Diets of larval Pacific hake, walleye pollock and Pacific herring in the Strait of Georgia.

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Abstract

Between 1997 and 2000 we sampled the guts of approximately 3700 larval Pacific hake, Pacific herring and walleye pollock from the Strait of Georgia. Copepod nauplii, copepodites and eggs were major diet items for all three species at the time of exogenous feeding. Copepod nauplii and copepodites were the primary diet item of Pacific hake and walleye pollock and copepod eggs were the primary diet item of Pacific herring. We propose that the recent dominance of Pacific hake in the Strait of Georgia results from a close matching of the timing of copepod production and the beginning of exogenous feeding.

Introduction

Pacific hake currently are the dominant resident fish species in the Strait of Georgia (Beamish and McFarlane 1999). In the 1970s it was first recognized that Pacific hake were abundant in the strait. In 1980, Kabata and Whitaker (1981) examined parasites in hake from the west coast of Vancouver Island and from the Strait of Georgia and showed that the two populations of Pacific hake were separate stocks. In recent years, hydroacoustic assessments of the Pacific hake abundance in the Strait of Georgia showed that there was an increase from the 1970s to the early 1990s (Saunders and McFarlane 1997). A maximum biomass estimate was recorded in 1993 (Beamish and McFarlane 1999), but the accuracy of these estimates is unknown. It is known that during this time, the average size of the hake in the Strait of Georgia decreased 13.0% in length and 51.2% in weight (Beamish and McFarlane 1999). This decline in size may indicate that the increasing density resulted in a stunting of individual fish.

Walleye pollock are at their southernmost distribution in the Strait of Georgia. Stock assessments of this species are based on landings from a small commercial fishery. Catches in the 1970s were low (< 100 t/year) and increased to an average of 600 t/year during the 1980s. Catches declined below 600t/year in the early 1990s but by 1997 increased to approximately 1000t/year (Saunders and Andrews 1998, Beamish and McFarlane 1998).

Pacific herring is perhaps the most important species in the Strait of Georgia and is a major contributor to the British Columbia commercial fishery. The estimated spawning biomass of Pacific Herring in the Strait of Georgia has increased steadily from approximately 20,000 t in the early 1970s to historic high levels of over 85,000 t by the late 1990s. The year class in 2000 was the largest observed since the early 1970s as indicated by a spawning biomass over 100,000 t in 2002 and 2003 (Schweigert 2004).

The Strait of Georgia is warming and it is possible that the changing climate and ocean environment is related to the increased abundances of Pacific hake and herring. Understanding how a change in the ocean affects these species improves the ability to forecast future abundance trends as the climate continues to change. Initial studies showed that copepods, specifically *Neocalanus plumchrus* and *Pseudocalanus minutus* were important in the diet of larval Pacific hake and herring (Beamish and McFarlane 1999). Based on these initial studies, we suspected that the increase in Pacific hake and Pacific herring abundances resulted from either an improved matching of the timing of the exogenous or first feeding of larval fish with prey or more prey or both. Thus, we determined the diet of first feeding Pacific hake, herring and walleye pollock in order to understand the mechanisms responsible for the recent large abundance. In this paper, we report the results of a gut analysis from larval Pacific hake, walleye Pollock and Pacific herring collected during the late winter and early spring of 1997 to 2000.

Methods

Larval fish were collected at three locations in the central Strait of Georgia (Figure 1) between January and June of 1997 to 2000. The number of plankton samples taken in any month and year was related to vessel availability and weather conditions ranging from 0 to 20 (Table 1). Plankton was collected using a 56 cm diameter bongo net with 250 µm nitex screen and a removable collecting jar at the cod end. The bongo nets were deployed and recovered at

2 meters per second to a depth of 50m with the research vessel moving at 1 to 2 knots. Samples were preserved in 5% formaldehyde.

Larval fish were removed from all samples in the laboratory and species were identified using the larval keys in Matarese et al. (1989). The fork length of the larvae was measured using a one mm grid on a dissecting microscope. For samples with more than 30 larvae of any species, guts were examined until 30 were found that were not empty. The total number of fish examined was recorded to determine the number of empty guts. The contents from the guts of larval hake, herring and pollock were counted individually and identified to the lowest taxonomic level possible. The lowest taxonomic level is often class or order, although information on species is included when available. When copepods were partially digested, the number present was determined by counting the number of prosomes present in the sample. Eggs were identified as copepod eggs or euphausiid eggs and identifications were based on size. Diets were compared between species and years by grouping all diet items into three major categories; copepods, copepod eggs and other. Empty guts were classified as guts with no items present and the number of empty guts was recorded for all samples examined.

Figure 1. Location of larval fish sampling in the Strait of Georgia 1997 - 2000

Results

Pacific hake

Table 1. Number of plankton tows in the Strait of Georgia and the number of larval Pacific hake, Pacific herring and walleye pollock.

	1997				1998				1999				2000			
	#	Pacific hake	Pacific herring	Pacific pollock	#	Pacific hake	Pacific herring	Pacific pollock	#	Pacific hake	Pacific herring	Pacific pollock	#	Pacific hake	Pacific herring	Pacific pollock
Jan	2	0	0	0	2	1	0	0	0	-	-	-	0	-	-	-
Feb	9	2	0	0	1	0	0	0	3	0	0	0	5	0	0	0
Mar	5	14	0	59	8	68	17	14	2	4	0	0	3	70	6	48
Apr	14	795	5462	165	13	1147	3332	162	20	467	270	124	8	590	408	95
May	0	-	-	-	0	-	-	-	4	553	6	6	0	-	-	-
Jun	2	0	0	0	2	2	0	0	2	4	0	0	0	-	-	-

A total of 3717 Pacific hake were collected in the four years of the study (Table 1). The average length of the Pacific hake in April, when 81% of the hake were collected, was 4.9mm (Figure 2a). There was no significant difference in mean length between the four years (ANOVA, $p \leq 0.05$). Guts were examined from 1628 of the first feeding Pacific hake (Table 2). A total of 54% of the 1478 guts examined to determine the percentage of empty guts were empty over the 4 year study with a range of 42-64% (Table 2). Nine percent of the larval hake examined still had yolk sacs.
Copepod nauplii and copepodites were the dominant diet item in the guts ranging from 69% in 2000 to

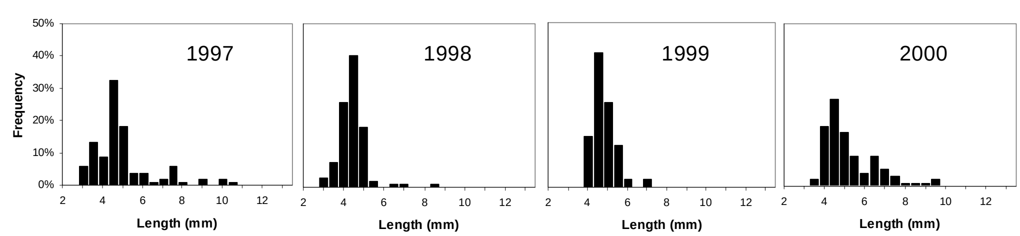

Figure 2a. Length frequency of larval Pacific hake in April of 1997-2000.

97% in 1998 (Figure 3). Calanoid or cyclopoid copepods represented 42% of all copepods and of these 87% were calanoid copepods. The remaining 58% of the copepods were not identified to lower taxonomic stages. Six percent of all copepods could be identified to species and most of these were *Neocalanus plumchrus* (64%) and *Pseudocalanus minutus* (21%). The remaining copepods were *Calanus pacifus* and *Metridia pacifica*. Copepod eggs were represented from 2% of the contents in 1998 to 24% in 1997 (Figure 3). The remainder of the items in the guts were grouped as “other” and included euphausiids nauplii and euphausiid eggs. These represented from 1% of the gut contents in 1997 and 1999 to 19% in 2000.

Table 2. Number of Pacific hake, Pacific herring and walleye pollock examined for gut contents in 1997 -2000.

	1997			1998			1999			2000		
	Pacific hake	Pacific herring	Pacific pollock	Pacific hake	Pacific herring	Pacific pollock	Pacific hake	Pacific herring	Pacific pollock	Pacific hake	Pacific herring	Pacific pollock
Jan	-	-	-	1	-	-	-	-	-	-	-	-
Feb	2	-	-	-	-	-	-	-	-	-	-	-
Mar	14	-	0	62	4	14	4	-	-	0	0	0
Apr	241	122	77	547	1482	132	140	73	46	451	150	102
May	-	-	-	-	-	-	166	6	6	-	-	-
Total	257	122	77	610	1486	146	310	79	52	451	150	102
% empty	63	49	5	52	80	69	42	27	31	59	67	38

Walleye pollock

There were 673 walleye pollock collected in 1997-2000 (Table 1). Eighty-one percent of the pollock were collected in April. The average length of pollock in April was 4.5mm (Figure 2b). There was no significant difference in average length between years (ANOVA, $p \leq 0.05$). Three hundred and twenty-five pollock were examined for gut contents and 46% of these were empty (Table 2). The percent of empty guts ranged from 5% in 1997 to 69% in 1998 (Table 2). Of the guts with contents, copepod nauplii and copepodites were the most frequent representing 56% of the gut contents in 2000 to 86% in 1997. Thirty-three percent of the copepods were identified to order and of these, calanoid copepods represented 92% cyclopoid copepods represented 8%. Sixty-seven percent of the copepods were not identifiable. Three percent of the copepods were identifiable to species and of these 40% were P. *minutus* and 30% were *N. plumchrus*. The remaining copepods were *Acartia longiremis* and *C. marshallae*. Copepod eggs were a frequent diet item comprising 12% of the gut contents in 1997 to 32% in 2000. The remainder of the gut contained a mixture of euphausiid nauplii and eggs and gastropods and are grouped as “other” (Figure 3).

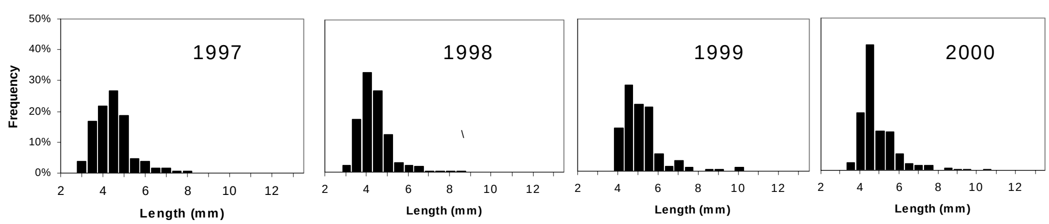

Figure 2b. Length frequency of larval walleye pollock in April of 1997-2000.

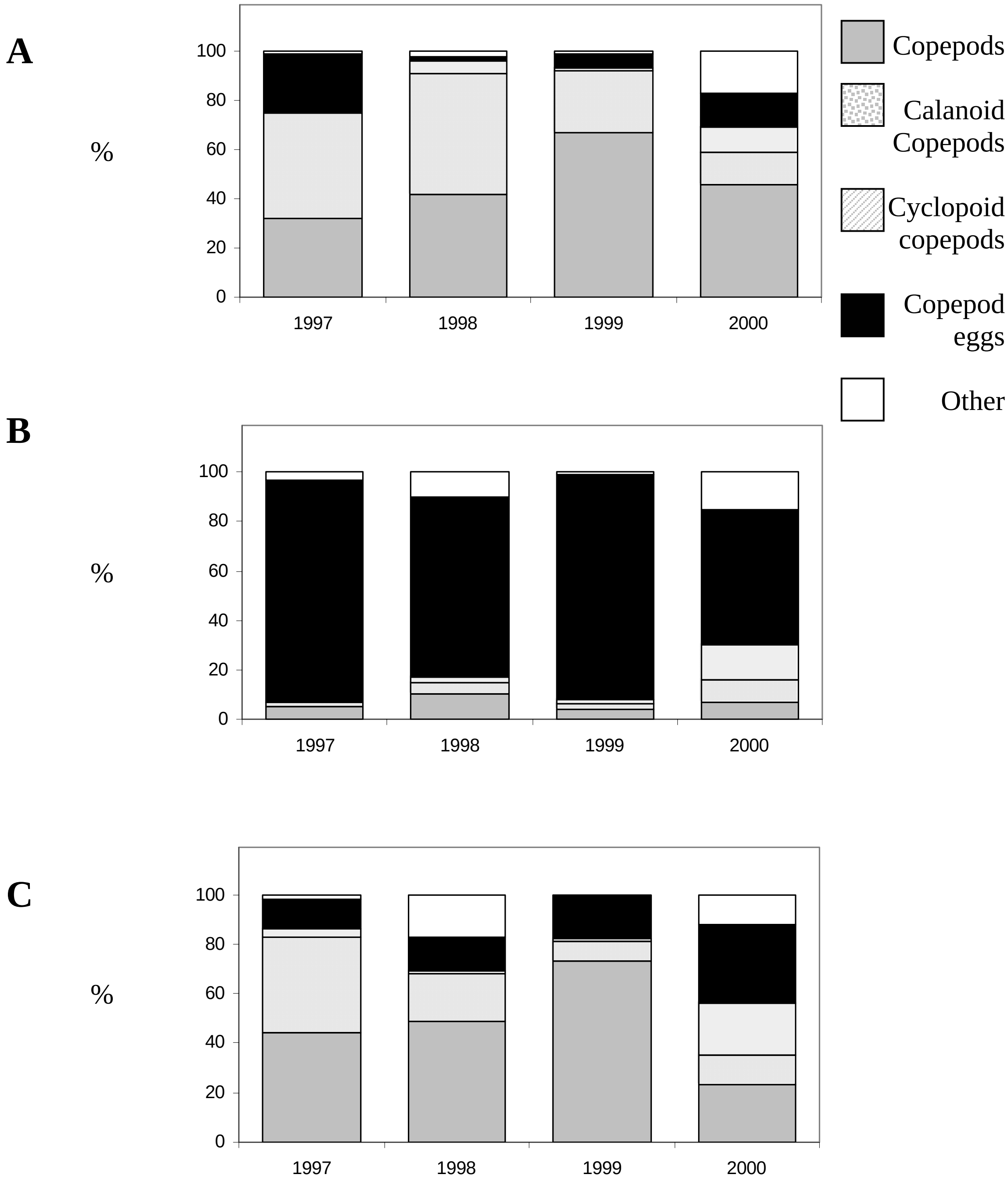

Figure 3. Major gut contents in (A) larval Pacific hake (B) larval Pacific herring and (C) larval walleye pollock.

Pacific herring

A total of 9501 larval Pacific herring were collected over the study period (Table 1). The average length of the larval herring in April was 12.2mm (Figure 2c). The length frequency of herring was bimodal in 1997 and 2000. The mean lengths differed between years with the largest larvae in 2000. Over 99% of all larval herring were collected in April. Guts were examined from 1837 of the larval Pacific herring. Seventy-five percent of the guts examined were empty with a low of 27% empty in 1999 and a high of 80% empty in 1998 (Table 2). The major diet item in the larval Pacific herring diet was copepod eggs representing from 55% of the gut contents in 2000 to 92% in 1999. Copepod nauplii and juveniles stages ranged from 7% in 1987 to 30% in 2000. Of the 12% that were identified to species, 47% were *N. plumchrus* and 41% were *P. minutus*. The remaining 12% were a combination of *Oncaea borealis, A. longiremis* and *M. pacifica*. Euphausiid nauplii and eggs were found in the gut and averaged 97% of all items in the "other" category of larval Pacific herring (Figure 3). In addition, smaller amounts of pelecypods, gastropods, bryozoans and polychaetes were in the "other category. The "other" category represented an average of 7% of the larval herring diet and ranged from 1% in 1999 to 10% of all items in 2000.

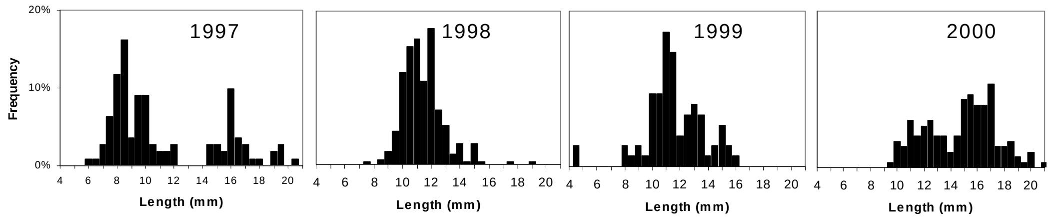

Figure 2c. Length frequency of larval Pacific herring in April of 1997-2000.

Discussion

Pacific hake, herring and walleye pollock represented the largest resident biomass of fish collectively in the Strait o Georgia and our study showed that the larval fish of these species were beginning exogenous feeding in April. Copepods and copepod eggs were primary diet items for these first feeding larval Pacific hake, walleye pollock and Pacific hake. Pacific hake in the California current also commonly fed on copepod eggs and copepidites (Cass-Calay 2003; Sumida and Moser 1980). These California current studies found that calanoid copepods, cyclopoid copepods and copepod eggs represented the majority of the gut contents of first feeding hake. Cass-Calay (2003) collected their samples in January and February of 1996 and 1997. This was approximately two months earlier than the samples. The presence of yolk sacs on 9% of the larval hake sampled in the Strait of Georgia indicates that these were first feeding larvae and clearly identifies a difference in spawning times of Pacific hake in the Strait of Georgia and those in the California current region. *N. plumchrus* was a dominant item in the diet of these larval fish and we assume that at least some of the copepod eggs were *N. plumchrus*.

Larval hake, pollock and herring in the Strait of Georgia occur at the time that *N. plumchrus* nauplii are found in the surface waters. *N. plumchrus* are reported to spawn at depth and the non-feeding nauplii and first stage copepidites migrate into the surface waters (Fulton 1973, Mackas et al. 1998). The period that these copepods feed in the surface waters is relatively short with maximum abundance in regions such as the Strait of Georgia lasting about 40 days (Mackas et al. 1998). Historically the greatest biomass of *N. plumchrus* occurred in the surface waters of the Strait of Georgia in mid-May (Bornhold et al. 2000). However, in the past 25 to 30 years, this production has been reported to have shifted to approximately 30 days earlier with peak-biomass now occurring in mid-April (Bornhold et al. 2000). Gardner (1977) correlated increasing abundance of overwintering *N. plumchrus* with warmer deep water temperatures. Bottom water temperatures in the Strait of Georgia increased approximately 0.5^{o} C since the 1970s (Beamish et al. 2004). Thus, the change in timing of production and the increased temperature may have resulted in eggs, nauplii and copepodites of *N. plumchrus* being more available for first feeding of larval Pacific hake, Pacific herring and walleye pollock.

The Pacific hake and walleye pollock in the strait had higher concentrations of copepod nauplii and copepidites in their guts than Pacific herring. Pacific herring, however, had the highest concentrations of copepod eggs ranging from 55% of gut contents in 2000 to 91% in 1999. The reasons for this variations between species is unclear but may be related to the size of the larvae as the herring were larger than either the hake or pollock. However, the larger larval herring might be expected to feed on larger food items and not the smaller eggs. It is possible that egg sacs were removed or eaten separately, but it was clear that copepod eggs were common in the diets in April indicating that the species producing the eggs was still spawning. The average size of the herring also varied between years with the largest herring observed in 2000.

The length frequency of the herring sampled in 2000 was bimodal possibly suggesting two spawning times. Schweigert (2004) reported that the 2000 year class was the strongest since the early 1970s and improved growth or multiple spawnings could have attributed to this year class strength.

The productivity of Pacific hake, herring and walleye pollock in the Strait of Georgia has improved since the mid 1970s. It was not until the early 1970s that Jergen Westerheim noticed in ecographs that Pacific hake were abundant in the Strait of Georgia. The recent analysis of scales from sediment cores from Saanich Inlet shows a low abundance of Pacific hake for the first half of the century and an increasing abundance beginning in the late 1970s (Figure 4, O'Connell 2000). This increase in abundance of Pacific hake since the 1970s appears to be a consequence of improved prey availability, but other factors such as reduced predation could also be involved.

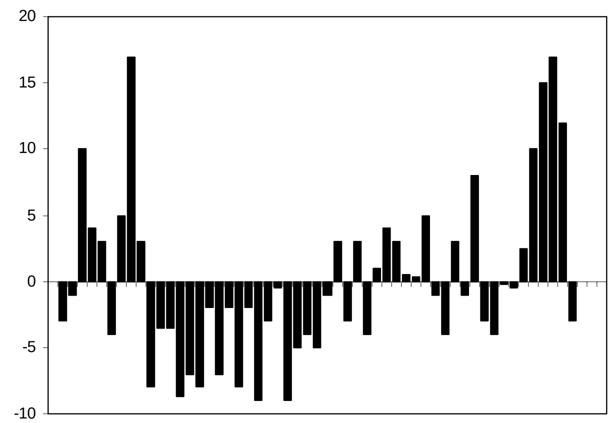

Figure 4. Anomaly of sediment record of Pacific hakescales from Saanich Inlet 1884-1990 (modified from O'Connell 2000.)

Literature cited

Beamish, R.J. and G.A McFarlane. 1999. Applying ecosystem management to fisheries in the Strait of Georgia. Alaska Sea Grant College Program AK-SG-99-01.

Beamish, R.J., A.J. Benson, R.M. Sweeting and C.M. Neville. 2004. Regimes and the history of the major fisheries off Canada's west coast. Prog. Ocean. 60: 355-385.

Bornhold, E., P. Harrison and D. Mackas. 1998. Interdecadal variations in development timing of the copepod *Neocalanus plumchrus* (Marukawa) in the Strait of Georgia. EOS 79(1) (Abstr.)

Cass-Calay, S.L. 2003. The feeding ecology of larval Pacific hake in the California Current region: an updated approach using a combined OPC/MOCNESS to estimate prey biovolume. Fish. Oceanogr. 12:34-48.

Fulton, J. 1973. Some aspects of the life history of *Calanus plumchrus* in the Strait of Georgia. J. Fish. Res. Board. 30: 811-815.

Gardner, G.A. 1977. Analysis of zooplankton population fluctuations in the Strait of Georgia, British Columbia. J. Fish. Res. Board Can. 34: 1196-1206.

Kabata, Z. and D.J. Whitaker. 1981. Two species of *Kudoa* (Myxosporea: Multivalvulida) parasitic in the flesh of *Merluccius productus* (Ayres, 1955) (Pisces: Teleostei) in the Canadian Pacific. Can. J. Zool. 59(11): 2085-2091.

Mackas, D.L, R. Goldblatt, and A.G. Lewis. 1998. Interdecadal variations in development timing of *Neocalanus plumchrus* populations at Ocean Station P in the subarctic North Pacific. Can. J. Fish. Aquat. Sci. 55: 1878-1893.

Matarese, A.C., A.W. Kendall Jr., D.M. Blood and B.M Vinter. 1989. The Laboratory Guide to Early Life History Stages of Northeast Pacific Fishes. NOAA Tech. Rep. NM-FS80, 652 pp.

O'Connell, J.M. 2000. Holocene fish remains from Saanich Inlet, British Columbia, Canada. PICES Sci. Rep.15.

Saunders, M.W. and W. Andrews. 1997. Walleye pollock stock assessment for 1997 and recommended yield options for 1998. Pacific Stock Assessment Review Committee Working Paper G97-7.

Saunders, M.W. and G.A. McFarlane. 1997. Pacific hake stock assessment for 1997 and recommended yield options for 1998. Pacific Stock Assessment Review Committee Working Paper G97-6.

Schweigert, J. 2004. Stock assessment for British Columbia herring in 2004 and forecasts of the potential catch in 2005. CSAS Research Doc. 2004/081.

Sumida, B.Y. and H.G. Moser. 1980. Food and feeding of Pacific hake larvae off southern California and northern Baja California. Calif. Coop. Oceanic Fish. Invest. Rep. 21:161-166.