NPAFC

Doc. 565

Rev.

Persistence of the improved productivity of 2000 in the Strait of Georgia, British Columbia, Canada, through to 2001

by

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Submitted to the

North Pacific Anadromous Fish Commission

by

CANADA

October 2001

This paper may be cited in the following format:
Beamish, R.J., C.M. Neville, R.M. Sweeting, and K.L. Poier. 2001. Persistence of the improved productivity of 2000 in the Strait of Georgia, British Columbia, Canada, through to 2001. (NPAFC Doc. 565). Fisheries and Oceans Canada, Science Branch – Pacific Region, Pacific Biological Station, Nanaimo, B.C., Canada   V9R 5K6. 19pp.

Abstract

In 2000 there was an abrupt increase in the productivity of the Strait of Georgia. The change was associated with a large-scale change in the climate and ocean environment around the subarctic Pacific in 1998. Our studies in 2001 indicate that the improved productivity has continued. In 2001, the abundance of ocean age 0 coho, chinook, and chum salmon remained high relative to the period from 1997 to 1999, but slightly lower than in 2000. Individual size and fitness also remained high. The increased growth for coho salmon in 2000 appears to be related to improved marine survival in 2001. The composition of the diets of coho, chinook, and chum in 2001 changed only slightly from 2000. In both 2000 and 2001, there was a decrease in the number of empty stomachs compared to the earlier years and the average volume of daily gut contents in 2000 and 2001 was substantially larger than the average volume in 1997, 1998, and 1999. The increased growth and early marine survival in 2000 and 2001 appears to be directly related to the increases in gut volume rather than changes in diet composition. The persistence of the changes observed in 2000 through to 2001 indicated that the Strait of Georgia ecosystem probably is in a new, more productive regime that should continue on a decadal scale.

Introduction

In July, 2000, we observed a major increase in the productivity of the Strait of Georgia (Beamish et al. 2000a, 2001). There were large increases in the abundance of ocean age 0 coho, chinook, and chum salmon. Individual size and fitness was much larger than observed in 1997, 1998 and 1999. There also was a doubling of euphausiid biomass and an increase in the mean size of euphausiids (Beamish et al. 2001, Macauley et al. 2001). These changes occurred after a period of low marine survival of coho during the mid to late 1990s (Beamish et al. 2000b). Marine survival of coho declined from an average of 11.2% in the mid-1970s to less than 2% in the late 1990s. At the same time coho altered their behaviour such that virtually all juveniles left the Strait of Georgia in their first marine year and did not return in the spring and summer of their second marine year (Beamish et al. 1999). The change in behaviour was unprecedented in any catch record or in the memory of biologists and fishermen.

In this report, we summarize the results of our July, 2001 cruise and compare these results to 2000 to show that the changes observed in 2000 have persisted. Persistence of increased levels of production is evidence of a shift in the state of the Strait of Georgia ecosystem.

Methods

The survey design was similar to previous years (Beamish et al 2000a). The net used in all previous cruises was fished at a speed of approximately 5 knots, form 6 am to 6 pm. The method of estimating abundance using swept volumes was described in Beamish et al 2000c. All lengths are fork lengths measured to the nearest mm. Weights were determined using a balance that compensated for the movement of the ship.

In all surveys, we examined the gut contents of juvenile salmon within 1 hour of capture and most contents were examined within 30 minutes of capture. All contents that we report were examined by the same experienced taxonomist, in all surveys, in all years. Species composition was determined by the experienced taxonomist using 10x magnification when necessary. Examining contents immediately after capture allowed a large number of fish to be examined and also facilitated the recognition of prey species such as “jellies” and “fish remains” that are difficult to identify from preserved samples. Our approach provides a general categorization of prey items rather than a detailed accounting at the species level. We examined the contents from the portion of the gut, usually defined as the esophagus, cardiac stomach, and fundic stomach. The pyloric stomach of the gut was not sampled in ocean age 0 fish. The volume of gut contents was estimated visually. Standard volume measures were used to assist in the visual estimate and determinations were periodically measured volumetrically to monitor the accuracy of the visual estimates. Estimates were made to 0.1 cc by the same individual for all reported estimates.

Results

The abundances of age 0 coho, chum, and chinook salmon in the June/July survey were lower than observed in 2000, but were larger than observed in 1997, 1998, and 1999 (Table 1). The abundance estimate of 9,460,000 coho in 2001was larger than the combined estimates of 1997, 1998, and 1999. Catches of pink salmon in 2001 (n=44) were substantially less than in 2000 (n=2433) because 2001 was not a cycle year for juvenile pink in the Strait of Georgia. Larger numbers of juvenile sockeye were caught in 2001 (n=968) than in 2000 (n=309), however, we do not believe that the June/July survey is a measure of relative abundance among years as most juvenile sockeye leave the Strait of Georgia before July.

The mean individual size of coho was smaller than in 2000, but significantly larger than in 1997, 1998, or 1999 (t test, $p<0.05$) (Table 2). Chum salmon juveniles were larger than in 2000 as were chinook salmon juveniles (Table 2). The mean condition factor for chum and chinook was the highest in the 5-year time series. The condition factor for coho was slightly but not significantly lower (t test $P>0.05$) than in 2000.

We tested our ability to estimate gut content volumes visually using a series of simulated gut content volumes. The estimates in Figure 1 were made by the individual that made all estimates during the surveys. Estimates in the range of most gut volumes (0.1 cc to 0.8 cc) were considered to be close approximations (Fig. 1). Estimates of 1.0 cc and larger tended to underestimate the true volume.

We record five categories of gut contents in this report. Decapods were primarily crab zoea and megalops, and teleost were mostly herring. The "other" category included barnacles, calanoid copepods, chaetognaths, elione, ctenophore, harpacticoid copeods, insects, jellyfish, mollusc, octopus, oikopleura, ootracod, polychaete, squid, plant material, unknown items, and digested items. For chum salmon, we record ctenophores separately. The category of ctenophores is 98% or greater ctenophores. The remaining 2% or less are other "jellies."

During the 5 years of surveys, we examined the gut contents of 3260 coho in the June/July surveys. Coho diet in 2000 was similar to 2001 and to previous years with crab larva (decapods) and herring (teleost) being the major items (Fig. 2). The category teleost is used because not all fish remains can be identified at the species level. However, the contents that could be identified were 60% herring in the total sample for the 5 years. The remaining contents would be mostly unidentifiable remains that probably were herring and a few other species such as sand lance. In 2001, the diet contained a higher percentage of herring and a lower percentage of decapods than in 2000. All other categories including euphausiids were relatively minor items in the diet. In 2000 and 2001, there was a reduction in the number of guts that were empty, which we defined as containing less than 0.1 cc of contents. There also was an increase in average volume of contents of all guts examined in 2000 and 2001(including empty guts). In 2000 and 2001, the average volumes were similar and approximately double the average volume in 1999. This indicates that individual fish were able to find and capture prey more effectively after the regime shift, but they continued to consume the same prey in about the same amounts.

The gut contents of 3677 ocean age 0 chinook salmon in the Strait of Georgia from 1997 to 2001 (Fig. 3). The most common item in the diet was consistently fish remains which could be determined to be approximately 49% herring on average for the 5 years. In 2000 and 2001, the percentage of fish remains decreased slightly. In 2000 and 2001, there were major reductions in the percentage of empty stomachs compared to 1997, 1998, and 1999 (Table 3). The average volume of the guts more than doubled in 2000 and 2001 compared to 1998 and 1999 (Table 3).

In the 5 years of surveys, 1850 chum salmon were examined for gut contents. Ctenophores and amphipods have been the major prey species, except in 1997 when a large percentage of fish had empty guts, and the few that had contents contained a large percentage of herring (Fig. 4). The percentage of fish with empty guts dropped dramatically in 2000 and again in 2001. At the same time, the average volume of gut contents increased substantially in 2000 and 2001 compared to 1997, 1998, and 1999 (Table 2).

Discussion

The combined abundance of ocean age 0 coho, chum, and chinook in 2001 was less than 2000 but larger than in 1997, 1998, and 1999. The reduction in chum salmon abundance may be related in part to the reductions in hatchery production. In Canada, in 2001, 96.2

million chum were released into the Strait of Georgia from hatcheries, compared to 124.6 million in 2000. Beamish et al. (2001) estimated that the total number of hatchery and wild coho entering the Strait of Georgia, including coho produced in the United States, was 14.70 million in 1997, 14.98 million in 1998, 13.86 million in 1999, and 16.02 million in 2000. Our preliminary estimate for 2001 is 140 million. The abundances reported here for coho for June/July of 2000 and 2001, therefore, represent a large percentage of the total production, particularly as the estimates are minimal abundance estimates. It is clear from the abundance and production estimates that the early marine survival of coho increased dramatically in 2000 and 2001. Average lengths of coho, chum, and chinook remained large and fitness was high. The larger abundances, larger sizes, and good condition indicated that the improved ocean conditions of 2000 persisted through to 2001. There were some shifts in the individual diets of the three most abundant species (coho, chum, and chinook) but in general the percentages of prey groups were similar among years. However, there was a striking increase in gut volume. The volume of the contents of coho, chum, and chinook approximately doubled in 2000 and 2001. Thus, it appears that the improved growth and condition is related to an improved ability to capture prey. This is an indication that prey density increased. In 2000, we showed that euphausiid biomass more than doubled compared to 1999 (Macauley et al. 2001; Beamish et al 2001), indicating that other prey items probably increased in abundance at the same time. In Beamish et al. (2001) we used an ecopath model to show that the increased euphausiid biomass would drop the percentage of euphausiids consumed by prey from 75.5% to 37.8%. This lower percentage is clear evidence that more prey would be available for higher trophic levels. As the major species of euphausiid in the Strait of Georgia feeds on phytoplankton, primary production must also have increased in 2000 and in 2001.

We estimated gut volumes by visually comparing gut contents with standards. The same individual made all estimates and periodically checked estimates using graduated cylinders. In tests for the range of volumes of most gut contents our estimates were very close to the real values, however, we probably underestimated larger volumes. We used this approach because it is not possible to obtain accurate measures using balances, and volume measurements were time consuming. We also used this approach because we examined only the anterior portion of the gut where stomach contents were the least digested. Examining only this portion of the gut provided a better estimate of species composition but would only approximate the total volume of the gut contents. If we were to have approximate estimates of gut volumes, we preferred to examine more fish and have larger sample sizes by estimating gut volumes rather than measuring all of the volumes.

It is noteworthy that euphausiids were not a major prey item for any species in any year. The key items were crab larvae, herring, amphipods, and ctenophores for all species in all years. Even after euphausiid abundance more than doubled in 2000 and probably remained high in 2001, there was little change in the percentage of euphausiids in the diets compared to 1999 and previous years. In fact, for chum and chinook, the percentage of euphausiids actually declined in 2000 from 1999.

The improved early marine survival of coho in 2000 and the larger size appear to have contributed an increase in total marine survival. Early reports indicate that large numbers of ocean age 1+ coho are in the Strait of Georgia for the first time in 6 years. Individual sizes also appear to be large, and in some cases sport catch size records have been broken. However, the final estimate of total marine survival will not be available until 2002. We do have preliminary reports of exceptional pink salmon returns to the Fraser River in 2001. This would indicate that marine survival of juvenile pink salmon in 2000 was high.

The dramatic improvement in production in the Strait of Georgia in 2000 and 2001 was associated with a dramatic change in climate. In 1998, there was a rapid change from El Niño conditions to a La Naña state (McPhaden 1999). Associated with this change was a large-scale change in climate and ocean conditions that was characteristic of a regime shift (Beamish et al. 1998; McFarlane et al. 2000). The changes associated with the mid-1998 shift had the most noticeable impact in the Strait of Georgia in 2000 and now in 2001. The evidence of persistence of the improved conditions in 2001 and the association with a new regime is an indication that it is probable that these improved conditions will continue.

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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	6,238,000 – 12,682,291
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
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

Table 2. Average length and condition factor of ocean age 0 coho, chinook, and chum during June/July from 1997 to 2001.

	Length			Condition factor		
	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
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
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

Table 3. Number of guts examined and the percentage that were empty (<0.1) cc. The average volume of contents includes fish with empty gut contents.

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

LIST OF FIGURES

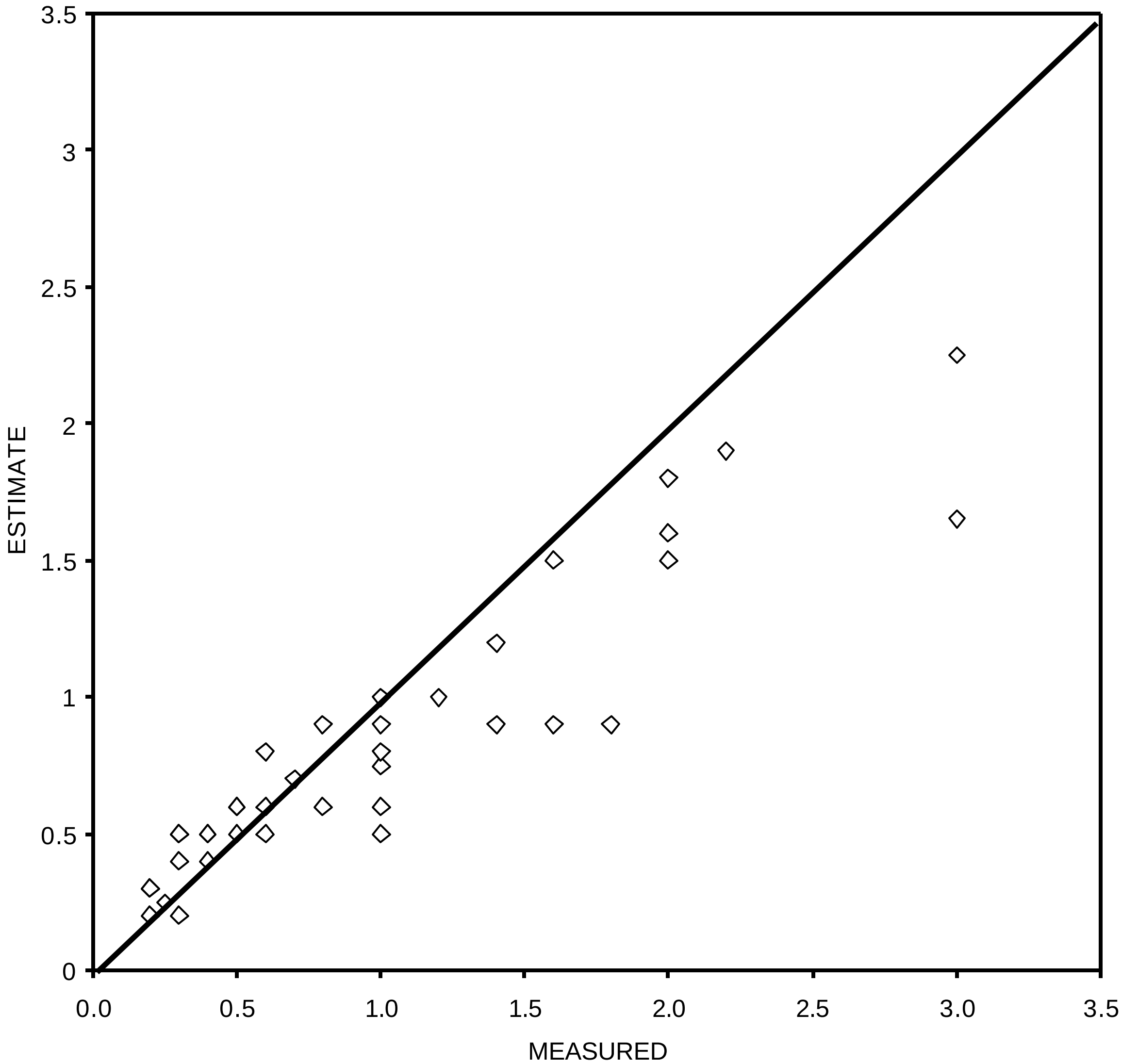

Fig. 1.

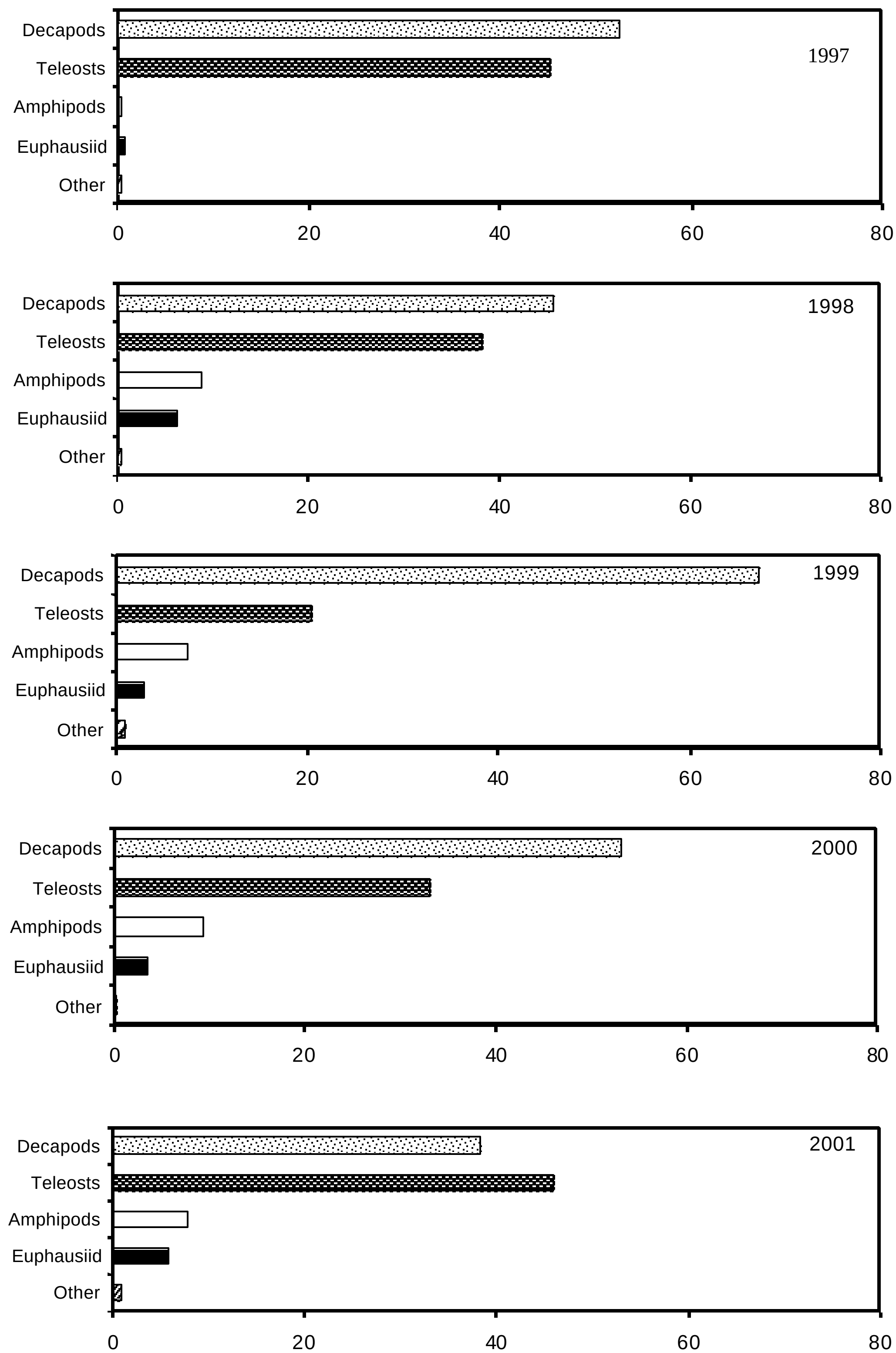
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Fig. 2.

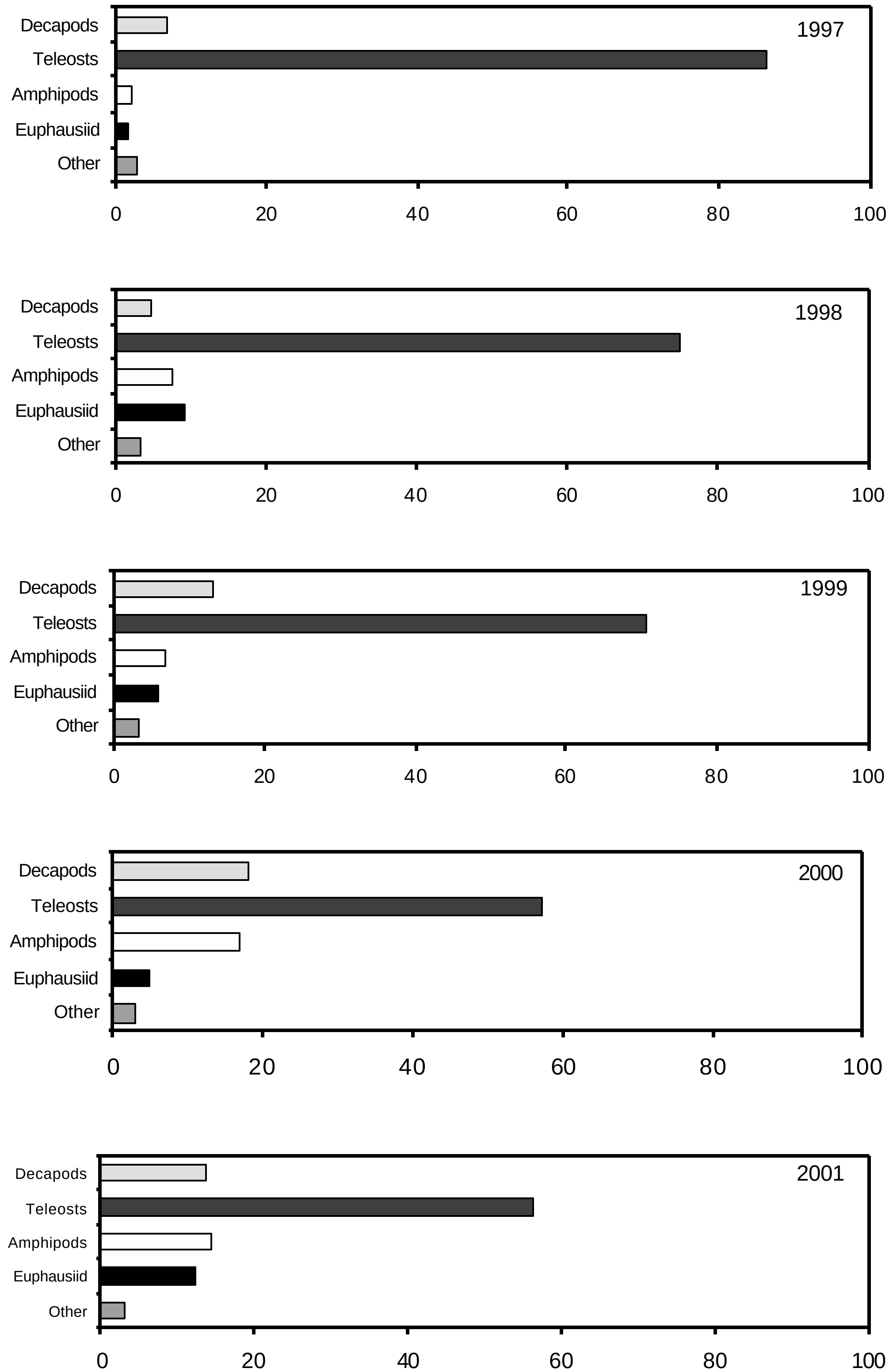
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Fig. 3.

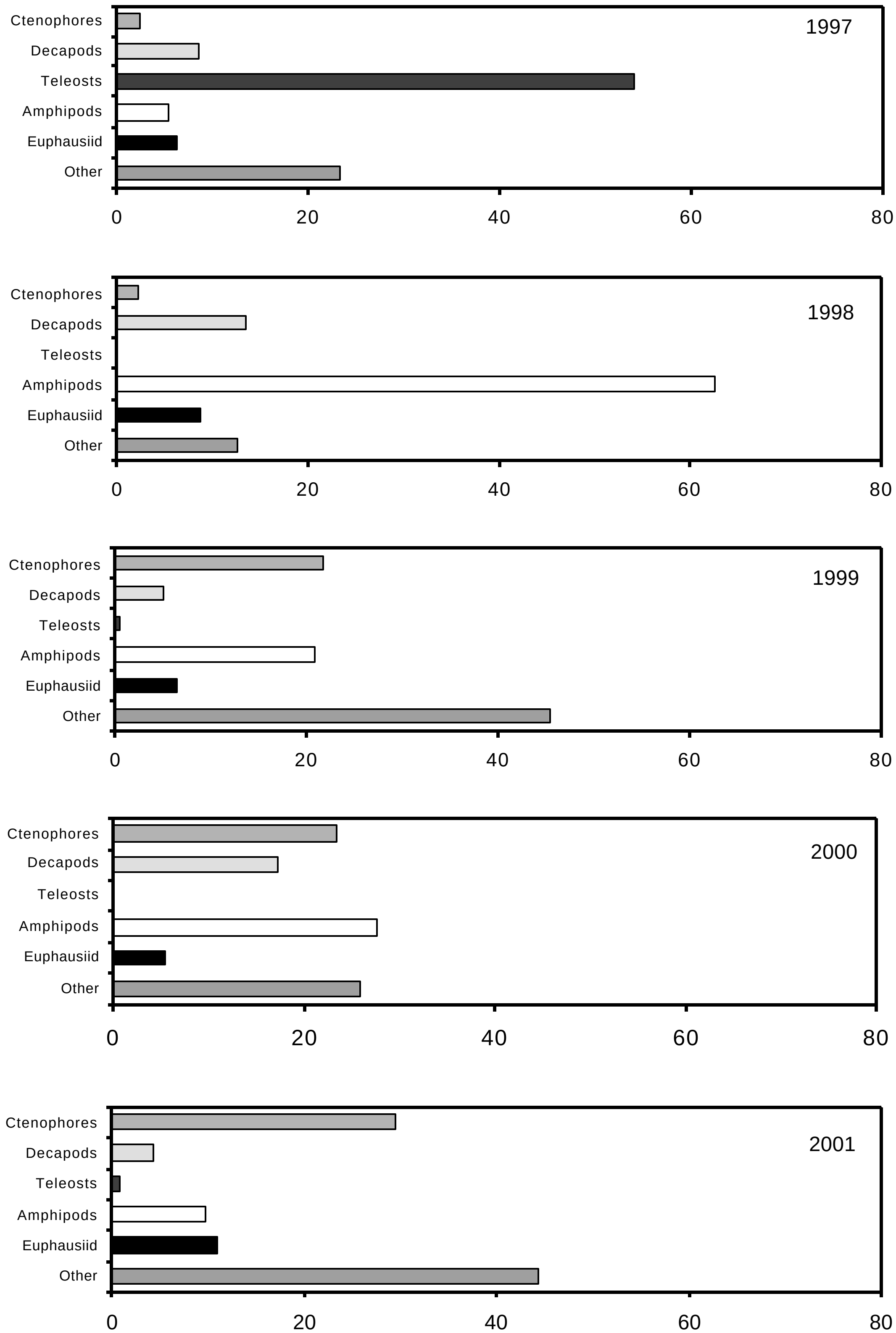
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Fig. 4.