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The continuation of the productive regime in the Strait of Georgia

by

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Abstract

Earlier reports noted that the increased productivity observed in the Strait of Georgia following the regime shift in mid-1998 had led to an increase in both abundance and average size of juvenile salmon in 2000 and 2001. A corresponding increase in prey abundance was reflected in fewer empty stomachs and greater volumes of food in individual stomachs. However, data from the 2002 survey showed that both estimated juvenile salmon abundances and individual sizes were smaller, and were similar to pre-2000 observations. Further, the average volumes of food in the stomachs were lower in 2002 and the percentages of empty stomachs were greater for coho, chum and pink, when compared to 2000 and 2001. The reduced abundance, smaller size and reduced stomach contents is interpreted to represent climate-related variability within the new regime. There were no surveys in July 2003. The 2004 survey indicates that juvenile Pacific salmon growth and abundance is consistent with the improved ocean conditions that followed the regime shift in the climate in 1998 and in the Strait of Georgia in 2000.

Introduction

Marine survival rates for Pacific salmon along the coasts of British Columbia, Washington and Oregon showed significant declines in the 1990s (Beamish et al. 1999, 2000a), which ultimately led to closures of some fisheries (e.g., coho salmon in the Strait of Georgia, British Columbia). Approximately one year after the regime shift in mid-1998, significant increases in euphausiid biomass and mean individual size were observed in the Strait of Georgia which continued through 2001 (Beamish et al. 2001a, 2001b, 2002). Subsequently, the early marine survival of juveniles Pacific salmon was also observed to increase dramatically. Mean individual size and fitness also significantly improved for all three species of salmon (Beamish et al. 2001a,b). However, conditions in 2002 did not reflect this improved productivity, and both marine survival and average size of juvenile salmon declined to levels observed in the previous regime (Sweeting and Beamish 2002). We postulated that interannual variability within the current regime led to reduced productivity for juvenile Pacific salmon entering the Strait of Georgia in 2002. Here, we discuss the results of the 2004 juvenile Pacific salmon survey and show that improved conditions were restored as indicated by increases in catch, average fork lengths, and possibly early marine survival. Diet analysis also confirms that juvenile Pacific salmon captured in 2004 had feeding habits similar to 2000 and 2001. Thus, in 2004, the Strait of Georgia appears to have returned to a productivity level that is characteristic for this current regime, one that is more positive for juvenile salmon growth and survival.

Methods

Set locations (Figure 1), depths, mid-water trawl, trawl speeds and fishing platform (W.E. Ricker) for the juvenile salmon survey in 2004 were all as previously reported (e.g., Beamish et al. 2000b). Abundance estimates using swept volumes were calculated using the procedures described in Beamish et al. (2000c). Average sizes (fork lengths) were measured to the nearest millimetre (mm). Determination of fish weights, when weather conditions permitted, were to the nearest gram (g). Condition factor, or overall fitness, was calculated as (weight/fork length^3) x 100,000. Gut contents of captured juvenile salmon were examined within 30 minutes of capture, with volume estimates to the nearest 0.1 cc. Stomachs were considered to be empty if the total estimated volume was less than 0.1 cc. Species composition was determined by the same experienced taxonomist as on earlier surveys (Beamish et al. 2001b).

Oceanographic conditions in the Strait of Georgia were obtained, as on earlier surveys, to determine whether physical conditions such as water temperatures (obtained from the sea temperature database constructed by the Nanoose Naval Base, located just north of Nanaimo, B.C., Canada), salinity (obtained from Institute of Oceanographic Studies, Victoria, B.C., Canada) or daily average flow rates for the Fraser River at Hope (Stn # 08MF005) (obtained from Environment Canada) would show corresponding shifts that may impact on survival and/or growth trends of the juvenile salmon upon ocean entry.

Statistical analyses were performed using T-tests, ANOVA and Student Newman-Keuls multiple range tests. Significance was accepted at the 0.05 level

Results

Abundance estimates of juvenile Pacific salmon calculated from July surveys (Table 1) performed from 1997 to 2004 are shown in Table 2. There was no survey in 2003 (Table 1) due to loss of ship time. Data for juvenile pink salmon occur only for the catch years of 1998, 2000, 2002 and 2004, as the Fraser River stocks spawn only in odd numbered years. The estimated abundances of juvenile Chinook, coho, chum, pink and sockeye all showed significant increases over estimates from 2002. Sockeye abundances exceeded the abundances in 2000 and pink salmon approached the levels observed in 2000. We captured 2439 juvenile sockeye salmon in the July 2004 survey, the highest catch since 1997, and 4699 juvenile pink salmon, also the highest catch since the 1997 survey. The high juvenile pink salmon catches in the past few surveys are a reflection of the historic high escapements of adult pink salmon into the Fraser River (Beamish 2002).

The average fork lengths (Table 3) for juvenile coho, chum and pink salmon collected in 2004 were significantly larger than observed in 2002, whereas juvenile Chinook and sockeye were significantly smaller (136 mm vs. 120 mm for Chinook, and 124 mm vs. 108 mm for sockeye). Mean fork length for juvenile sockeye salmon from the 2004 survey was the lowest recorded since 1998. The average condition factors for the 5 species of Pacific salmon are also shown in Table 3. No clear pattern emerges from this data, with condition factor “K” in 2004 higher for coho, very slightly higher for pink and sockeye salmon, but lower for Chinook and chum.

Gut content analyses for juvenile Pacific salmon are shown in Table 4 and Figures 2-6. The percentage of empty stomachs (defined as < 0.1 cc) showed no clear trend for Chinook or coho salmon in 2004, with similar values as observed from 2000-2002. However, the combined 2000-2004 mean values were lower than the mean levels observed from 1997-1999 (for Chinook: 32.0 ± 12.12 vs. 13.0 ± 0.82, P = 0.0015; for coho: 10.0 ± 2.65 vs. 6.25 ± 2.06, P = .09). Juvenile chum salmon had a slightly higher percentage of empty stomachs in 2004 as compared to 2002, although the 2002-2004 average was again much higher than the levels observed in 1997-1999 (46.0 ± 23.26 vs. 13.3 ± 7.93, P = 0.04). Juvenile sockeye salmon consistently have had a high percentage of empty stomachs across all years of the survey, with the 2000-2004 average lower than the 1997-1999 average (51.0 ± 24.76 vs. 29.3 ± 7.76, P = 0.12). Due to the odd-year spawning cycle, a similar analysis was not possible for pink salmon, as there is only a single value from the 1997-1999 period. However, the percentage of empty stomachs in pink salmon from the 2004 survey was approximately equal to the 2000-2002 average and considerably lower than the 53% observed in 1997.

The mean volume of prey in the guts of Chinook salmon (Table 4) was slightly higher than recorded for the 2002 survey, but not quite to the average volumes observed in 2000 or 2001. The regime averages (0.64 ± 0.203 vs. 0.90 ± 0.054 cc) were not significantly different (P = 0.12). For juvenile coho salmon, the average volume of prey in the stomachs in 2004 was the highest level recorded over the period of this study. The 2000-2004 average (1.59 ± 0.284 cc) is significantly higher than that observed from 1997-1999 (0.74 ± 0.422 cc) (P = 0.02). Volumes of prey in the stomachs of juvenile chum salmon exhibited much the same pattern as observed for juvenile Chinook: slightly higher than the 2002 value, but not approaching the levels observed in 2000 or 2001. The average volume from 2000-2004 (0.44 ± 0.093 cc) was significantly higher than the average observed for 1997-1999 (0.20 ± 0.069 cc) (P = 0.015). Again, such analysis was not possible for juvenile pink salmon. However, as with the percentage of empty stomachs, the average prey volume for juvenile pink salmon in 2004 was approximately the 2000-2004 average. Except for Chinook salmon, the average diet volumes in the 2000-2004 surveys were roughly 2-fold higher than the values obtained from the 1997-1999 surveys.

The percentages of gut contents for prey categories are shown in Figures 2-6. For juvenile Chinook, coho, pink and sockeye salmon, there are five categories, whereas juvenile chum salmon have an additional one. The Decapods category consists primarily of crab (mostly zoea and megalops) and shrimp (mostly zoea). The Teleost category consists mostly of Pacific herring, along with significant contributions from juvenile sandlance, juvenile rockfish, juvenile hake and larval flatfish. The Amphipod category consists mostly of hyperids, along with some gammarids. The ‘Other’ category includes pretty much everything else: barnacle nauplii, calanoid copepods, chaetognaths, ctenophores, harpacticoid copepods, insects, jellyfish, molluscs, juvenile octopi, oikopleura, ostracods, polychaetes, plant material, squid, unknown items and material too digested for accurate identification. Ctenophores were recorded as a separate category in the diet of juvenile chum salmon, as ctenophores (along with small numbers of jellyfish) can represent a substantial proportion of the ‘Other’ category in this species.

For the most part, there are no particular patterns discernible across years or regimes. All five species of juvenile Pacific salmon had large increases in the decapod component of their diet in 2004. Juvenile chinook salmon (Figure 2) demonstrate a steady and significant decline in percent of teleosts in their diets over the 7 years of study, replaced generally by decapods and, to a lesser extent, euphausiids and amphipods. Juvenile coho salmon, on the other hand, show remarkably regular patterns on dietary composition from 1997 through to 2004 (Figure 3), with decapods and teleosts consistently making up a large percentage of the diet (> 75%). As noted earlier, and particularly for juvenile chum salmon, there was a very large increase in the frequency of decapods in juvenile chum salmon stomachs in 2004, such that they replaced the ‘other’ category as the dominant food group (Figure 4). The frequency of ctenophores found in chum stomachs continued to decline from the levels seen from 1999-2001. Pink salmon exhibit alternate cycles of dominance, so only stomach data from surveys in 1998, 2000, 2002, and 2004 are discussed. As with chum (and, to a lesser extent, Chinook and coho), the prevalence of decapods in the diet of juvenile pink salmon was exceptionally high in 2004, double that seen in previous surveys (Figure 5). Amphipods and Other make up the majority of the remaining diet items. Juvenile sockeye salmon diets (Figure 6) also showed an increase in decapod prevalence in the 2004 survey, but not to the levels of dominance observed for chum and pink salmon. Teleosts, as in 2002, were also a very dominant diet item for juvenile sockeye salmon. This generally has not been the case for sockeye over years, when amphipods made up a significant proportion of the diet. Euphausiids were at the lowest level in the sockeye diet since 1997.

The temperature data for the Nanoose site, which is approximately in the middle of the Strait of Georgia, show the cooling trend of annual surface temperatures that becomes clear beginning in 2000 (Figure 7). Sea surface temperatures from 1999 to 2001 are much lower than in the average seen throughout the 1990s, but are still higher than in the regime prior to 1977. Similar trends exist for the 10m temperatures but with reduced variability. Interestingly, the bottom temperatures remained warm, continuing the warming trend since the 1960s.

Discussion

The estimates of abundance for all juveniles of all five species Pacific salmon in July of 2004 were higher than seen in 2002 and, in most cases, approached the levels estimated in 2000 and 2001. The single exception to this observation was coho salmon, where abundances in 2004 (~ 4 million) were approximately 25% higher than observed in 2002, but did not come close to the levels observed in 2000 or 2001 (~ 7 million, average). The reasons for the response of coho are unclear. The releases of coho (and Chinook) salmon from hatcheries in 2004 does not appear to be significantly different from the previous 10 years, implying that the differences in abundance are not related to changes in the numbers of fish of hatchery origin.

Coho, chum and pink salmon had larger average sizes than observed in 2002, whereas average fork lengths for both Chinook and sockeye were amongst the lowest observed in the time series. For Chinook salmon at least, the lower average fork length can be partially explained by the contribution of a large cluster of small fish (in the 80-100 mm range). In previous years, the contribution of this group was much less. Thus, the observed decrease in average size of Chinook in 2004 may be partially explained by a larger proportion of smaller fish.

For sockeye salmon, the low average size seen in 2004 may be the result of interactions with pink salmon populations, as the average fork length in strong juvenile pink years (1998, 2000, 2002 and 2004) are consistently lower than values seen the previous non-pink years. This hypothesis is supported somewhat by comparison of the diet analysis, wherein the primary diet choices for juvenile pink and sockeye salmon are very similar (i.e., decapods, amphipods and others). Juvenile sockeye salmon have, particularly in the past two summer surveys, increased their consumption of teleosts, perhaps in response to this inter-species competition for food resources.

Stomach volumes (i.e., volume of prey/food in the stomach) generally increased slightly for all species, except for juvenile sockeye which showed a significant reduction from the previous three surveys. The percentage of empty stomachs (i.e., less than 0.1 cc) for all five species of Pacific salmon in the 2004 survey was similar to that seen in the 2000-2002 surveys. This parameter appears to be one of the better regime indicators, with the average percentage of empty stomachs generally much higher in the pre-2000 regime than in the current one. Overall, the increased abundances, increased overall size and increased stomach volumes all suggest that the productivity of the Strait of Georgia was higher in 2004, perhaps approaching the levels observed in 2000 and 2001. It is unfortunate we were unable to conduct parallel euphausiid surveys as we did in 2000, to corroborate the increased productivity state. The complexity of the Strait of Georgia ecosystem is reflected both in the variability across years and the diverse impacts on juvenile salmonids.

The dietary analysis, as mentioned earlier, not only offers insight into the prey items over time, but also can provide evidence of inter-species competition. King and Beamish (2000) noted such a diet overlap between juvenile chum and coho salmon and the authors suggested that a partial explanation for the decline in coho ocean survival was due to competition from elevated juvenile chum populations. Clearly, such an interpretation may also be applied to juvenile pink and sockeye marine survival rates. The trend for increases in percentage of teleosts in the diet of juvenile sockeye is somewhat mirrored by the fairly steady decline in consumption of teleosts by juvenile chinook salmon over the time course of the study, which may indicate yet another inter-species dietary competition.

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Table 1. Dates of summer surveys for juvenile Pacific salmon in the Strait of Georgia.

Year	Dates	Number of sets
1997	June 17-20, July 06-11	69
1998	June 30 - July 09	95
1999	June 30 – July 08	98
2000	July 11– 20	85
2001	July 07 – 15	89
2002	July 02 – 11	93
2004	July 04 - 13	105

Table 2. Abundance of ocean age 0 Pacific salmon in the Strait of Georgia in June/July from 1997 to 2004. Pink salmon juveniles only occur in the Strait of Georgia on even years. Depth strata used in the abundance estimate are shown in parentheses. The lower and upper interval is ± 2 standard deviations. Note that there was no survey conducted in 2003.

	Abundance	Lower Interval – Upper Interval
CHINOOK (0-60 metres)		
1997	4,740,000	1,810,000 – 7,660,000
1998	2,420,000	1,200,000 – 3,650,000
1999	4,410,000	3,050,000 – 5,760,000
2000	7,940,000	3,160,000 – 12,710,000
2001	5,889,000	4,120,000 – 7,658,000
2002	3,906,000	1,800,000 – 4,200,000
2004	5,686,000	4,486,000 – 6,886,000
COHO (0-45 metres)		
1997	1,660,000	350,000 – 2,970,000
1998	2,430,000	1,510,000 – 3,350,000
1999	3,400,000	2,220,000 – 4,570,000
2000	11,220,000	6,600,000 – 15,840,000
2001	9,460,000	6,240,000 – 12,680,000
2002	3,002,000	2,130,000 – 3,870,000
2004	3,996,000	2,836,000 – 5,156,000
CHUM (0-30 metres)		
1997	1,980,000	800,000 – 3,150,000
1998	11,000,000	3,530,000 – 18,470,000
1999	7,280,000	1,300,000 – 14,400,000
2000	27,000,000	7,330,000 – 46,660,000

2001	14,236,000	9,001,000 – 19,471,000
2002	1,447,000	500,000 – 3,500,000
2004	15,500,000	8,636,000 – 22,364,000
PINK (0-30 metres)		
1998	3,700,000	1,626,000 – 5,774,000
2000	7,400,000	3,184,000 – 11,616,000
2002	3,590, 000	2,211,000 – 4,969,000
2004	7,009,000	2,504,000 – 11,667,000
SOCKEYE (0-30 metres)		
1997	7,340,000	1,721,000 – 12,959,000
1998	720,000	44,000 – 1,396,000
1999	1,330,000	520,000 – 2,140,000
2000	520,000	103,000 – 937,000
2001	2,250,000	1,548,000 – 2,952,000
2002	298,000	197,300 – 400,000
2004	3,552,000	358,000 – 6,746,000

Table 3. Average lengths (mm) and condition factor [(weight/length^3)*100,000] for ocean age 0 coho, Chinook, chum, pink and sockeye salmon captured in June/July surveys from 1997 to 2004 (no survey conducted in 2003).

	Fork Length			Condition Factor		
Species	Average (mm)	SD	Sample (N)	Average	SD	Sample (N)
CHINOOK						
1997	141	40.7	680	1.19	0.19	680
1998	133	35.0	694	1.17	0.16	695
1999	146	28.3	890	1.19	0.43	890
2000	143	37.2	1780	1.19	0.15	722
2001	145	29.8	2205	1.23	0.11	288
2002	136	28.8	1984	1.22	0.11	939
2004	120	37.0	3073	1.18	0.14	725
COHO						
1997	172	23.6	126	1.15	.15	126
1998	177	23.4	825	1.19	.11	825
1999	172	20.2	1332	1.15	.10	1332
2000	200	24.0	2961	1.22	.13	2174
2001	185	21.2	2959	1.22	.10	962
2002	169	22.7	1887	1.20	.11	1132
2004	179	28.2	2257	1.23	.13	957
CHUM						
1997	134	26.6	290	0.94	0.11	290
1998	124	15.3	418	1.00	0.10	418
1999	116	20.2	309	0.98	0.12	309
2000	128	18.5	2159	1.00	0.09	314
2001	130	17.5	2193	1.05	0.09	220
2002	116	34.5	1067	0.99	0.10	280
2004	123	25.1	2915	0.95	0.09	428
PINK						
1998	119	13.6	1432	0.96	0.11	340
2000	118	12.6	1985	0.92	0.09	250
2002	111	15.4	2188	0.94	0.09	337
2004	116	15.5	1465	0.95	0.10	254
SOCKEYE						
1997	115	10.7	1580	0.95	0.14	151
1998	86	17.8	371	1.02	0.11	167
1999	120	17.5	640	0.95	0.13	173
2000	117	17.3	464	0.96	0.12	205
2001	133	12.9	858	1.01	0.09	143
2002	124	15.0	248	0.98	0.08	144
2004	108	16.1	609	0.99	0.12	116

Table 4. Results of gut examination in ocean age 0 Pacific salmon from June/July surveys 1997-2004, including total number examined, percentage that were empty (<0.1 cc.) and the average volume of contents (includes fish with empty gut contents) (no survey conducted in 2003).

	1997	1998	1999	2000	2001	2002	2004
CHINOOK							
Number	631	677	930	772	667	821	804
% empty	30%	45%	21%	12%	13%	14%	13%
Avg volume (cc)	0.87	0.54	0.50	0.96	0.91	0.83	0.89
COHO							
Number	272	573	776	813	826	668	630
% empty	11%	12%	7%	5%	4%	8%	8%
Avg volume (cc)	0.98	0.98	0.58	1.40	1.51	1.43	2.00
CHUM							
Number	191	408	379	460	412	281	561
Empty	71%	42%	25%	11%	4%	15%	23%
Avg volume (cc)	0.16	0.28	0.16	0.52	0.51	0.34	0.37
PINK							
Number		428		327		366	308
Empty		53%		11.6		32%	19%
Avg volume (cc)		0.14		0.43		0.30	0.33
SOCKEYE							
Number	206	142	261	193	308	143	171
Empty	42%	79%	32%	32%	23%	23%	39%
Avg volume (cc)	0.25	0.05	0.17	0.36	0.40	0.32	0.16

Table 5. Water temperatures (ºC) for the month of July from 1997 to 2004 at surface, 10m, 30m, and 50m in the Strait of Georgia. The "N" represents the numbers of days in July that temperature profiles were obtained. Data from Nanoose Bay database, Nanaimo, B.C.

DEPTH	1996	1997	1998	1999	2000	2001	2002	2003
Surface	16.0	17.4	17.8	15.8	14.8	18.2	18.4	17.9
10 M	12.3	12.2	13.6	13.1	12.6	13.2	14.7	13.0
30 M	9.5	9.8	10.7	10.2	9.9	9.9	10.4	10.0
50 M	8.9	9.3	9.7	9.4	9.3	9.3	9.5	9.2
N	6	6	7	3	5	5	2	3

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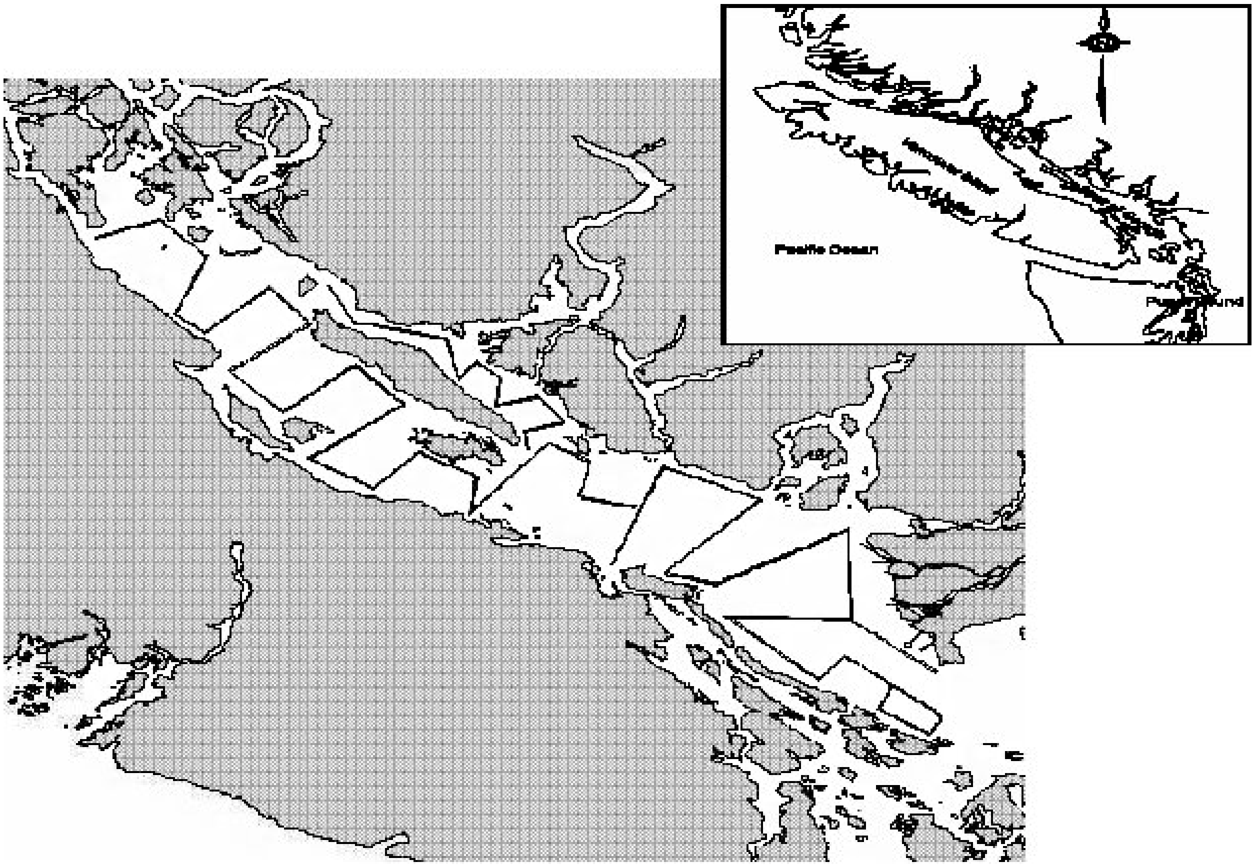


Figure 1.

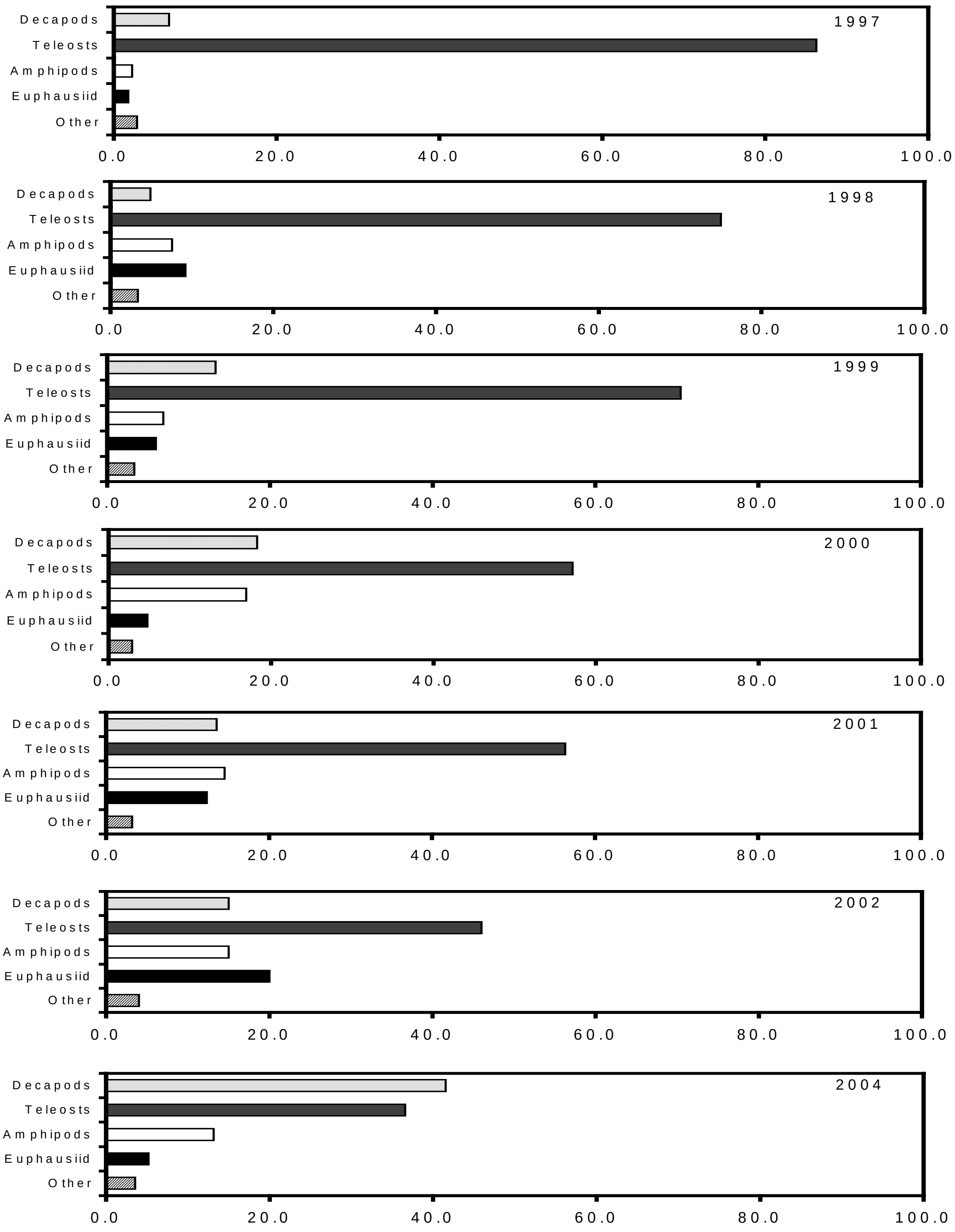


Figure 2. Chinook

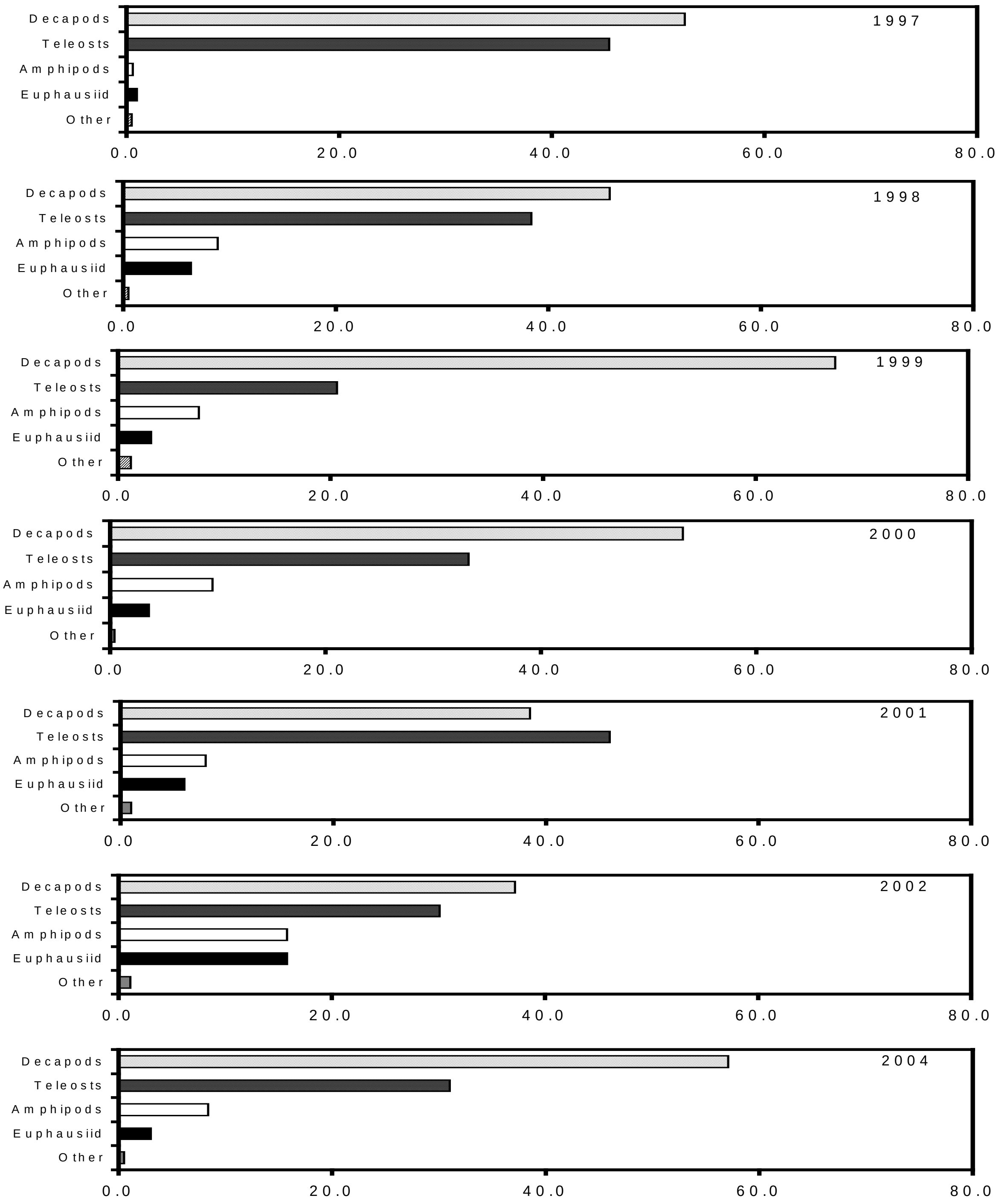


Figure 3. Coho diets

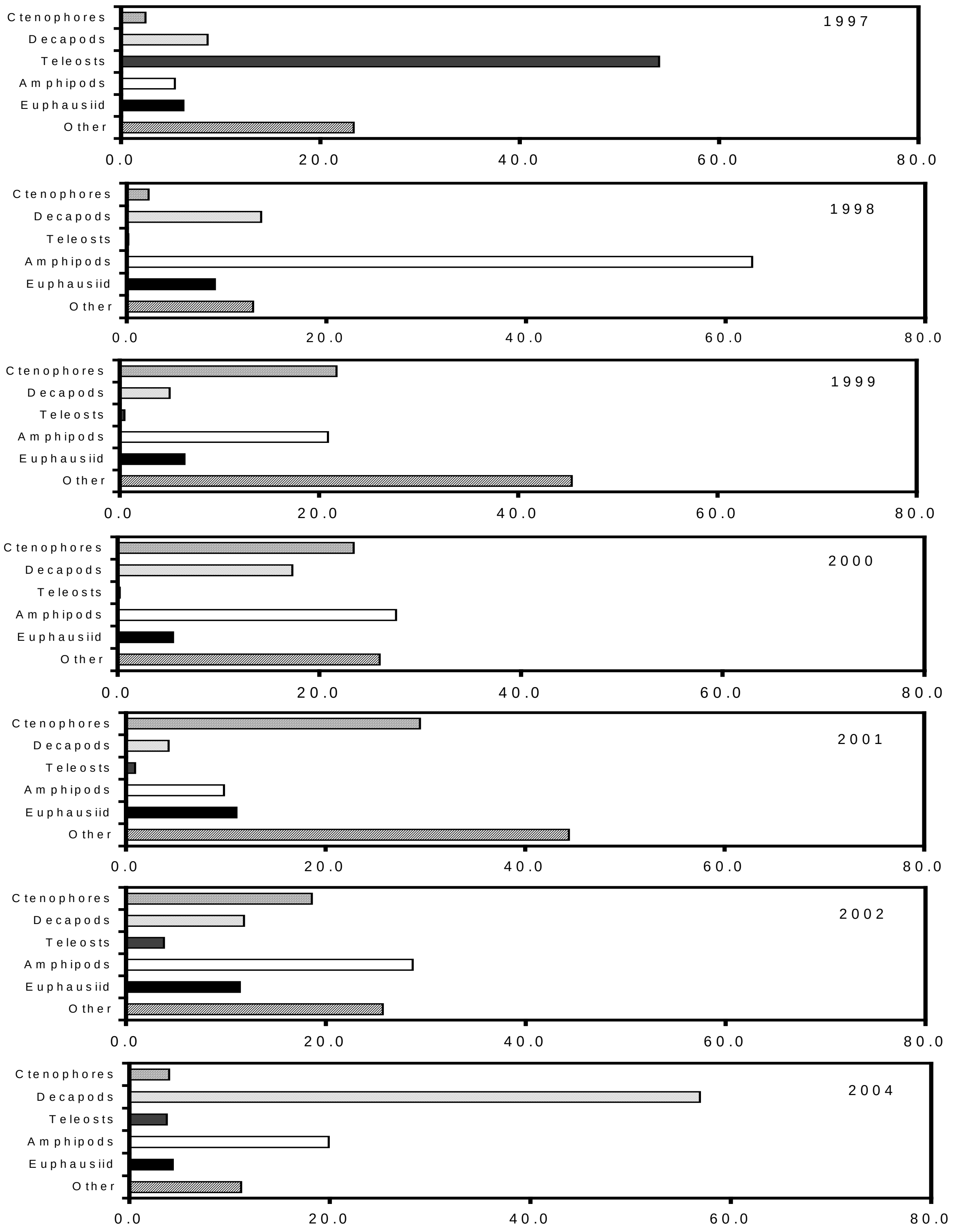


Figure 4. Chum diets

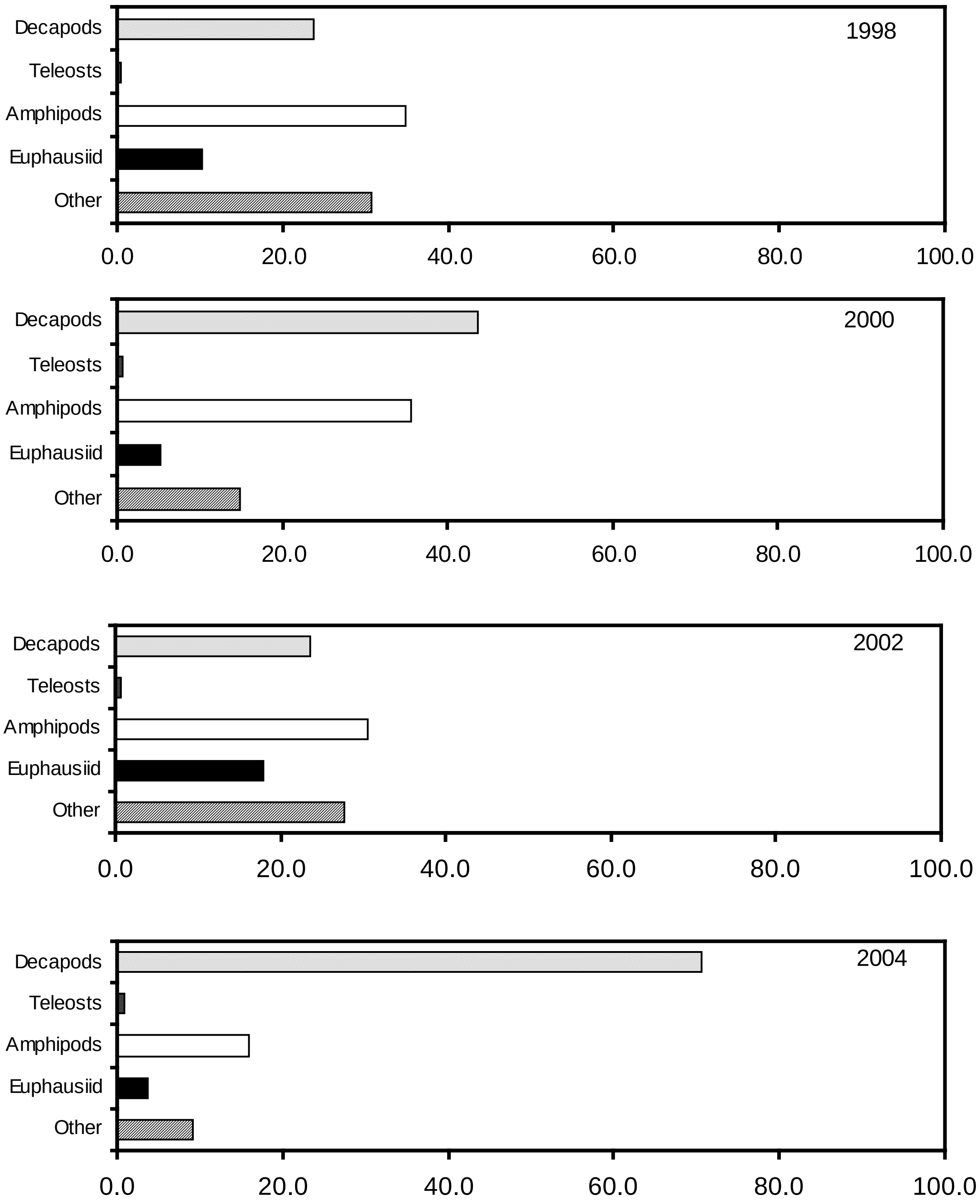


Figure 5. Pink Diets

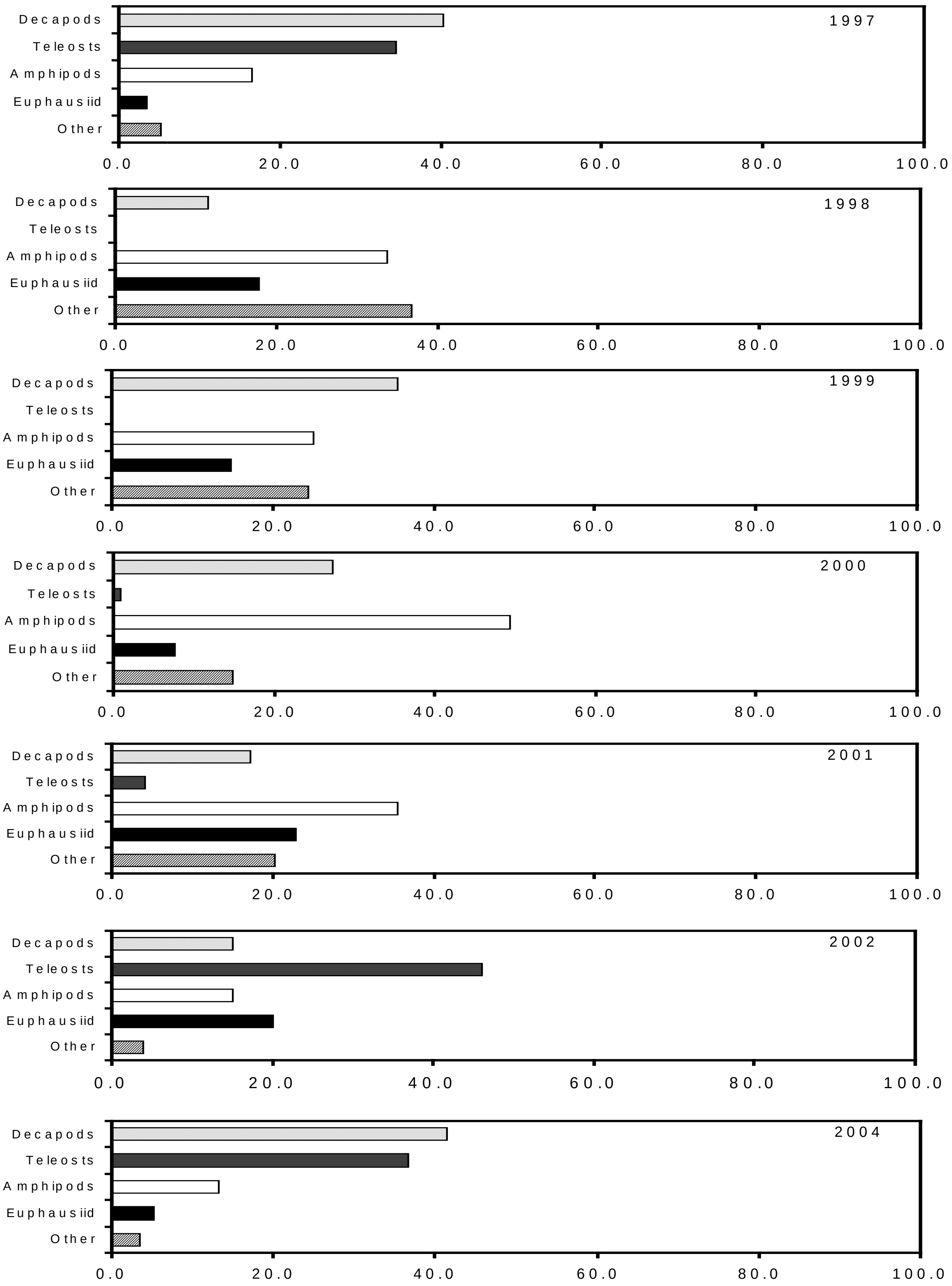
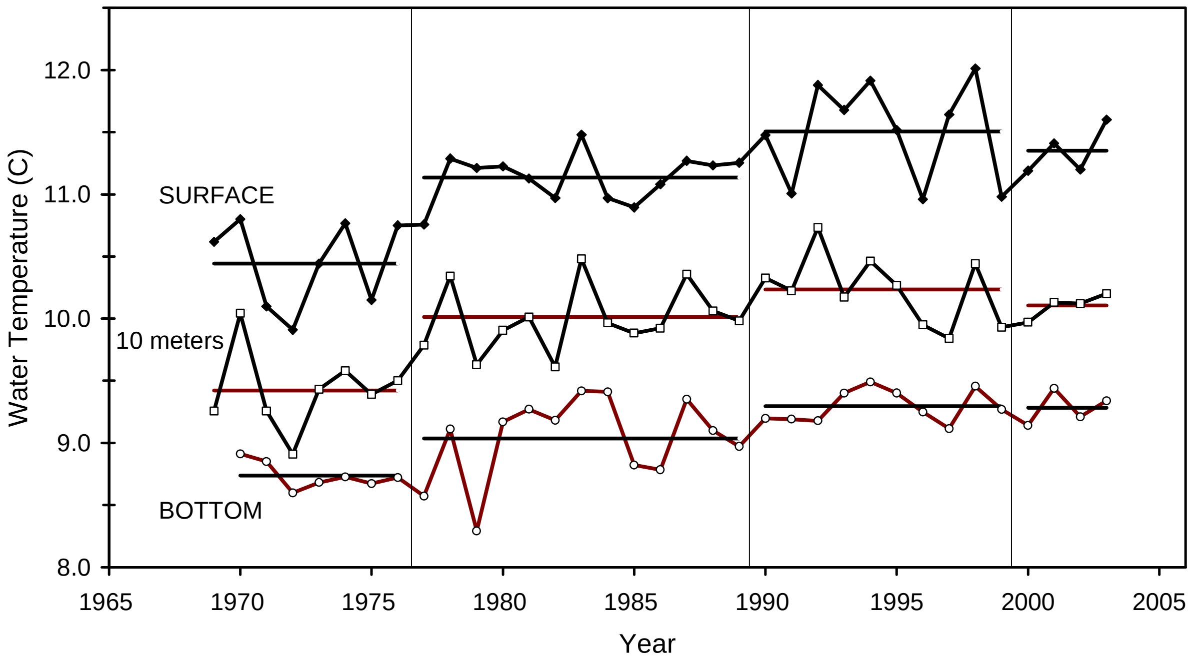


Figure 6. Sockeye diets



SURFACE
10 meters
BOTTOM
Water Temperature (C)
12.0
11.0
10.0
9.0
8.0
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year

Figure 7.