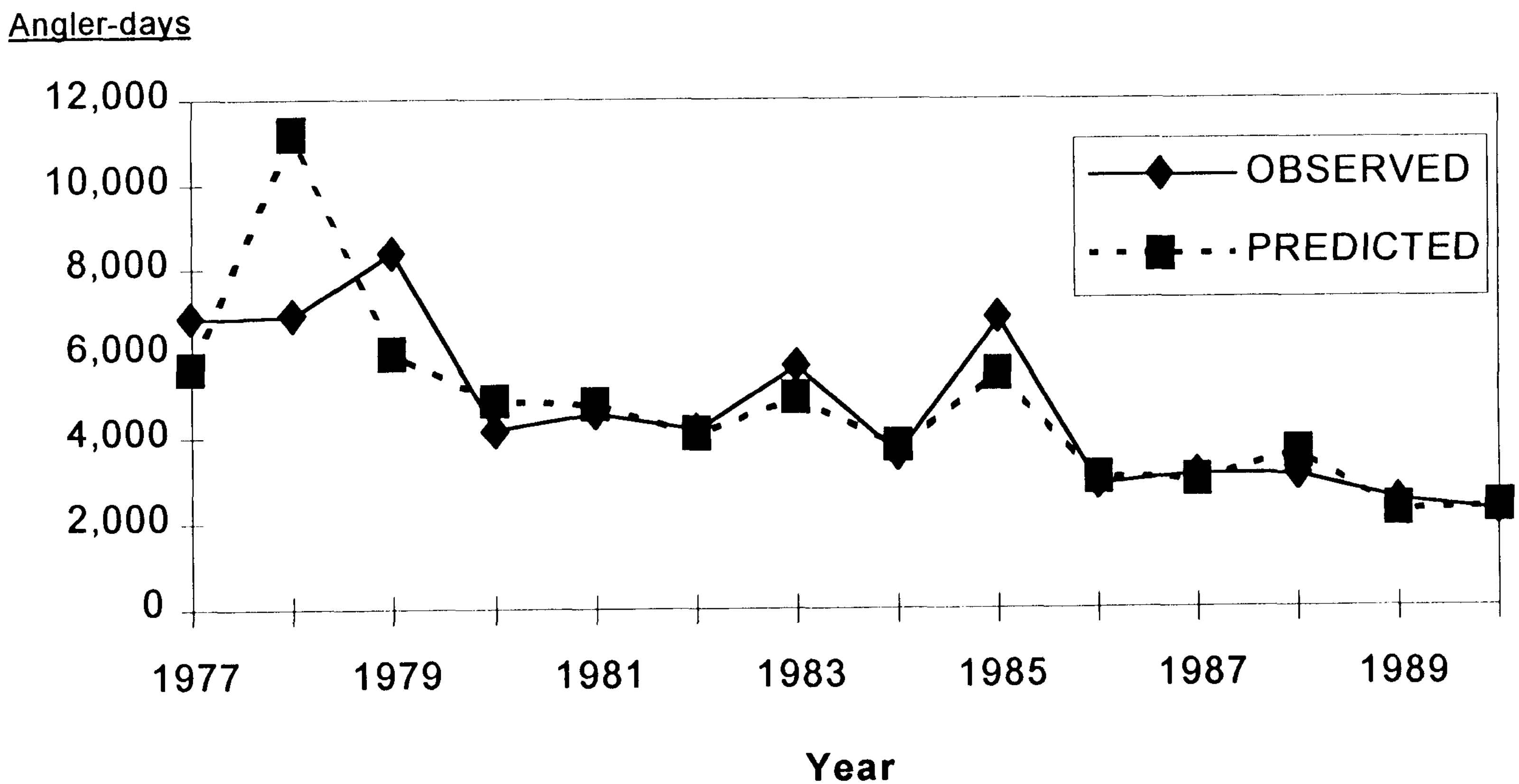

Figure 6. Comparison of observed effort with effort predicted from the CAGEAN model, Delta Clearwater River, 1977-1990.

Table 4. Estimates of abundance, fishing mortality rate, exploitation rate, recruitment, and standard errors from the CAGEAN model for age 5 and older Arctic grayling in the Delta Clearwater River, 1977-1990.

Year	N[a]	SE[b]	F[c]	SE	u[d]	B[e]	SE
1977	9,702	1,234	0.60	0.16	41.5	5,784	773
1978	8,826	1,279	1.19	0.13	64.4	4,484	1,005
1979	6,258	885	0.64	0.20	43.3	4,067	892
1980	6,175	832	0.52	0.16	37.2	3,471	725
1981	9,829	1,461	0.51	0.17	36.6	6,833	1,391
1982	9,369	1,159	0.43	0.17	32.1	4,542	911
1983	12,760	1,746	0.53	0.16	37.4	7,788	1,518
1984	11,063	1,276	0.40	0.17	30.4	4,888	1,012
1985	10,767	1,388	0.59	0.19	40.6	4,725	972
1986	7,840	1,148	0.32	0.19	25.3	2,940	561
1987	7,684	1,289	0.32	0.23	24.8	3,045	686
1988	8,845	1,962	0.39	0.24	29.2	4,269	1,306
1989	6,482	1,751	0.45	0.33	32.9	1,559	487
1990	4,477	1,766	0.46	0.49	33.9	1,085	694
Averages	8,577	709	0.53	0.08	37.6	4,249	553

[a] N is estimated abundance (age 5 and older) from the CAGEAN model.

[b] SE is the estimated standard error from 100 bootstrap iterations of the CAGEAN model.

[c] F is the estimated instantaneous fishing mortality rate (assuming a natural mortality rate of 0.20) from the CAGEAN model.

[d] u is the estimated annual exploitation rate (assuming a natural mortality of $M = 0.20$) or

$$u = \frac{F}{(F + M)}\left(1 - e^{-(F+M)}\right),$$ expressed in percent.

[e] B is estimated recruitment (abundance of age 5 fish) from the CAGEAN model.

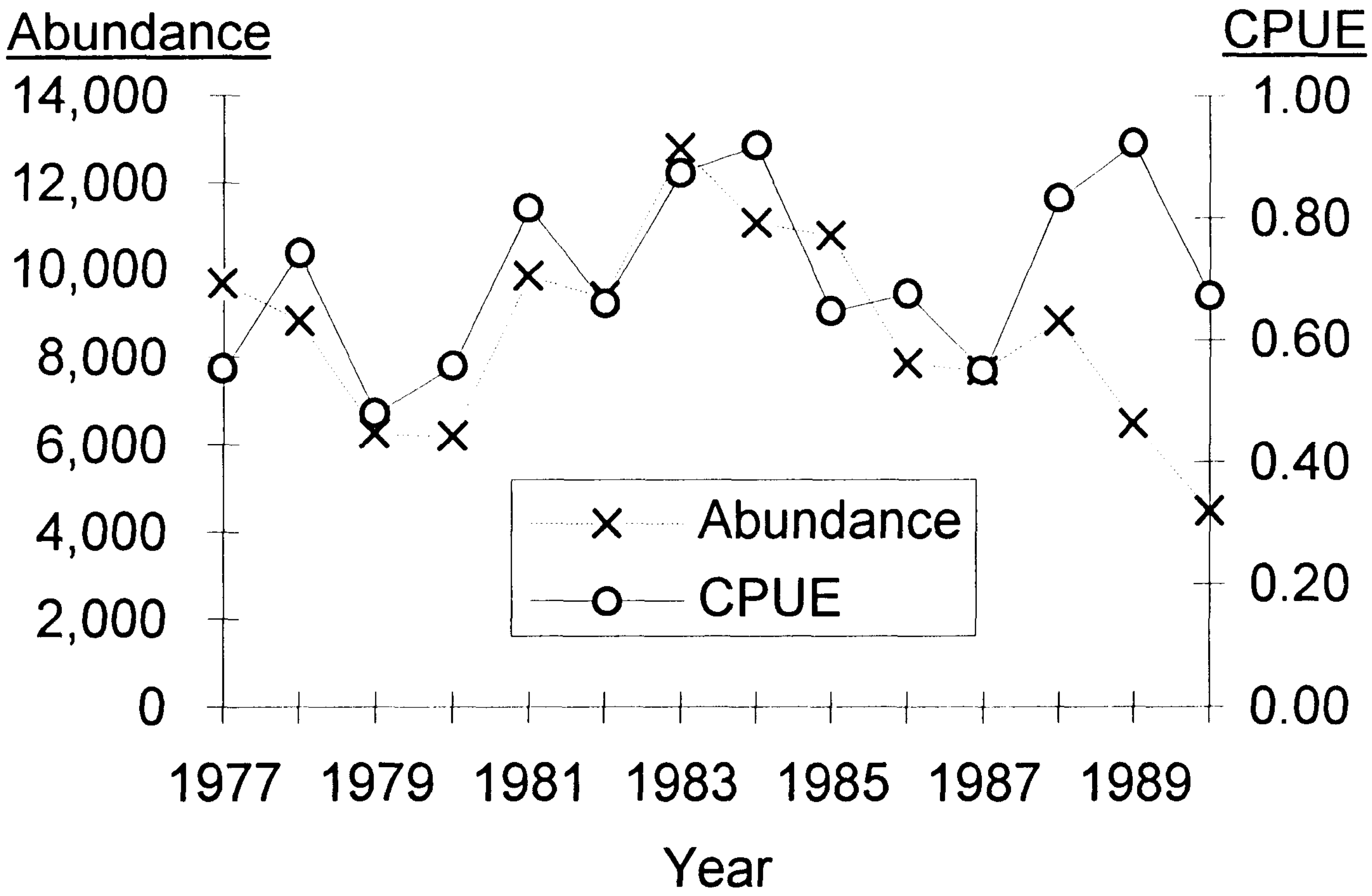

Figure 7. Comparison of estimates of catch-per-angler-day (age 5 and older; CPUE) with estimates of abundance from the CAGEAN model from the Delta Clearwater River during 1977-1990.

An index of relative abundance estimated from the DCR during these years does not compare well with estimated abundance from the CAGEAN model (Table 3 and Figure 8).

The DCR index was regarded as inaccurate for many years and was discontinued in 1988 (Ridder *Unpublished*). However, the relative abundance index from the Richardson Clearwater River, a smaller more easily electrofished clearwater stream, is thought to represent relative abundance accurately (Ridder 1985). The trend in abundance in Richardson Clearwater River compares very well with abundance in the DCR, although the trends do not exactly agree (Table 3 and Figure 9). Trends in Arctic grayling abundance in the lower Goodpaster River, one of the plausible parent rivers, tended to track with the estimated trend in the DCR, although the magnitude of high and low abundances do not match (Table 3 and Figure 10). The trend in recruitment in the DCR compared well with the trend in recruitment estimated from the Chena River (Table 3 and Figure 11), suggesting that recruitment to the DCR comes from runoff streams (e.g., the Goodpaster River) that share the same influence of stream flows during early life history on recruitment as the Chena River (Clark 1992).

Abundance estimates calculated for DCR independently of the ASA estimates are few and have low precision. Ridder (*Unpublished*) estimated from releases of tagged fish during April that there were 6,781 and 9,660 fish in the DCR during 1977 and 1978, respectively. The estimate from 1978 was comparable to that from the CAGEAN model (8,826 fish), although the 1977 estimate was not (9,702 fish). Ridder (*Unpublished*) also estimated 6,180 fish in the DCR in 1988, somewhat less than the estimate of 8,845 fish from the CAGEAN model. Moreover, these comparisons do qualify the abundances estimated from the CAGEAN model into the same order of magnitude as mark-recapture estimates.

DISCUSSION

The CAGEAN model gave satisfactory estimates of trend in abundance, fishing mortality, and recruitment through time. These trends were partially linked to changes in fishing effort when catchability was assumed constant. In reality, catchability is likely to change each year with changes in weather, distribution of fish, and the degree of catch-and-release fishing that occurs. However, the only change in catchability that was modeled was from 1988 to 1989, when catchability increased almost 100% (from 1.07×10^{-4} to 2.00×10^{-4}). The increase could have been due to a change in regulations (a 12-inch or 305 mm length limit was imposed in 1987) that caused increased retention of fish age 5 and older, although the regulation was changed in 1987 and not 1989. Moreover, Arctic grayling are known for their ease of capture, even when stock size is declining, so that fishing mortality may have increased during years when the stock was smallest (1989 and 1990).

Assuming the CAGEAN model adequately represents actual abundances and mortality rates in the DCR fishery, annual rates of exploitation appear to be higher than what is normally sustainable for Arctic grayling populations in

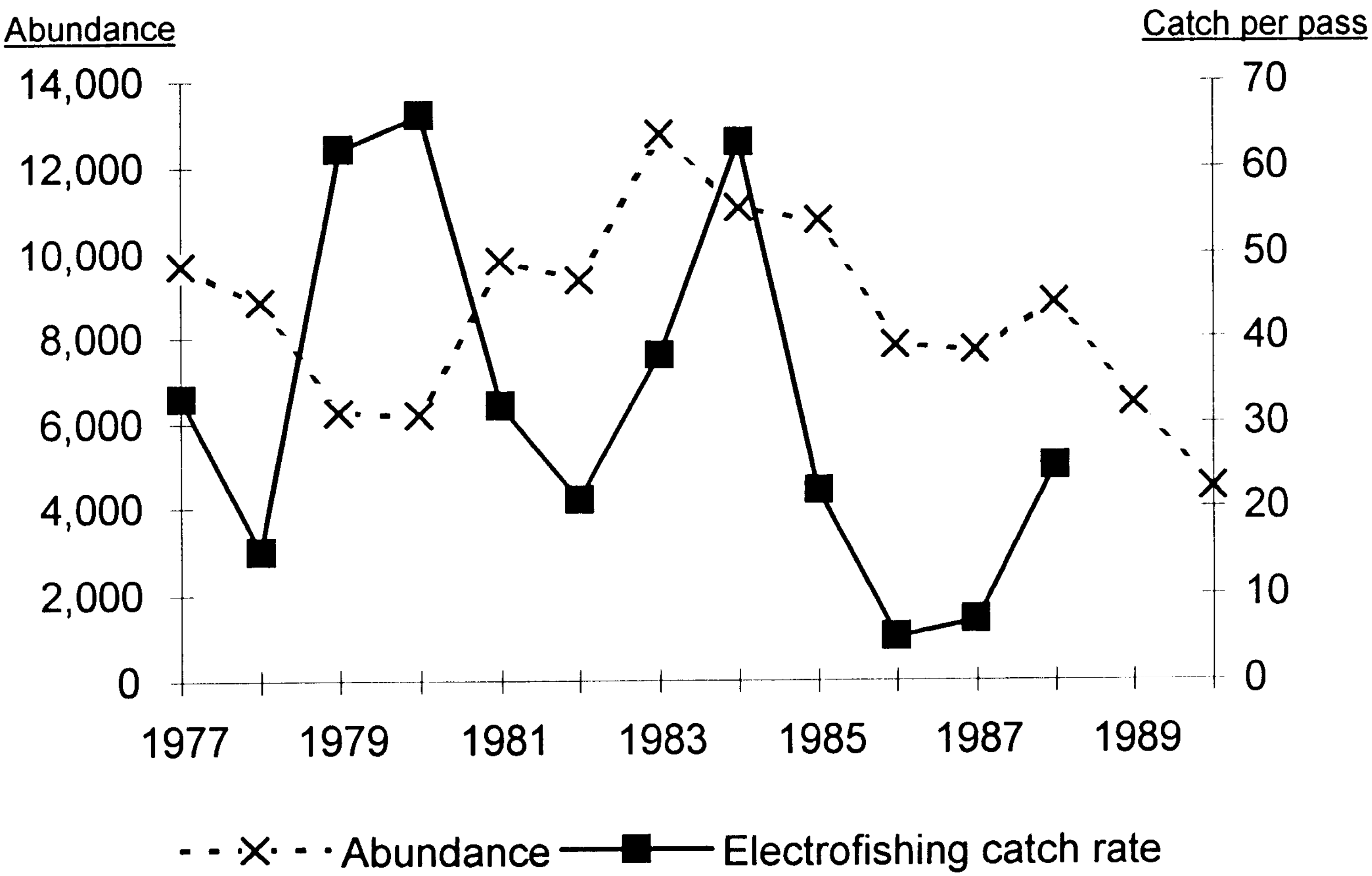

Figure 8. Comparison of estimates of electrofishing catch rate (age 5 and older) during 1977-1988 with estimates of abundance from the CAGEAN model in the Delta Clearwater River during 1977-1990.

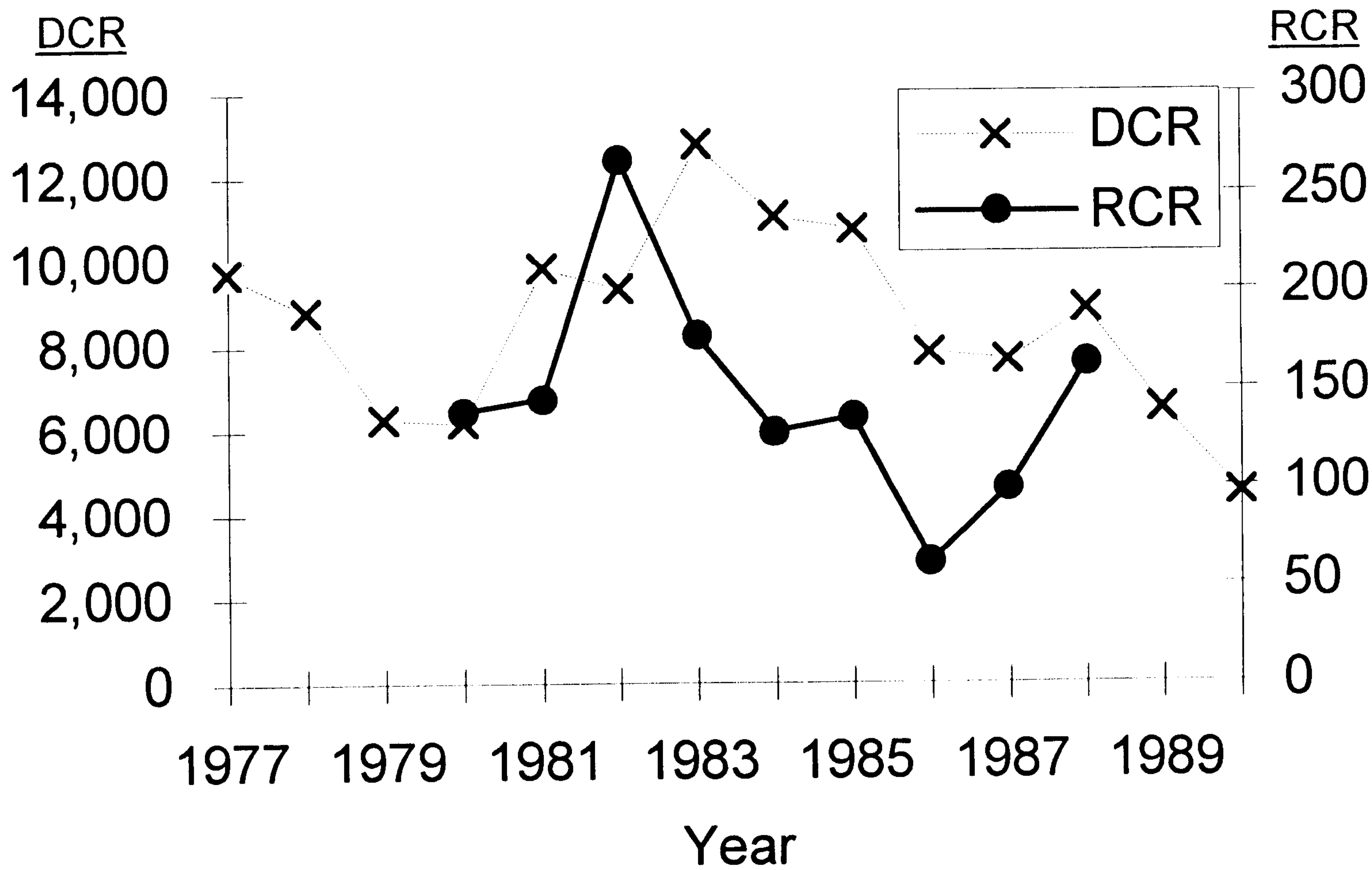

Figure 9. Comparison of estimates of relative abundance (age 5 and older) from the Richardson Clearwater River (RCR) during 1980-1988 with estimates of abundance from the CAGEAN model of the Delta Clearwater River (DCR) during 1977-1990 (RCR estimates are rescaled).

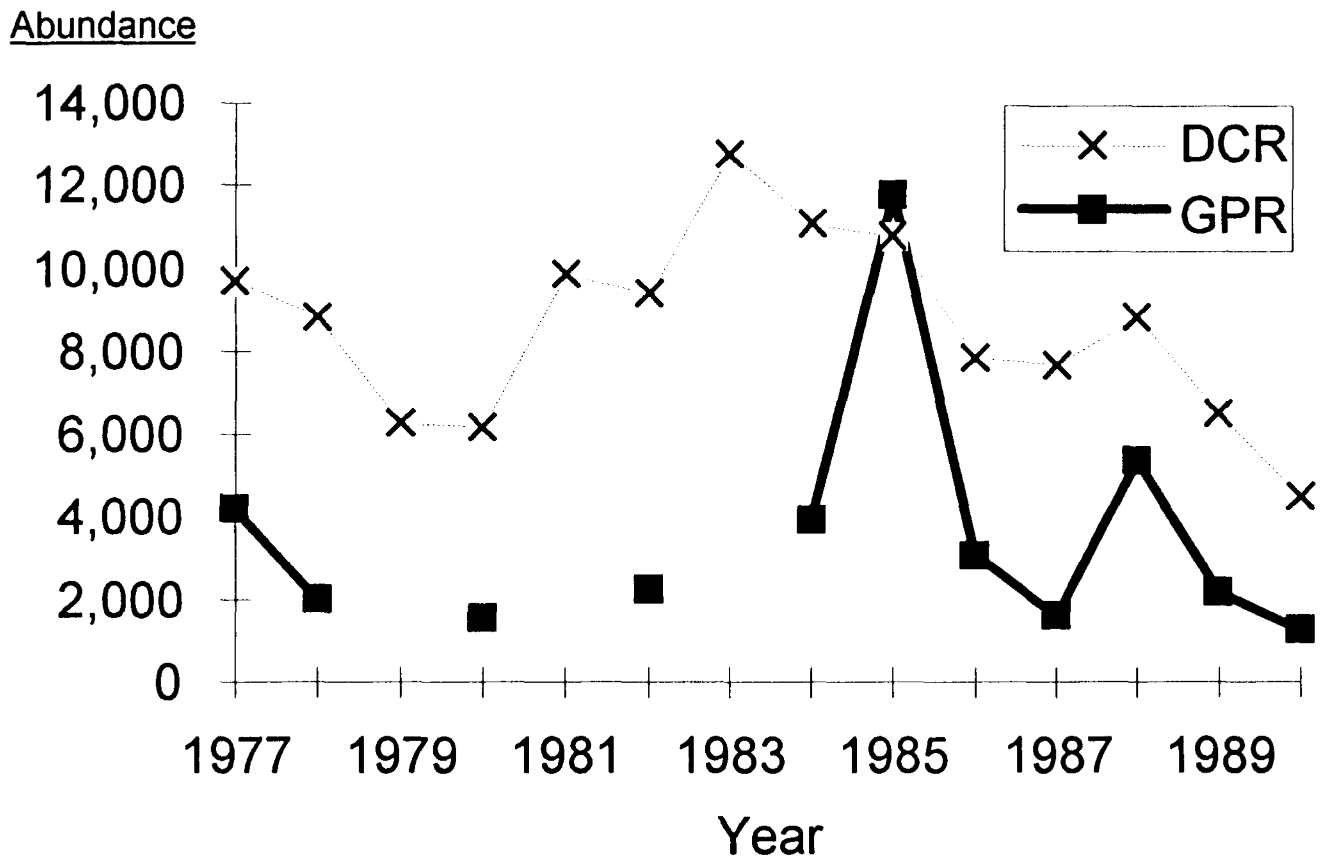

Figure 10. Comparison of estimates of relative abundance (age 5 and older) from the Goodpaster River (GPR) with estimates of abundance from the CAGEAN model from the Delta Clearwater River (DCR) during 1977-1990.

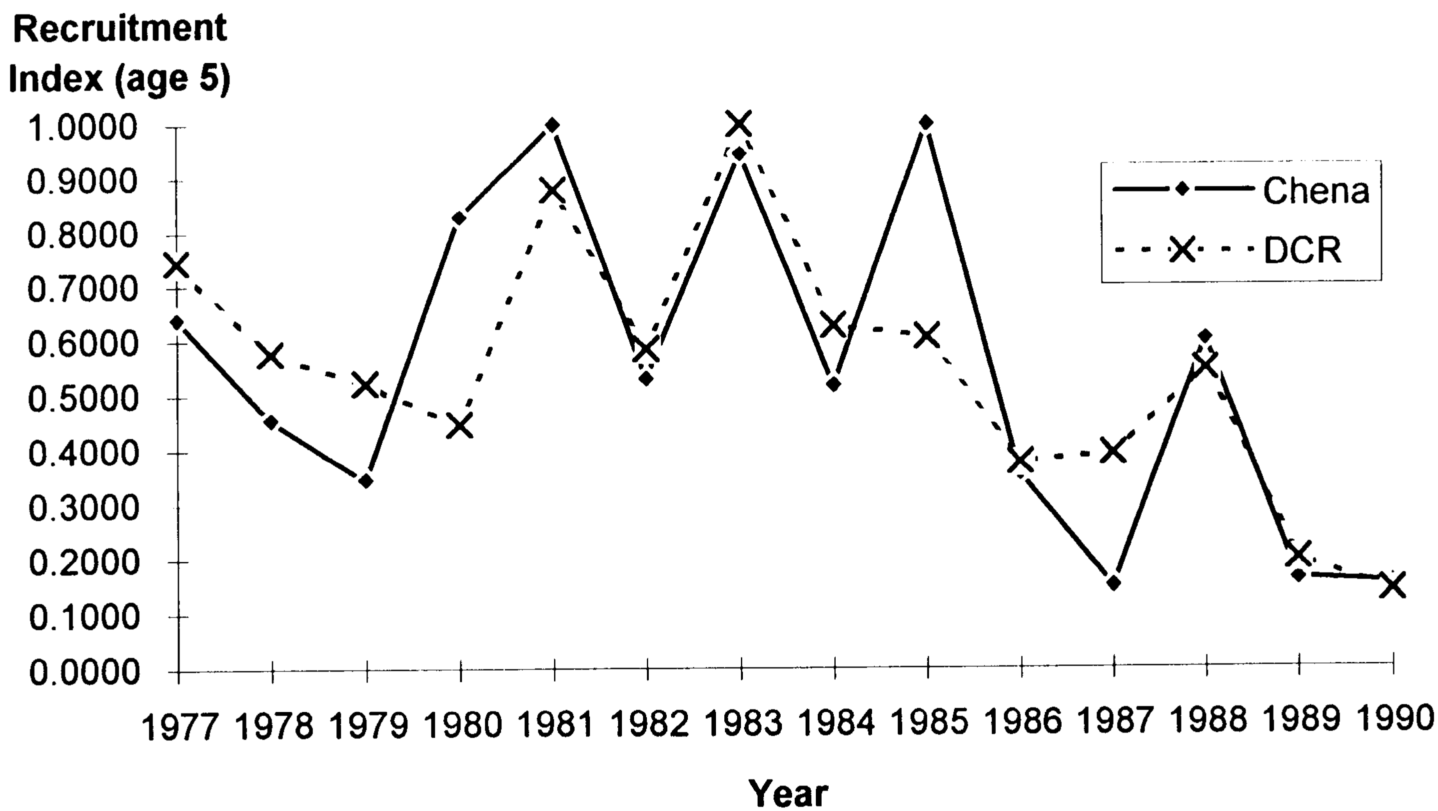

Figure 11. Comparison of estimates of relative recruitment (age 5 fish) from the Chena River (Chena) with estimates of relative recruitment from the CAGEAN model from the Delta Clearwater River (DCR) during 1977-1990.

the Tanana River drainage. Examples of sustainable exploitation rate in Arctic grayling are few, but it is generally thought that rates of 20% or less are long-term sustainable. Specifically, Clark (*Unpublished*) found that through Monte Carlo simulation of the Chena River fishery, long-term stability of abundance was obtained at an average exploitation rate of 14% over a 20 year period. Clark (1992) did find that the average annual rate of exploitation on age 3 and older Arctic grayling in the Chena River during 1979 through 1990 was 32.1% and was not sustainable. At Fielding Lake in the Alaska Range Clark (1994b) found that the average exploitation rate of 16% on fish greater than 199 mm FL was sustainable during 1986 through 1990. Exploitation rate of DCR bound Arctic grayling in the assumed parent rivers may be low (e.g., Volkmar and Goodpaster Rivers) to moderate (e.g., Shaw Creek and the Salcha River), although the contributions of fish from these rivers is unknown. If a single parent river contributes to the DCR and exploitation rate is low in the parent river, sustainability of the DCR fishery would then depend entirely on the rate of contribution, or proportion of the stock that uses the DCR. The situation becomes more complex if there are more than one parent stock, exploitation rates differ in each, and contribution rates differ in each. If recruitment to the DCR is more complex than one or two parent stocks it is unlikely that the resultant contributions could be estimated with sufficient precision to be of value for management of Arctic grayling in the DCR. However, identification and qualitative estimates of contribution of potential parent stocks by radio-telemetry and anchor-tagging is feasible.

RECOMMENDATIONS

1. Continue on-site catch sampling on the DCR to estimate the age composition of the catch.

2. Attempt to estimate the age composition of the catch from the DCR during 1991 through 1993. Use inferences from the 1990 catch and abundance and the 1994 catch.

3. Attempt to qualify hypotheses concerning the number and identity of parent rivers. Use radio-telemetry, anchor-tagging, and ASA estimates of abundance in the DCR to calculate approximate estimates of contributions from parent rivers.

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APPENDIX A
Catches-at-Age

Appendix A1. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1977.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.04	0.02	220	136
3	0.11	0.03	704	371
4	0.24	0.04	1,452	730
5	0.33	0.04	2,025	1,004
6	0.19	0.03	1,144	582
7	0.09	0.02	528	286
8	0.01	0.01	44	44
9	0.00	0.00	0	0
10+	0.00	0.00	0	0
Totals	1.00	---	6,118	2,962
Age 5+	0.62	---	3,741	1,825

[a] p is the proportion of the harvest-at-age (sample size = 139 fish).
[b] C is the harvest-at-age.

Appendix A2. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1978.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.02	0.01	138	108
3	0.07	0.02	552	314
4	0.24	0.04	1,863	943
5	0.17	0.04	1,311	679
6	0.16	0.03	1,242	646
7	0.26	0.04	2,000	1,008
8	0.07	0.02	552	314
9	0.00	0.00	0	0
10+	0.00	0.00	0	0
Totals	1.00	---	7,657	3,707
Age 5+	0.66	---	5,105	2,490

[a] p is the proportion of the harvest-at-age (sample size = 111 fish).
[b] C is the harvest-at-age.

Appendix A3. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1979.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.02	0.01	115	75
3	0.17	0.02	1,096	550
4	0.20	0.03	1,270	633
5	0.45	0.03	2,914	1,424
6	0.11	0.02	692	355
7	0.06	0.02	375	202
8	<0.01	<0.01	29	29
9	0.00	0.00	0	0
10	0.00	0.00	0	0
Totals	1.00	---	6,492	3,143
Age 5+	0.63	---	4,011	1,951

[a] p is the proportion of the harvest-at-age (sample size = 225 fish).
[b] C is the harvest-at-age.

Appendix A4. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1980.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.05	0.02	270	158
3	0.13	0.03	734	381
4	0.41	0.04	2,357	1,159
5	0.24	0.03	1,352	678
6	0.12	0.03	696	363
7	0.03	0.01	155	100
8	0.02	0.01	116	81
9	0.00	0.00	0	0
10+	0.00	0.00	0	0
Totals	1.00	---	5,680	2,750
Age 5+	0.41	---	2,318	1,141

[a] p is the proportion of the harvest-at-age (sample size = 147 fish).
[b] C is the harvest-at-age.

Appendix A5. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1981.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.01	0.01	96	75
3	0.20	0.03	1,492	752
4	0.28	0.04	2,069	1,029
5	0.31	0.04	2,310	1,144
6	0.12	0.03	866	452
7	0.06	0.02	433	243
8	0.01	0.01	48	48
9	0.01	0.01	48	48
10+	0.00	0.00	0	0
Totals	1.00	---	7,362	3,565
Age 5+	0.51	---	3,705	1,813

[a] p is the proportion of the harvest-at-age (sample size = 153 fish).
[b] C is the harvest-at-age.

Appendix A6. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1982.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.01	0.01	52	52
3	0.11	0.03	519	286
4	0.30	0.05	1,454	733
5	0.26	0.05	1,247	634
6	0.22	0.04	1,039	535
7	0.06	0.03	312	186
8	0.01	0.01	52	52
9	0.02	0.01	104	81
10+	0.00	0.00	0	0
Totals	1.00	---	4,779	2,314
Age 5+	0.57	---	2,753	1,351

a p is the proportion of the harvest-at-age (sample size = 92 fish).
b C is the harvest-at-age.

Appendix A7. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1983.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.00	0.00	0	0
3	0.06	0.02	419	239
4	0.18	0.03	1,152	591
5	0.47	0.04	3,090	1,518
6	0.14	0.03	890	466
7	0.13	0.03	838	441
8	0.02	0.01	105	82
9	0.00	0.00	0	0
10+	0.01	0.01	52	52
Totals	1.00	---	6,546	3,170
Age 5+	0.77	---	4,975	2,419

a p is the proportion of the harvest-at-age (sample size = 125 fish).
b C is the harvest-at-age.

Appendix A8. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1984.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.00	0.00	0	0
3	0.01	0.01	55	55
4	0.20	0.05	828	435
5	0.30	0.05	1,269	644
6	0.30	0.05	1,269	644
7	0.08	0.03	331	197
8	0.08	0.03	331	197
9	0.01	0.01	55	55
10+	0.01	0.01	55	55
Totals	1.00	---	4,193	2,030
Age 5+	0.78	---	3,310	1,612

[a] p is the proportion of the harvest-at-age (sample size = 76 fish).
[b] C is the harvest-at-age.

Appendix A9. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1985.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.07	0.02	428	220
3	0.01	0.01	71	56
4	0.16	0.03	927	472
5	0.30	0.04	1,746	865
6	0.18	0.03	1,034	523
7	0.20	0.03	1,140	575
8	0.06	0.02	356	197
9	0.02	0.01	107	75
10+	0.00	0.00	0	0
Totals	1.00	---	5,809	2,813
Age 5+	0.76	---	4,383	2,129

[a] p is the proportion of the harvest-at-age (sample size = 163 fish).
[b] C is the harvest-at-age.

Appendix A10. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1986.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.01	0.01	24	24
3	0.05	0.02	120	74
4	0.11	0.03	263	143
5	0.23	0.04	550	280
6	0.30	0.05	693	349
7	0.13	0.03	311	166
8	0.09	0.03	215	120
9	0.03	0.02	72	50
10+	0.04	0.01	96	52
Totals	1.00	---	2,343	1,134
Age 5+	0.82	---	1,937	941

[a] p is the proportion of the harvest-at-age (sample size = 98 fish).
[b] C is the harvest-at-age.

Appendix A11. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1987.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.00	0.00	0	0
3	0.01	0.01	29	20
4	0.13	0.02	269	137
5	0.25	0.03	508	252
6	0.21	0.03	413	206
7	0.15	0.02	297	150
8	0.12	0.02	249	127
9	0.07	0.02	134	72
10+	0.05	0.01	105	46
Totals	1.00	---	2,005	971
Age 5+	0.85	---	1,708	828

[a] p is the proportion of the harvest-at-age (sample size = 209 fish).
[b] C is the harvest-at-age.

Appendix A12. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1988.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.01	<0.01	20	14
3	0.03	0.01	95	51
4	0.08	0.01	224	114
5	0.39	0.02	1,129	550
6	0.17	0.02	490	241
7	0.15	0.02	435	215
8	0.10	0.01	279	140
9	0.04	0.01	129	68
10+	0.03	0.01	109	45
Totals	1.00	---	2,910	1,409
Age 5+	0.88	---	2,570	1,245

[a] p is the proportion of the harvest-at-age (sample size = 428 fish).
[b] C is the harvest-at-age.

Appendix A13. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1989.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.00	0.00	0	0
3	0.03	0.01	86	34
4	0.21	0.02	630	187
5	0.17	0.02	509	153
6	0.29	0.02	881	257
7	0.16	0.02	480	145
8	0.06	0.01	179	61
9	0.04	0.01	107	40
10+	0.05	0.01	143	41
Totals	1.00	---	3,016	853
Age 5+	0.77	---	2,300	653

[a] p is the proportion of the harvest-at-age (sample size = 421 fish).
[b] C is the harvest-at-age.

Appendix A14. Estimates of age composition of the harvest, harvest-at-age, and standard error of Arctic grayling from the Delta Clearwater River in 1990.

Age	p[a]	SE[p]	C[b]	SE[C]
2	0.00	0.00	0	0
3	0.02	0.01	33	19
4	0.12	0.02	219	106
5	0.21	0.02	368	175
6	0.16	0.02	280	134
7	0.23	0.02	415	197
8	0.11	0.02	201	97
9	0.06	0.01	107	54
10+	0.09	0.02	150	54
Totals	1.00	---	1,772	827
Age 5+	0.86	---	1,520	710

a p is the proportion of the harvest-at-age (sample size = 380 fish).
b C is the harvest-at-age.