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Results of the July survey in the Strait of Georgia, British Columbia, indicate that 2002 may be a year of cool temperatures and reduced productivity for juvenile Pacific salmon

by

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Abstract

The regime shift in mid-1998 first affected the productivity of Pacific salmon in the Strait of Georgia in 2000. The increased productivity resulted in an increase in abundance of juvenile salmon and an increase in average fork length. A corresponding in prey abundance was reflected in fewer empty stomachs and greater volumes of food in individual stomachs. In 2002, juvenile salmon abundances declined and individual sizes were smaller than in 2000 or 2001, and were similar to pre-2000 lengths. The average volumes of food in the stomachs were lower for coho and chum salmon than observed in 2000 or 2001 but larger than observed prior to 2000. The volumes of prey in stomachs of pink and chinook remained high. The percentages of empty stomachs were unchanged for chinook salmon, but greater for coho, chum and pink, when compared to 2000 and 2001. Water temperatures in July of 2002 were similar to those observed in July of 2001. The reduced abundance, smaller size and reduced stomach contents is interpreted to represent climate-related variability within the new regime.

Introduction

The mid- to late 1990s were characterized by marine survival rates for coho salmon along the coasts of British Columbia, Washington and Oregon of less than 2%. This compares to rates that exceeded 10% in most years of the 1970s and 1980s (Beamish et al. 1999, 2000a). The mid- to late 1990s were also a period in which virtual all juvenile coho salmon left the Strait of Georgia in their first marine year and remained on the outside coast of Vancouver Island until the late summer of their second marine year. This behaviour was unprecedented in historical catch records. In 2000, there was an abrupt increase in productivity in the Strait of Georgia (Beamish et al. 2000b, Beamish et al. 2001a) which continued through 2001 (Beamish et al., 2001b). This increase in productivity was observed as significant increases both in euphausiid biomass and mean individual size (Beamish et al. 2001a, 2002) as well as significant increases in early marine survival of juvenile coho, chinook and chum salmon. Mean individual size and fitness also significantly improved for all three species of salmon (Beamish et al. 2001a,b). Juvenile coho salmon again left the Strait of Georgia in 2000, but substantial numbers returned in the early spring of 2001, a return to the behaviour of the 1980s and earlier. In this report, we summarize our data from the July 2002 survey and show that interannual variability within this new regime probably will be characterized by cooler temperatures and reduced productivity for juvenile Pacific salmon entering the Strait of Georgia in 2002.

Methods

The survey design and effort was similar to previous years (Beamish et al. 2000b,c). However, the survey was made using the Viking Storm, a 104-foot trawler, instead of the W.E. Ricker as in previous surveys. Set locations, depths, gear, and trawl speeds were all as previously reported. Abundance estimates using swept volumes were calculated using the procedures described in Beamish et al. (2000c). All fork lengths were measured to the nearest (mm), and all weights to the nearest (g). Fitness, or condition factor, was calculated as (wt/fork length^3) X 100,000. Gut contents were examined within 1 hour of capture, with volume estimates to the nearest 0.1 cc. Species composition was determined, as described in Beamish et al. (2001b), by the same experienced taxonomist as on earlier surveys. Strait of Georgia water temperatures were obtained from the sea temperature database constructed by the Nanoose Naval Base, located just north of Nanaimo, B.C., Canada. Daily average flow rates for the Fraser River at Hope (Stn # 08MF005) were obtained from Environment Canada. Statistical analyses were performed using ANOVA and Student Newman Keuls multiple range test. Significance was accepted at the 0.05 level

Results

Abundance estimates of juvenile coho, chinook and chum salmon were lower than estimates from 2000 or 2001 (Table 1). Catches of pink salmon (n=2755) were slightly higher than in 2000 (n=2433), a response to a the historical high in escapement to the Fraser River in 2001 (Beamish 2002). Juvenile sockeye salmon catches (n=233) were lower than in 2000 (n=309) and much lower than in 2001 (n=968).

The mean individual fork lengths of juvenile coho, chinook and chum salmon were significantly lower than in the previous two years (ANOVA, $P < 0.05$)(Table 2). The mean fork length of juvenile coho salmon was the lowest recorded since our surveys began in 1997. The average condition of juvenile coho and chinook salmon was, however, not significantly different than that observed over the previous two years. The condition of juvenile chum salmon was significantly lower than that observed in 2001, but not from the long-term average (Table 2). The condition of juvenile pink salmon was 0.94, slightly higher than in 2000 (not estimated for 1999 or 2001, as catches in these non-cycle years were minimal).

We recorded five categories of gut contents for juvenile coho and chinook salmon, and six for juvenile chum salmon. As in previous years, the decapod category consisted primarily of crab zoea and megalops, and teleosts were mostly Pacific herring, along with sandlance, juvenile rockfish and juvenile hake. The amphipod category consisted mostly of hyperids, along with some gammarids. The 'other' category includes barnacle nauplii, calanoid copepods, chaetognaths, ctenophores, harpacticoid copepods, insects, jellyfish, mollusc, octopus, oikopleura, ostracod, polychaete, plant material, squid, unknown items and material too digested for accurate identification. Ctenophores are recorded as a separate category in the diet of juvenile chum salmon, as ctenophores (along with small numbers of jellyfish) represent a substantial proportion of the 'other' category in this species.

The mean volume of prey in the guts of coho salmon (n=668) (Table 3) was lower than recorded for the July 2001 survey, but higher than observed from 1997 to 1999. The number of empty stomachs (empty or volume less than 0.1 cc) was 55 of 668, or 8.2%, which was double the 2001 value and similar to values prior to 2000. For juvenile chinook and chum salmon, the mean stomach volumes were lower than observed for 2000 or 2001, but still greater than values observed in 1998 or 1999. The number of empty chinook stomachs was 115 out of 821 examined, or 14%. Juvenile chum salmon in 2002 also had a substantial increase in the number of empty stomachs: 43 of 281 examined, or 15%. Generally, the average stomach volumes for all three species were higher for 2000-2002 combined than for 1997-1999 combined. Similarly, the combined average percentage of empty stomachs from 2000-2002 were lower than the combined average for 1997-1999.

The percentages of gut contents for prey categories are shown in Figures 2-4. In general there were no substantial differences from previous years, although some specifics changed. Juvenile coho salmon, for example, preyed less on teleosts in 2002 whereas both amphipods and euphausiids were found in a greater proportion of the coho stomachs examined (N=621). For juvenile chinook salmon (N=706), the were no major changes in frequency of any prey group from previous surveys although euphausiids also appeared more frequently. There was a very large increase in the frequency of amphipods in juvenile chum salmon stomachs (N=237), such that they replaced the 'other' category as the dominant food group. Frequency of ctenophores found in chum stomachs also declined from levels seen in 2001 and 2000.

Pink stomachs were also examined for gut volumes of food and empty stomachs. However, because pink salmon exhibit alternate cycles of dominance, only stomach data from surveys in 1998 (N=427), 2000 (N=327), and 2002 (N=339) are discussed. The number of empty stomachs (including those with food volumes of < 0.1 cc) in 1998 was 229, or 53.6% of the total. In 2000, the number of empty stomachs observed was 12.5% (41 of 327), whereas in 2002, 31.6% or 107 of 339 were considered empty. The average volume (not including 'empty' stomachs) in 1998 was 0.29 cc ± 0.199, whereas average stomach volumes were significantly greater in 2000 (0.49 cc ± 0.326) and 2002 (0.44 cc ± 0.381).

The temperature data for the Nanoose site, which is approximately in the middle of the Strait of Georgia, show the cooling trend of annual temperatures that becomes clear beginning in 2000. 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 (Figure 5a). Similar trends exist for the 10m and bottom temperatures. Surface and 10 meter water temperatures in July of 2001 and 2002 are not different (Table 4) but are higher than observed in 1999 or 2000. Water temperatures at 30 or 50 meters show much less variability.

Flows from the Fraser River affect the surface salinity (and temperature) of the Strait of Georgia and the estuarine circulation that may result in nutrient-rich bottom water entering the Strait of Georgia from offshore through Juan de Fuca Strait. Beginning in 1997, there was a period of extreme fluctuations in annual discharge (Figure 5b). The amount of fluctuation is unprecedented, but a similar frequency of change was observed in the early 1970s, prior to the 1977 regime shift. Preliminary estimates combined with some "informed" guesses indicates that the average flow in 2002 will probably be higher than in the past two years.

Discussion

The estimates of abundance for juvenile coho, chinook and chum salmon were all significantly lower than expected, based on the results of the July surveys from 2000 and 2001**.** Preliminary data suggests that hatchery releases of juvenile salmon in 2002 were similar to previous levels (S. Lehmann, Habitat & Enhancement Branch, DFO, pers. comm.). Thus, the low catches do not appear to be the result of reduced releases. It is unfortunate that mechanical breakdowns prevented us from performing the 2002 survey on the W.E. Ricker, as on previous surveys. It is possible that differences in the ship performance, or some subtle changes in net efficiency, contributed to the low catches of juvenile salmon. However, the significant reduction in mean fork lengths of all juvenile salmon in an indication that there was a change in the Strait of Georgia ecosystem in 2002. If growth was significantly reduced in the summer of 2002, then the critical size and critical period theory (Beamish and Mahnken 2001) would predict decreases in overall abundance of returning adults resulting from increased mortality in the fall and winter of 2002. The slight decreases in overall stomach volumes observed in all juvenile salmon in the July survey of this year also supports the idea of a less productive ecosystem in the Strait of Georgia in 2002. While fitness, or condition factor, was lower in 2002 than in previous years, none of the changes were significant. However, the general trend is that the condition for coho, chinook and chum for the combined years from 2000, 2001 and 2002 is greater than for the combined 1997-1999 period.

Overall, the reduced abundances, reduced fork lengths and lower mean volume of stomach contents for juvenile coho, chinook and chum salmon suggest that the increased productivity which characterized the Strait of Georgia in the past two seasons did not occur in 2002. While the mechanisms for this apparent reduction in productivity could not be studied, there is no evidence for a regime shift after 1999. This reversal in trend appears to be part of the interannual variability that would occur within any given regime and it is possible that marine survival and resulting adult returns from this brood year may be less than the past two years.

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Table 1. Abundance of ocean age 0 coho, chinook, and chum salmon in the Strait of Georgia in June/July from 1997 to 2001. Depth strata used in the abundance estimate are shown in parentheses. The lower and upper interval is ± 2 standard deviations.

	Abundance	Lower Interval – Upper Interval
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
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
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	130,000 – 1,440,000
2000	27,000,000	7,330,000 – 46,660,000
2001	14,236,000	9,001,000 – 19,471,000
2002	1,447,000	2,500,000 – 3,500,000

Table 2. Average lengths (mm) and condition factor [(wt/l^3)*100,000] for ocean age 0 coho, chinook and chum salmon captured in June/July surveys from 1997 to 2002.

	Fork Length			Condition Factor		
Species	Average (mm)	SD	Sample (N)	Average	SD	Sample (N)
COHO						
1997	172	23.6	126	1.15	0.15	126
1998	177	23.4	825	1.19	0.11	825
1999	172	20.2	1332	1.15	0.10	1332
2000	200	24.0	2961	1.22	0.13	2174
2001	185	21.2	2959	1.22	0.10	962
2002	169	22.7	1887	1.20	0.11	1132
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
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
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

Table 3. Results of gut examination in ocean age 0 coho, chinook and chum salmon from June/July surveys 1997-2002, including total number examined, percentage that were empty (<0.1 cc.) and the average volume of contents (includes fish with empty gut contents).

	1997	1998	1999	2000	2001	2002
COHO						
Number	272	573	776	813	826	668
% empty	11%	12%	7%	5%	4%	8%
Avg volume (cc)	0.98	0.98	0.58	1.40	1.51	1.43
CHINOOK						
Number	631	677	930	772	667	821
% empty	30%	45%	21%	12%	13%	14%
Avg volume (cc)	0.87	0.54	0.50	0.96	0.91	0.83
CHUM						
Number	191	408	379	460	412	281
Empty	71%	42%	25%	11%	4%	15%
Avg volume (cc)	0.16	0.28	0.16	0.52	0.51	0.34

Table 4. Water temperatures (Co) for the month of July from 1997 to 2002 at surface, 10m, 30 , 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.

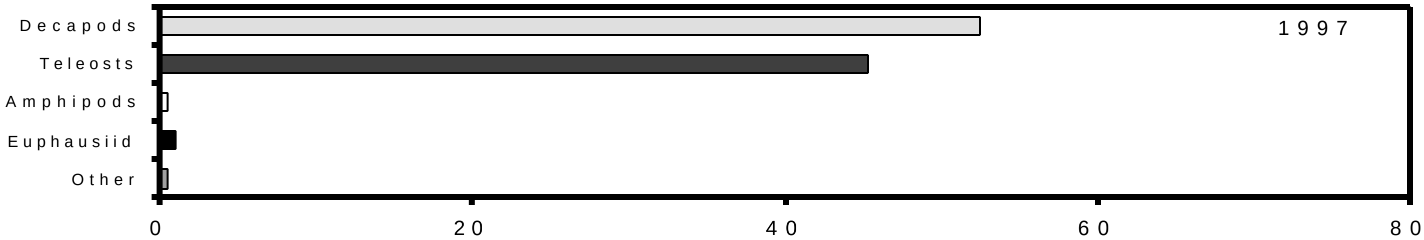
DEPTH	1996	1997	1998	1999	2000	2001	2002
Surface	16.0	17.4	17.8	15.8	14.8	18.2	18.0
10 M	12.3	12.2	13.6	13.1	12.6	13.2	13.7
30 M	9.5	9.8	10.7	10.2	9.9	9.9	10.2
50 M	8.9	9.3	9.7	9.4	9.3	9.3	9.3
N	6	6	7	3	5	5	3

Fig. 1. Percentage of gut contents for coho in five general categories. The percentages do not include empty guts.

Fig. 2. Percentage of gut contents for chinook in five general categories. The percentages do not include empty guts.

Fig. 3. Percentage of gut contents for chum in six general categories. The percentages do not include empty guts. Ctenophores for chum are listed separately from the "other" category, but it is probable that the "other" category for chum includes a large percentage of digested ctenophore remains.

Fig. 4. (A) Strait of Georgia water temperatures from 1970 to 2002 at surface (circles), 10 meters (squares) and 400 meters (triangles). Solid lines represent average annual temperatures during regimes 1970-1977, 1978-1988, 1989-1999 and 2000-2001. Data obtained from Nanoose Bay Naval Station database. (B) Annual Fraser Rivers flow rates at Hope (in m3/sec) for 1970 to 2002. Solid lines represent average annual flows during regimes 1970-1977, 1978-1988, 1989-1999 and 2000-2001. Date obtained from Environment Canada. Note that the annual flow for 2002 (solid circle) is an estimated value.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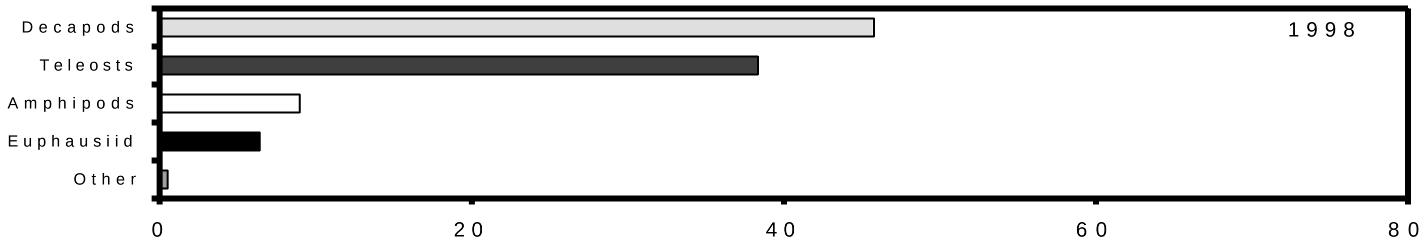
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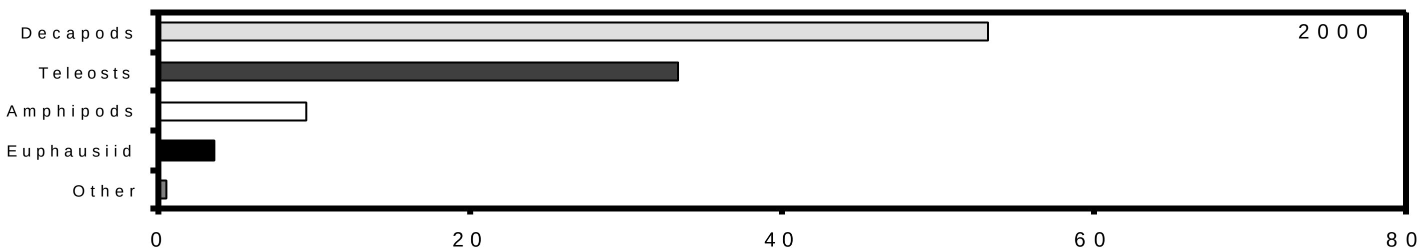
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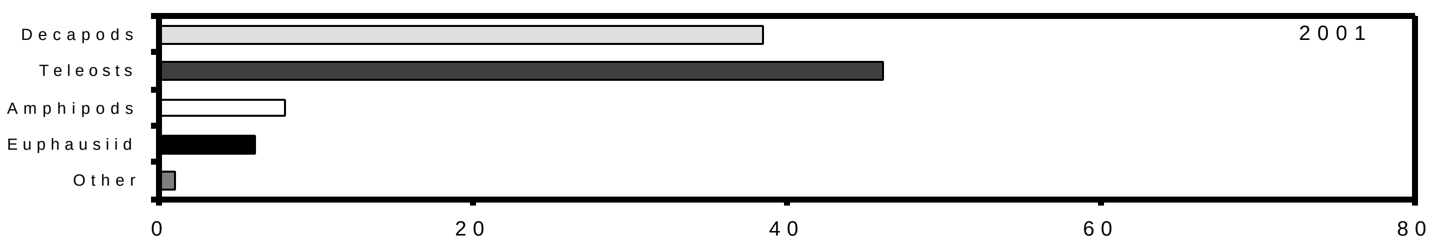
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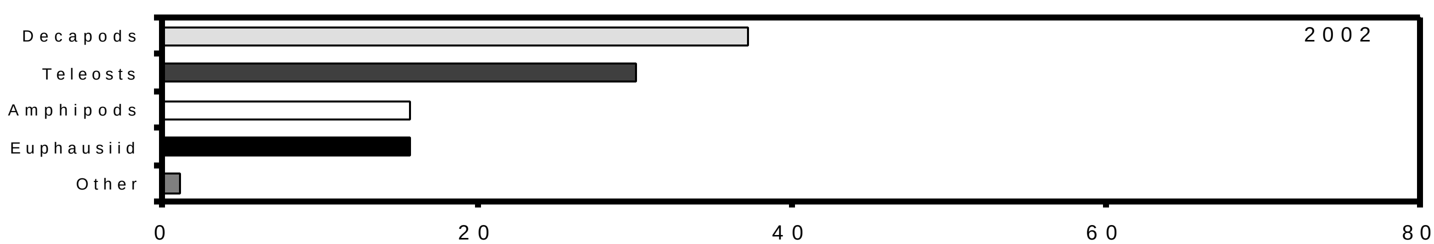
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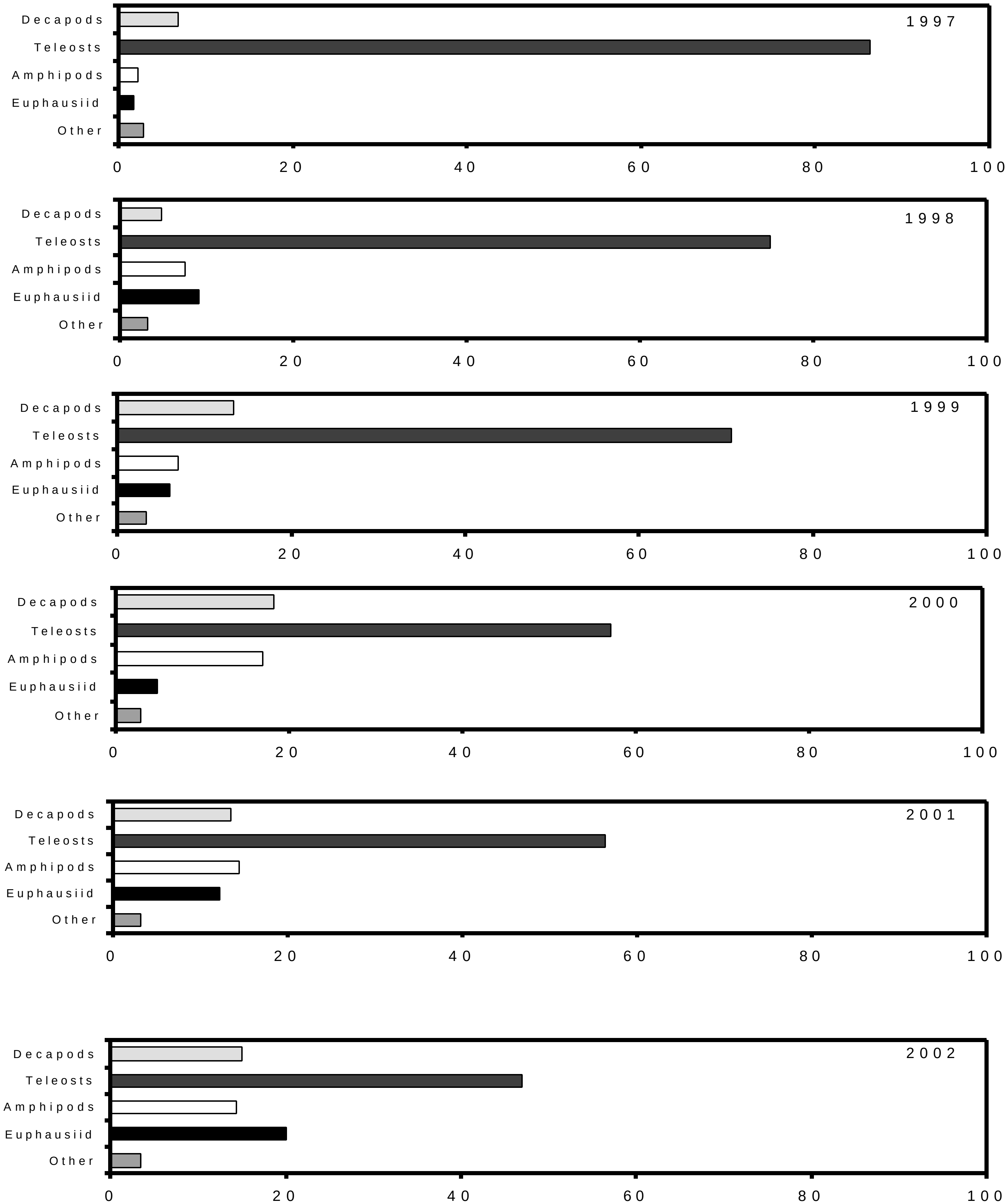
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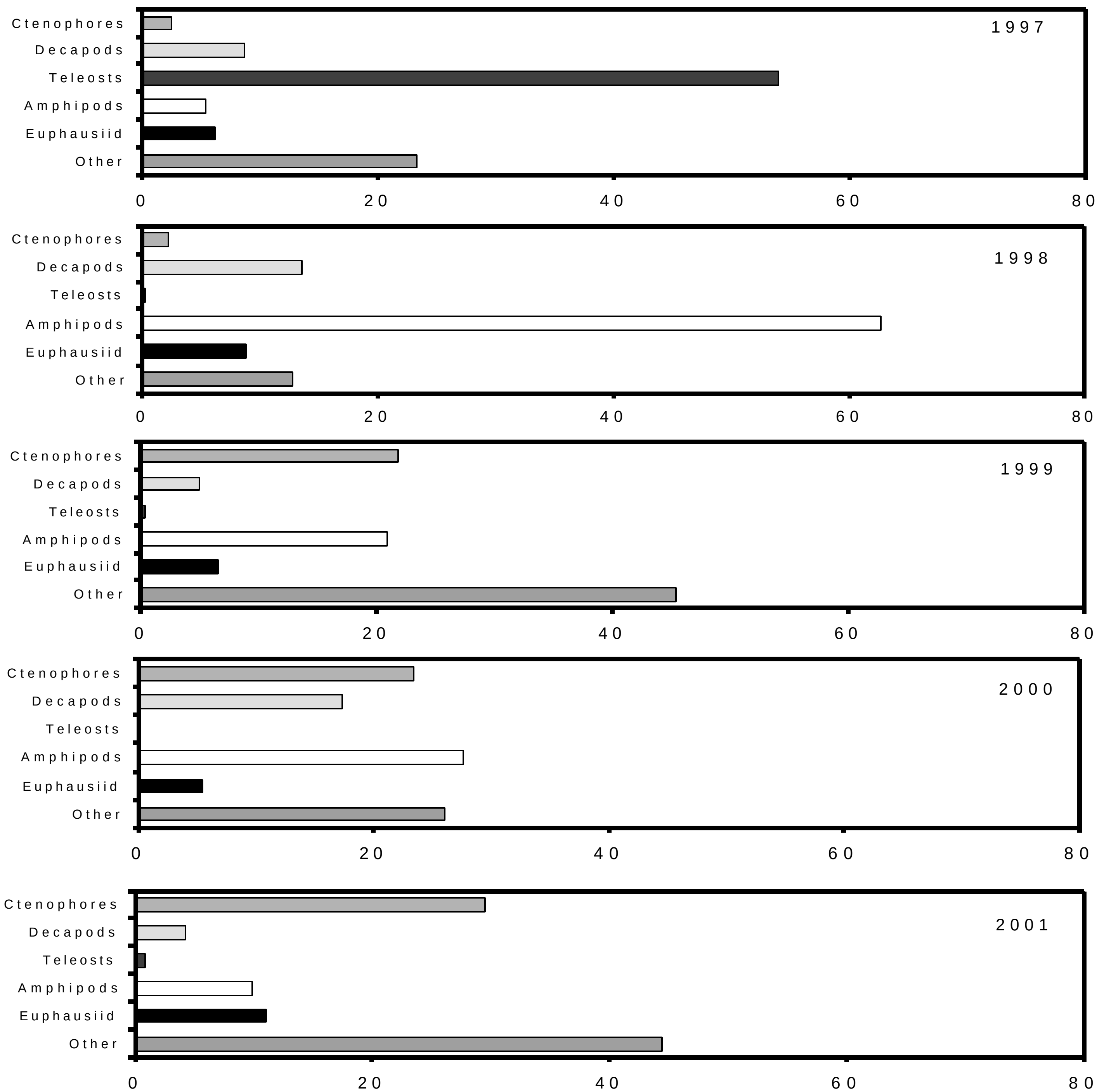
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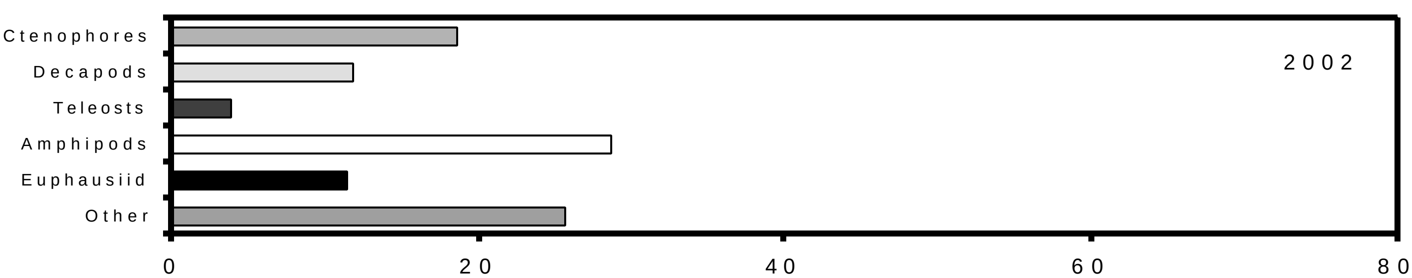
Fig. 4.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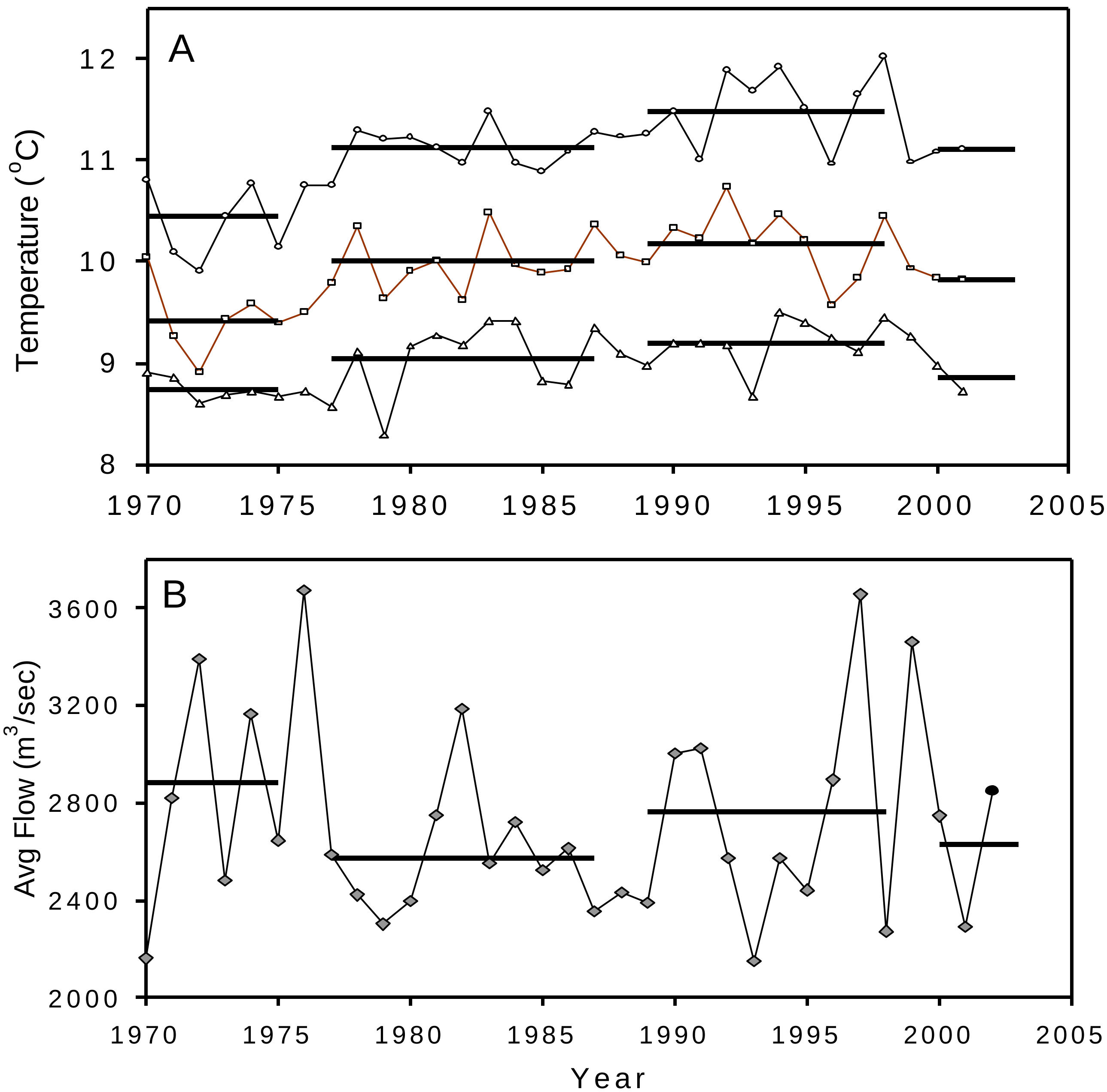
A
B
Temperature (°C)
Avg Flow (m3/sec)
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