DISTRIBUTION AND BIOLOGY OF PACIFIC SARDINES (*SARDINOPS SAGAX*) OFF BRITISH COLUMBIA, CANADA

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ABSTRACT

Pacific sardines (*Sardinops sagax*) in the northeastern Pacific Ocean once supported one of the largest fisheries in the world, with catches off the west coast of Canada averaging 40,000 t annually from the mid-1920s to the mid-1940s. The stock collapsed in the late-1940s and disappeared from Canadian waters. In 1992, sardines were once again captured off the southwest coast of Vancouver Island. Abundance continued to increase off British Columbia, and by the mid-1990s experimental fisheries were initiated. Evidence of spawning was observed, and in some years sardines remained in Canadian waters year-round. The northern distribution of sardines continued to expand, and in the 1997–98 El Niño years sardines were found as far north as Alaska. In recent years, fish have been found infrequently in offshore areas but are abundant in the several large inlets on the west coast of Vancouver Island. In this paper we examine the distribution, biology, and ecology of sardines in British Columbia since 1992 and discuss sardine dynamics in relation to ocean temperature.

INTRODUCTION

The Pacific sardine (*Sardinops sagax*) constituted the largest fishery in British Columbia from the 1920s to the mid-1940s. Catches during this period averaged 40,000 t annually, then collapsed in 1947 as sardines disappeared from the British Columbia coast. The collapse of sardines off the west coast was historically cited as an example of overfishing (Hilborn and Walters 1992) rather than a result of distributional change, and sardines were not expected to return to Canadian waters (Murphy 1966; MacCall 1979). In Canada, the Pacific sardine was listed as a species of concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 1987 (Schweigert 1988).

Sardines reappeared in British Columbia waters in 1992 in commercial and research catches of Pacific hake (*Merluccius productus*) (Hargreaves et al. 1994), and an experimental scientific fishery was opened in 1995. Research surveys targeting sardines were first conducted in 1997, capturing the fish in large numbers in surface waters. The abundance of sardines in British Columbia waters increased through 1999, then began to decline in outer coastal waters as their numbers and range decreased. In the past two years, sardines have been a less abundant component of offshore waters but are still found in large numbers in the inlets of Vancouver Island's west coast. This recent reappearance of sardines off British Columbia has been linked to changes in climate/ocean conditions (McFarlane and Beamish 1999; McFarlane et al. 2000; McFarlane and Beamish 2001).

Sardine spawning in Canadian waters has historically been considered rare, and supporting evidence of it is circumstantial. Generally, these events were considered limited to unusually warm periods (DFO 2004). However, recent data suggest that sardines frequently remain in Canadian waters year-round. Evidence of successful spawning and juvenile populations indicates behavioral changes coincident with the recent re-expansion into Canadian waters (McFarlane and Beamish 2001).

This report presents recent distribution and biological data and fishery and management information on Pacific sardine. In addition, we examine regional distribution changes in relation to ocean conditions (sea surface temperature). These documented changes in sardine population abundance and dynamics in Canadian waters over the past decade will be useful in developing future coastwide (Mexico to Canada) assessments.

METHODS

Biological Data

Since the reappearance of sardines in 1992, over 40 surface-trawl surveys (see McFarlane and MacDougall 2001 for details of surveys) have been conducted to examine their abundance and biology (with the exception of 1994) using a model 250/350/14 midwater rope trawl (Cantrawl Pacific Ltd., Richmond, British Columbia). Catch and biological data have been collected for sardines during all research trawling operations since they reappeared in catches in 1992. Fork length (in mm), sex, and maturity were recorded for all sardines sampled. Based on visual assessment of gonads, sardine maturities were classified as immature, maturing, mature/ripe, or spent.

Plankton sampling was conducted during June in 1992 and 1993 and from May to September in 2004, using a 236 mesh Bongo VNH net, towed obliquely from the surface to depths ranging from 52 to 250 m, and retrieved at 1 m/s.

Sardine otoliths were collected from randomly selected samples of 50 fish during research cruises off the west coast of Vancouver Island (WCVI) from 1997 to 2002. Samples were collected from throughout the entire range of the fish. Otoliths were extracted from sardines during onboard sampling, or were extracted in the laboratory from sardines that were frozen, and processed at the Pacific Biological Station, Nanaimo, British Columbia. After otoliths were extracted, they were rinsed in water to cleanse and remove tissue and stored dry for subsequent aging. Otoliths were placed under a film of water in a shallow container and observed under a dissecting microscope on 25X power with a 10X eyepiece, using reflected light. Against a dark background, opaque bands appeared light, translucent bands appeared dark. Annuli were defined as the area consisting of one opaque zone (summer growth) and one translucent zone (winter growth). We have chosen a 1 January birthdate because that date does not straddle the growth cycle for a complete growth year. In our aging methodology, an otolith that displays one full light band and dark band is a 1-year-old. Similarly, for an older fish, an otolith showing four sets of light and dark bands is considered a 4-year-old.

Sardine stomachs were collected from randomly selected samples of 50 fish during trawl surveys conducted off WCVI from March–October 1997–2002, aboard the R/V *W.E. Ricker*. Stomachs were excised and preserved in 3.7% formalin. In the laboratory, contents were identified under a dissecting microscope to the lowest taxonomic group possible. Authors have omitted stomachs analyzed using methodology inconsistent with the described laboratory methods, along with stomachs collected in spring or fall, empty stomachs, and stomachs containing 100% scales or 100% digested material.

Prey item volume was expressed as a proportion of a full stomach and as an estimate of the item's volume in cubic centimeters. The degree of contents digestion was recorded as a percentage, with 0% denoting fresh contents. The contribution of each prey item was determined by its frequency of occurrence (%FO), average volume per stomach (%C), and proportion of overall volume of all stomach contents (%V). Prey items were assigned to a unique category for further analysis if present in at least 5% of the stomachs in a particular year (%FO $\geq$ 5%) and recorded in at least three of the five survey years. Prey items not meeting these criteria were combined in an "other" category.

Relative importance (RI) of each prey group was determined using a modification (King and Beamish 2000) of the index of relative importance (IRI) (Pinkas et al. 1971). Similar to the IRI, each prey item's RI describes its average volume per stomach, how many fish eat that prey item, and how much that prey item contributes to the total volume of food consumed by all sardines. The RI ranges from 0, where a prey item is not consumed at all, to 20,000, where a prey item is consumed exclusively. In this report, the RI values are expressed as a percent of the maximum attainable value of 20,000 (%RI) to allow for a direct comparison between prey items. Percent RI values are not cumulative within a year; the %RI values for all prey items within a year may sum to more than 100.

$$RI = \%FO \times (\%C + \%V) \text{ where:}$$

%FO = % frequency of occurrence: % of stomachs in which prey groups are present

%C = the average % volume of stomach contents contributed by the prey group

%V = the ratio of the total prey group's volume to the total volume of the stomach contents.

Three-way-graphs were used to show which variable in the index (i.e. %V, %FO, or %C) was the most influential in determining the %RI value.

Abundance Data

Biomass estimates were calculated from data collected during directed abundance cruises conducted in July of 1997, 1999, and 2001. Biomass estimates were calculated according to the method described in Beamish et al. (2000). The WCVI was partitioned into six major regions determined during a cruise in 1997. The total volume for each region was calculated by multiplying the estimated area of each region by the maximum net depth (30 m, or 0.03 km).

The volume swept during each set was determined by multiplying the area of the midwater trawl net used during fishing operations by the distance traveled during fishing. Abundance in numbers of sardines was converted to weight (kg) by multiplying abundance in numbers by average weight (kg) of an individual sardine (calculated to be 0.165 kg) from 1997, 1999, and 2001, as the average size of fish during these years was similar. Areas where sardines were captured in three or fewer sets were not included in abundance estimates. Total abundance for each region was determined from numbers of sardines in the swept volume, extrapolated to the total volume. Minimum and maximum estimates were

TABLE 1
Catch (t) of Pacific sardine (*Sardinops sagax*) by Statistical Area in the experimental fishery since 1995 based on validated landings[3]

	Area										
	Queen Charlotte Sound Inlets			North West Vancouver Island Inlets			South West Vancouver Island Inlets		Offshore South West Vancouver Island		
Year	8	10	12	25	26	27	23	24	121	123	Total (t)
1995				23							23
1996					80						80
1997			27				4				31
1998		162	301	94	9			109			675
1999	8	352	346	9	245	100	74				1134
2000	55		80	768	145	302	208				1558
2001	85		41	436	68	395	183		41	19	1268
2002		370	54	297	41	147	104				1013
2003				82		36	921	39			1078
2004		81		2266	829	69	192	822			4259

*Note: Current as of 11 January 2005. Last landing date included is 8 December 2004.

TABLE 2
Canadian commercial sardine catch (t) by month from 2000 to 2004

Year	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Total
2000/01		496	583	183	457				1559
2001/02		328	785	283					1266
2002/03			448	161	96	111			1013
2003/04	86	37	713	241			135	63	1077
2004/05		52	1586	1762	859				4258

determined using the 95% confidence interval for the calculated average swept volume within each major area.

Temperature Data

Sea surface temperature data (SST) were assessed from three coastal buoys (buoy 46206, La Perouse; buoy 46132, South Brooks; buoy 46185, South Hecate Strait), three offshore buoys (buoy 46207, East Dellwood; buoy 46205, West Dixon Entrance; buoy 46004, Middle Nomad), and three lighthouse stations (Amphitrite Point, Kains Island, and McInnes Island). Lighthouse data were compiled from a British Columbia lighthouse database[1] and anchored ocean buoy temperature data were provided by Roy Hourston and Richard Thomson[2]. Monthly mean temperatures from June to August for 1990 to 2003 were calculated from daily mean data when available.

RESULTS

Fishery and Research Catches

In 1992, sardines were captured in research and commercial sets targeting Pacific hake (*Engraulis mordax*). By 1995 sardines were noted in abundance in Nootka Sound, WCVI, and a small experimental fishery was initiated (tab. 1). Expansion of the experimental fishery proceeded slowly, and in 1997 this fishery was extended for a three-year period with a pilot individual quota system consisting of seven participants with 73 t of allocations (of a total quota of 508 t, 31 t were landed; tab. 1). In 1999, the quota was increased to 1089 t (145 t/vessel plus 73 t for research). In 2000, the quota was increased to 180 t per vessel; and in 2004 it was increased again to 300 t per vessel. Landings increased from 676 t in 1998 to 1559 t in 2000 and averaged about 1000 t through 2004 when they increased again to 4258 t (tab. 1). The delisting of sardine as a species of concern by COSEWIC in 2002 provided additional opportunity for expanding the commercial fishery, but market conditions were unfavorable. In both 2001 and 2002 experimental fisheries occurred with gillnet and traps, but they were subsequently discontinued. Since the inception of the sardine fishery, the majority of the catch has been taken on the WCVI primarily from areas 25 and 26 (tab. 1). In some

[1] BC lighthouse database is available at URL: <http://www-sci.pac.dfo-mpo.gc.ca/osap/data/searchtools/searchlighthouse_e.htm> [Accessed on: 30 August 2005].

[2] Roy Hourston Institute of Ocean Sciences, 9860 West Saanich Road, P.O. Box 6000 Sidney, British Columbia, Canada,V8L 4B2; Richard Thomson, Institute of Ocean Sciences, 9860 West Saanich Road, P.O. Box 6000 Sidney, British Columbia, Canada,V8L 4B2.

[3] For detailed description of Statistical Areas see website URL <http://www.pac.dfo-mpo.gc.ca/ops/fm/Areas/areamap_e.htm>. [Accessed on: 30 August 2005].

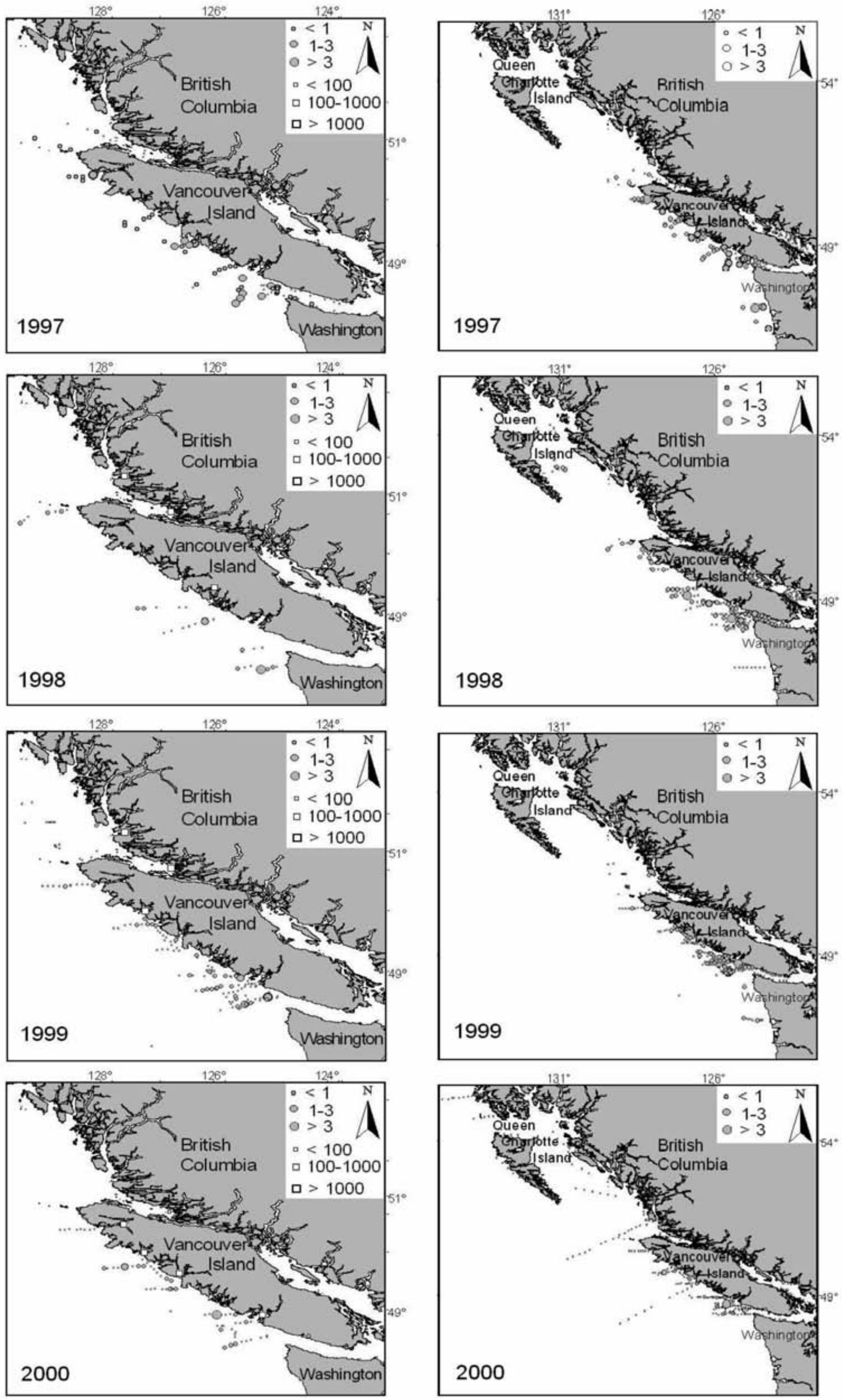

Figure 1. Pacific sardine (*Sardinops sagax*) distribution in research and commercial surveys, for all months and June through August 1997–2004. Panels on the right illustrate research catch from all months of the year; left hand panels illustrate research catch from June to August only and commercial catches. Note: circles represent sites of research catch, squares represent sites of commercial catch. Catches in tons.

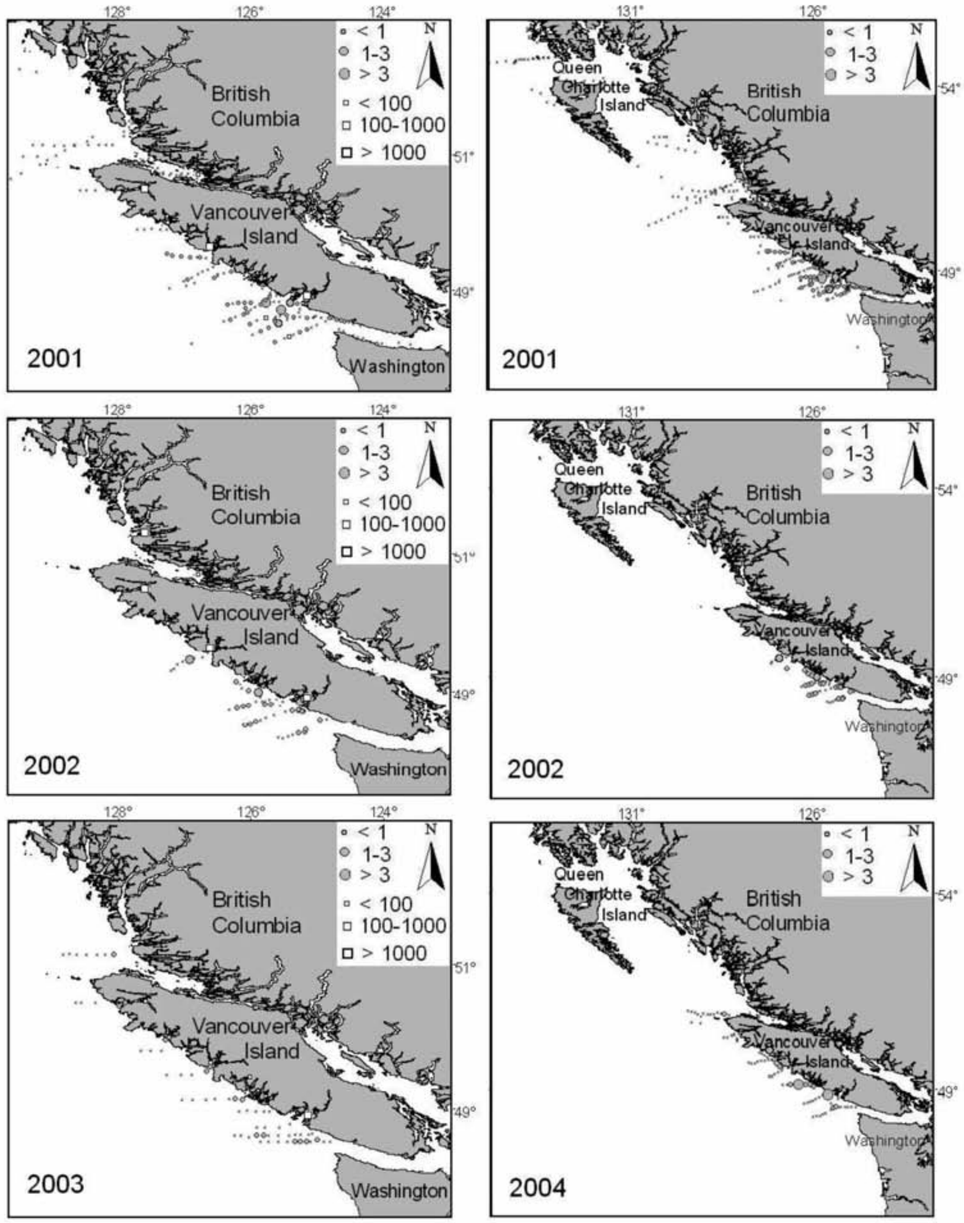

Figure 1 (continued). Pacific sardine (*Sardinops sagax*) distribution in research and commercial surveys, for all months and June through August 1997–2004. Panels on the right illustrate research catch from all months of the year; left hand panels illustrate research catch from June to August only and commercial catches. Note: circles represent sites of research catch, squares represent sites of commercial catch. Catches in tons.

years, the bulk of the catch came from inlets off Queen Charlotte Sound (tab. 1) and from as far north as Smith Inlet. The bulk of the annual catch has been taken in September and October (tab. 2).

Distribution

From 1992 to 1996 small numbers of sardines were captured in both commercial and research sets targeting Pacific hake off the southwest coast of Vancouver Island. Since 1997, large numbers of sardines have been captured in surface water research sets targeted on sardine off the west and northeast coasts of Vancouver Island, Queen Charlotte Sound, and in a small commercial fishery for sardines in inlets surrounding Vancouver Island. From 1997 to 2000, sardines were captured in cruises during February to April and June to November, with the majority of sardines captured between June and August. From 1997 to 1999, sardines were found in the Strait of Juan de Fuca and as far north as the east coast of Queen Charlotte Sound. In 1998, sardines were also found on the northeast coast of Vancouver Island, the southern Strait of Georgia, Hecate Strait, and in waters

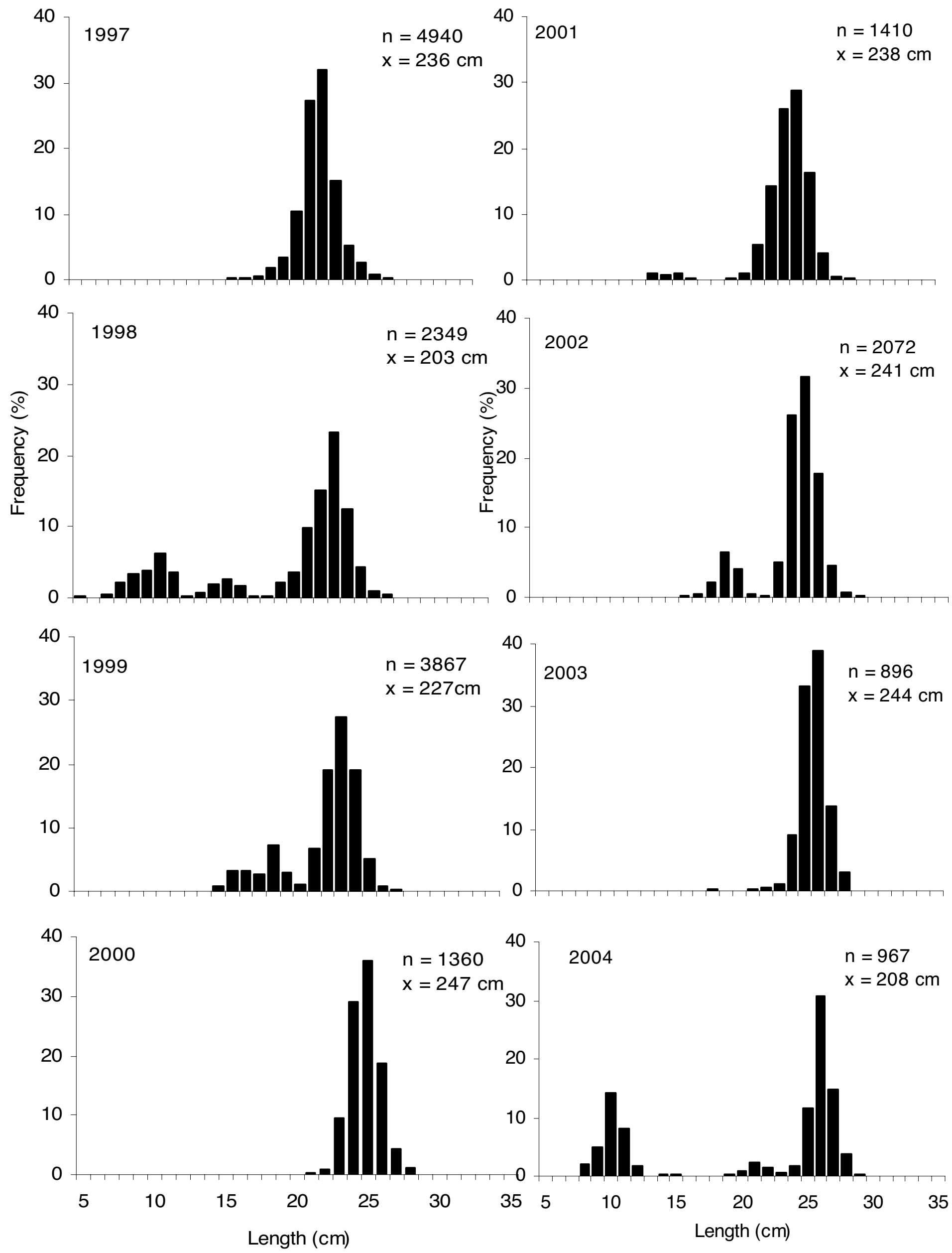

Figure 2. Length frequency data of Pacific sardines (*Sardinops sagax*) captured during research cruises off WCVI, 1997–2004.

off southeast Alaska (McFarlane and Beamish 2001). The sardine distribution in 2000 was concentrated on the WCVI and ranged as far south as Barkley Sound and as far north as mainland British Columbia, north of Vancouver Island. From 2001 to 2003, sardine distribution became progressively concentrated near shore along the southwest Vancouver Island coast and progressively less prevalent in research cruises. By 2004, sardines were rarely captured offshore or along the research grid; however, large catches of sardines were made in inlets and the shallows along the WCVI, and in 2004 in Queen Charlotte Sound inlets (fig. 1).

Abundance

Biomass estimates were calculated from directed abundance cruises conducted in July of 1997, 1999, and 2001: 88,843 t (95% CI = 66,947 – 136,288 t), 79,393 t (95% CI = 64,656 – 100,972 t), and 43,845 t (95% CI = 33,839 – 62,336 t), respectively. McFarlane and Beamish (2001) present detailed abundance estimates for 1997 and 1999. The 2001 estimate is based on the same methodology. We also note that the 2001 estimate of 43,845 t is from the southern portion of the WCVI only. These are minimum estimates as they included neither the sardines in the large inlets along the WCVI, nor the

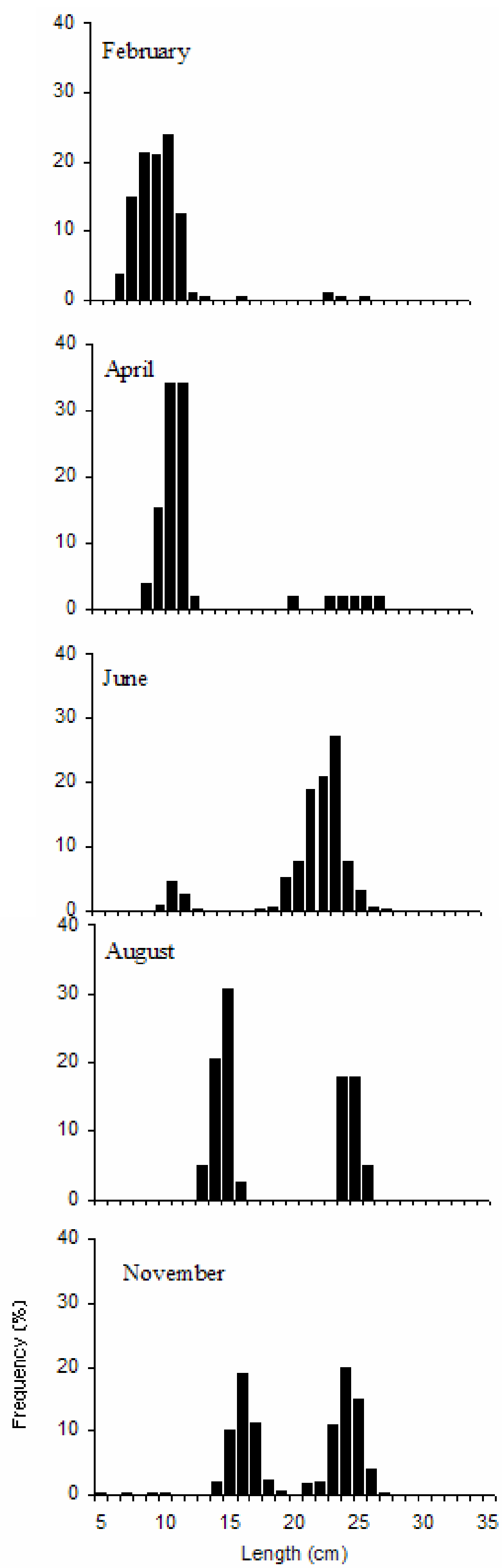

Figure 3. Pacific sardine (*Sardinops sagax*) length frequency for February to November 1998 collected throughout the year off WCVI. Note the appearance and persistence of young-of-the-year (1997 year-class).

large concentrations north of the survey area on the northeast tip of Vancouver Island. They are also based on the unlikely assumption that sardine catchability was 100%.

Biology

Length and Age A total of 17,888 sardine lengths have been recorded from research surveys since 1992 (fig. 2). The majority of lengths have been collected from summer and fall cruises. Lengths ranged from 50 mm in 1998 to 349 mm in 1997; however, only in 1998 and 2004 were sardines smaller than 140 mm sampled. Mean lengths ranged from 203 mm in 1998 to 247 mm in 2000. During 1998 and 2004, surveys conducted on the WCVI throughout the year captured sardines. For example, in 1998 a mode of small fish (50 mm to 120 mm) is present in the length frequency data representing the 1997 year class. These fish can be tracked through the year as a mode of 110 mm in February, April, and June; 150 mm in August, and 160 mm in November (fig. 3).

A similar length distribution progression was present throughout the year in 2003/2004. The results suggest juvenile sardines survive and remain in Canadian waters year-round. There was no difference in the mean lengths of sardines captured in northern (samples from Nootka Sound and north: 49.50°N; 126.56°W) or southern (samples collected south of Nootka Sound) waters during the study period (fig. 4).

Ages have been estimated for a total of 1859 sardines since 1999. Ages range from 1 to 9 years (fig. 5). From 1999 to 2002, the average was between 4.6 and 5.4 years, with a modal age of 5 years. In 2003 and 2004 more older fish were present in Canadian waters (fig. 5); the average age in 2004 was 6.5, with a modal age of 7, and 83% of sampled fish were 6 or older. Analysis of age by area since 1999 (tab. 3) indicates a trend for older fish to be present in areas in or north of Nootka Sound (49.50°N; 126.56°W) (North).

Maturity A total of 2893 sardines were sampled from research surveys from 1992 to 2004. Mature sardines and sardines in spawning condition were dominant in all years (fig. 6).

Egg surveys Sardine eggs were collected from oblique plankton tows in 1992, 1993, and 2004 (fig. 7). In 1992, five of eight plankton tow samples contained sardine eggs; in 1993 only one of eight samples contained sardine eggs, while in 2004 ten samples contained eggs. In 2004, sardine eggs were recovered from samples collected from 27 May to 7 September, at depths ranging from 0 m to 256 m (tab. 4).

Stomach Contents Analysis A total of 1231 stomachs were examined from research cruises off the WCVI from 1997 to 2002. Of these, 362 stomachs were collected during summer months (June to August), examined using

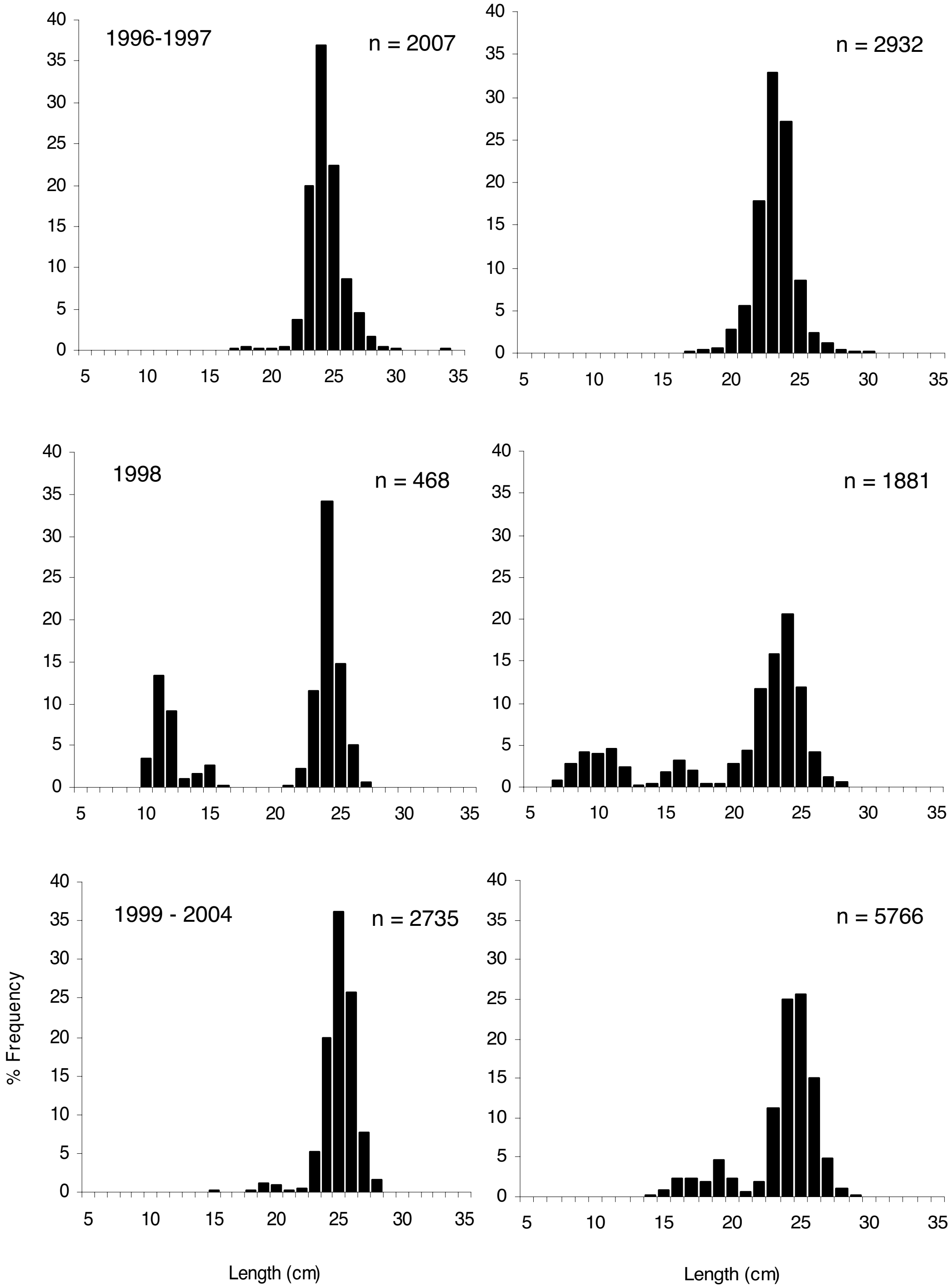

Figure 4. Length-frequency of Pacific sardine (*Sardinops sagax*) captured in or north of Nootka Sound (49.50° N; 126.56° W) (North: Left panels) compared with sardine captured south of Nootka Sound (South: Right panels), 1996–2004.

standardized laboratory procedures, and contained prey items (i.e. volume was not 100% digested material or scales). Consequently, they were included in this report (tab. 5). Mean volume per stomach (for stomachs collected from June to August) declined yearly from 0.86 cc in 1997 to 0.13 cc in 2001, while the largest volume of prey items was recorded in 2002 (average 1.7 cc per stomach). The mean percent of digested material per stomach ranged from a low of 29% in 1998 to a high of 90% in 2001. Despite the paucity of identifiable contents from 2001 samples, these data have been included to maintain the time series.

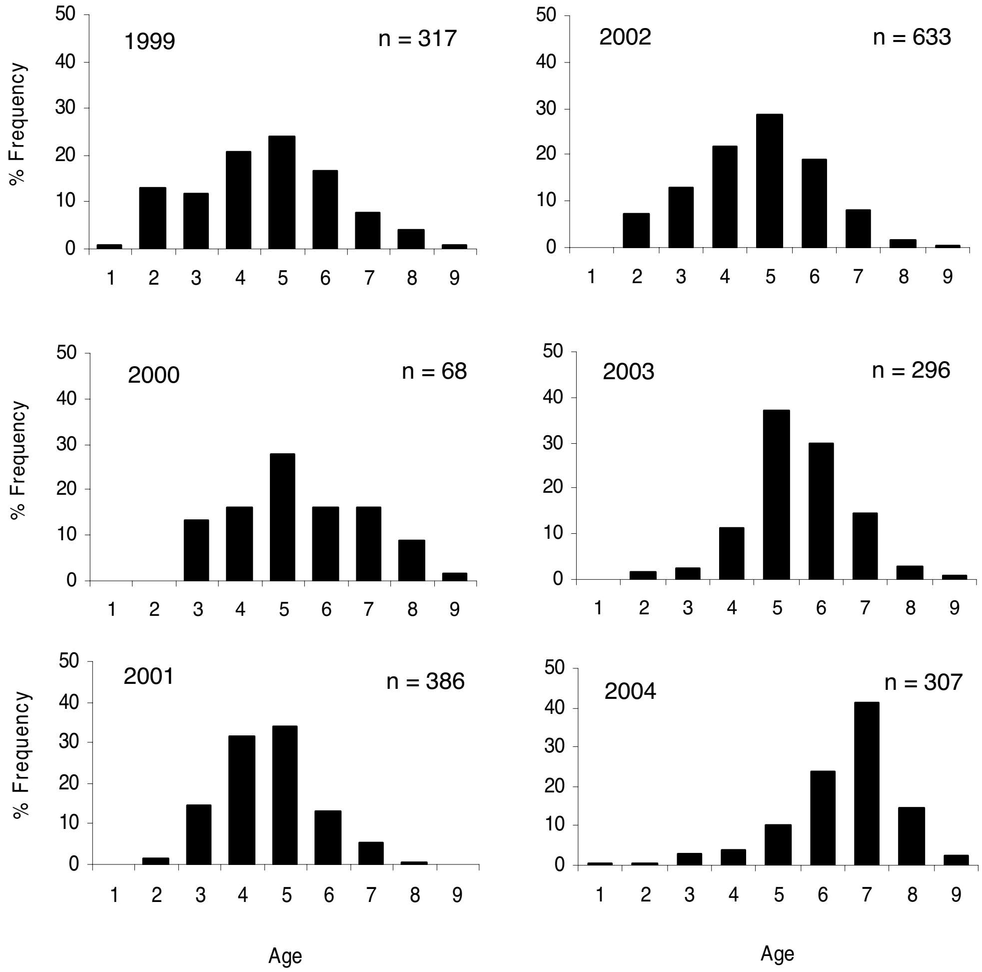

Figure 5. Age-frequency from Pacific sardines (*Sardinops sagax*) captured during research and commercial cruises off WCVI, 1999–2004.

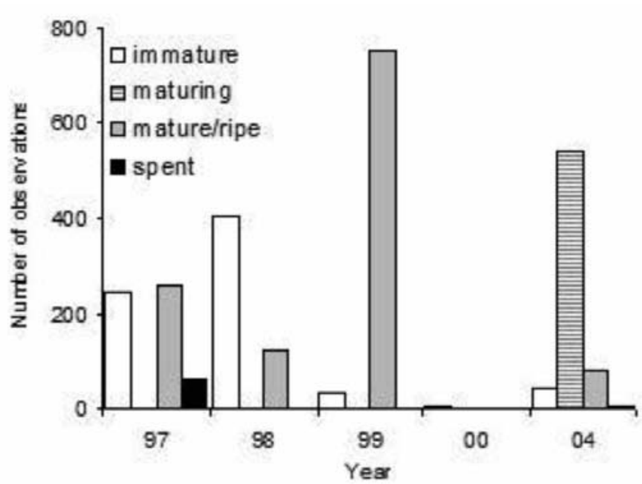

Figure 6. Maturity stages for Pacific sardines (*Sardinops sagax*) captured in research cruises off WCVI, July–August 1997–2000 and 2004.

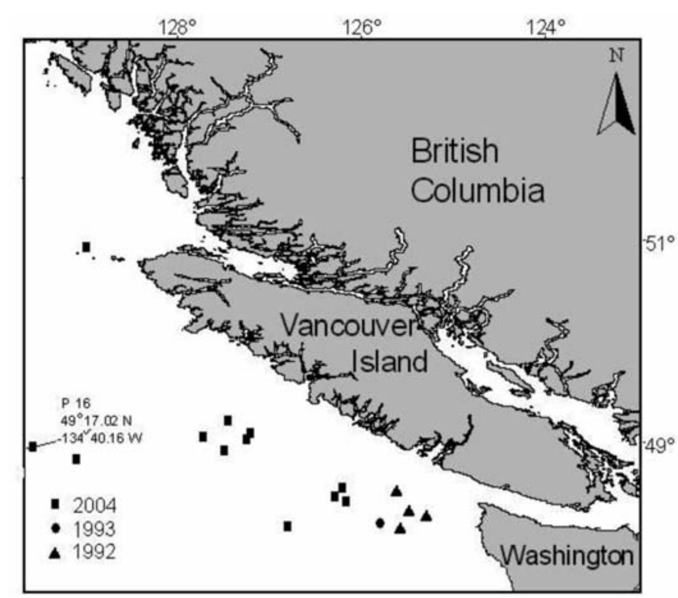

Figure 7. Locations of plankton tows (bongos) in which Pacific sardine (*Sardinops sagax*) eggs were present, 1992, 1993, and 2004.

TABLE 3
Mean age and range of Pacific sardine (*Sardinops sagax*) captured off WCVI, 1999–2002, 2003 and 2004. North includes sardines captured in or north of Nootka Sound (49.50°N; 126.56°W) (North) compared with sardines captured south of Nootka Sound

	1999–2002		2003		2004	
	n	mean (range)	*n*	mean (range)	*n*	mean (range)
North	1014	4.9 (2-9)	148	5.46 (2-9)	109	6.84 (4-9)
South	242	4.1 (2-9)	49	5.25 (3-7)	198	5.0 (1-9)

TABLE 4
Location (latitude and longitude) of oblique plankton tows in which Pacific sardine (*Sardinops sagax*) eggs were present: 1992, 1993, and 2004

Station	Date	Latitude	Longitude	Depth(m)
COPRA	1992 (June–Aug)	within 48°40 and 49°00	within 125°30 and 126°00	n/a
COPRA	1993 (June–Aug)	within 48°40 and 49°00	within 125°30 and 126°00	n/a
A4	2004/5/27	48° 15.01	126° 40.02	0–250
LC09	2004/5/27	48° 26.00	126° 13.79	0–249
A1	2004/5/27	48° 29.93	126° 6.36	0–178
CS05	2004/5/29	50° 56.01	128° 59.99	0–52
LG09	2004/5/31	48° 51.16	127° 19.45	0–250
LG07	2004/5/31	48° 59.42	127° 0.70	0–248
P08	2004/6/3	48° 49.03	128° 40.04	0–249
P16	2004/8/23	49° 17.02	134° 40.16	0–256
LG09	2004/9/7	48° 51.18	127° 19.40	0–250
LG07	2004/9/7	48° 58.76	127° 7.42	0–250

TABLE 5
Summary of stomach analysis for Pacific sardines (*Sardinops sagax*) captured off WCVI, 1997–2002. Stomachs from this list were included in the following report if they were analyzed using described methodology, collected in summer (June–August) months, and contained identifiable prey (i.e. did not contain 100% digested matter nor 100% scales)

Year/Month	# of stomachs analyzed	# by standard lab method	# empty	# 100% digested or 00% scales	# stomachs summarized for report	Total volume	Volume without digested	Average volume per stomach
1997								
June	549	67	0	51	16	44.50	6.24	0.67
July	22	5	0	5	0	4.80	0.54	0.96
August	53	53	0	39	14	50.80	15.26	0.95
October	15	15	0	14	1	14	7.20	0.92
1997 Total	**639**	**140**	**0**	**109**	**31**	**114.1**	**29.24**	**0.81**
1998								
May	14	14	3	3	8	6.90	6.40	0.69
June	57	57	0	3	54	30.76	19.96	0.54
August	14	14	1	0	13	11.40	11.35	0.87
September	45	45	13	2	30	7.38	0.44	0.21
October	20	20	1	10	9	4.90	1.24	0.26
1998 Total	**150**	**150**	**18**	**18**	**114**	**61.34**	**39.39**	**0.46**
1999								
March	30	30	0	0	30	13.50	4.61	0.45
July	81	81	1	0	80	16.50	11.82	0.21
August	45	45	0	0	45	5.80	2.20	0.13
1999 Total	**156**	**156**	**1**	**0**	**155**	**35.8**	**18.63**	**0.23**
2000								
September	74	74	0	0	74	9.50	0.53	0.13
2000 Total	**74**	**74**	**0**	**0**	**74**	**9.50**	**0.53**	**0.13**
2001								
July	38	38	0	0	38	4.80	0.30	0.13
August	22	22	0	0	22	3.70	0.25	0.17
October	50	50	0	2	48	5.70	0.70	0.11
2001 Total	**110**	**110**	**0**	**2**	**108**	**14.20**	**1.25**	**0.13**
2002								
August	80	80	0	0	80	136.1	90.1	1.701
September	22	22	0	0	—	21.2	6.02	0.9636
2002 Total	**102**	**102**	**0**	**0**	**80**	**157.3**	**23.735**	**1.33**

TABLE 6
Pacific sardine (*Sardinops sagax*) diet composition by year, 1997–2002. Data from summer months (June–August) only

	Euph-ausiid	Copepod	Diatoms	Euphausiid eggs	Oiko-pleura	Eggs	Crab zoea	Clado-ceran	Barnacle nauplii	Fish eggs	Cyclo-poid	Amphi-pod	Other*
1997 summer: 30 stomachs													
%C		21.05	0.50	0.00	0.00	0.00	5.00	3.67	0.00	0.00	0.00	0.00	0.33
1.00													
% FO	56.67	6.67	0.00	0.00	0.00	20.00	26.67	0.00	0.00	0.00	0.00	3.33	3.4
% V	59.02	1.64	0.00	0.00	0.00	17.16	9.20	0.00	0.00	0.00	0.00	0.47	3.3
%RI	22.69	0.07	0.00	0.00	0.00	2.25	1.72	0.00	0.00	0.00	0.00	0.01	0.1
1998 summer: 67 stomachs													
%C	18.21	1.05	36.40	21.01	0.00	0.00	0.00	0.00	0.31	0.01	0.07	1.05	2.5
% FO	23.88	17.91	74.63	74.63	0.00	0.00	0.00	0.00	7.46	1.49	1.49	11.94	11.5
% V	35.18	3.09	33.11	19.83	0.00	0.00	0.00	0.00	0.32	0.02	0.08	1.68	4.5
%RI	6.38	0.37	25.94	15.24	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.16	0.25
1999 summer: 125 stomachs													
%C	0.09	17.23	2.40	13.34	16.65	0.93	0.34	0.17	0.14	0.52	0.18	0.22	0.1
% FO	1.59	95.24	46.03	65.08	37.30	9.52	10.32	2.38	11.90	7.94	10.32	3.17	1.3
% V	0.36	31.17	5.55	20.31	36.48	2.13	1.17	0.21	0.22	1.64	0.23	0.50	0.1
%RI	0.00	23.05	1.83	10.95	9.91	0.15	0.08	0.00	0.02	0.09	0.02	0.01	0.05
2001 summer: 60 stomachs													
%C	0.50	2.052	2.00	0.17	0.15	0.081	0.823	0.1	0.066	0.00	0.162	0.13	0.01
% FO	8.33	95.00	71.67	15.00	8.33	1.67	3.33	10.00	6.67	0.00	10.00	6.67	1.6
% V	8.70	35.45	32.44	2.84	1.84	2.51	8.53	1.51	1.17	0.00	2.01	2.68	0.3
%RI	0.38	17.81	12.34	0.23	0.08	0.02	0.16	0.08	0.04	0.00	0.11	0.09	0.01
2002 summer: 80 stomachs													
%C	9.61	19.58	25.06	1.11	5.21	0.00	0.14	2.01	1.10	0.28	0.08	0.00	0.2
% FO	78.75	98.75	100.0	37.50	73.75	0.00	8.75	58.75	53.75	3.75	7.50	0.00	9.1
% V	1.07	47.18	35.31	0.00	7.26	0.00	0.18	5.01	3.84	0.06	0.00	0.00	0.1
%RI	4.21	32.96	30.19	0.21	4.60	0.00	0.01	2.06	1.33	0.01	0.00	0.00	0.1

* "Other" category includes barnacle cyprids, crab megalops, algae, shrimp zoea, fish larvae, gastropod, ostracod, and chaetognath. Individuals from these groups occurred in fewer than 5% of stomachs per year and in two or less years of data.

In 1997, the total volume of identifiable stomach contents (n = 30) was 22.04 cc (tab. 5) from which seven prey items were identified (tab. 6). Euphausiids were the most important (%RI of 23%), with importance influenced mainly by %FO and %V (fig. 8a). Specifically, euphausiids were identified from over 55% of sardine stomachs (%FO) and contributed nearly 60% of the overall stomach contents volume (%V), resulting in the highest %RI value calculated from 1997 data. From 1998 samples, 67 stomachs had a total identifiable volume of 31.31 cc (tab. 5). Thirteen prey items were identified (tab. 6), with three dominant items: phytoplankton (diatoms) (%RI = 26), euphausiid eggs (%RI = 15), and euphausiids (%RI = 6) (fig. 8b). In 1999 samples, 18.63 cc of contents were examined from 125 stomachs. Fourteen prey items were identified with copepods (%RI = 23%, found in 96% of stomachs), euphausiid eggs (%RI = 11%), and oikopleurids (%RI = 10%) identified as important prey items (fig. 8C). No stomachs were collected in the summer months in 2000. In 2001, 60 stomachs were collected. Total volume of identifiable contents was only 0.55 cc, as digested material accounted for over 90% of the volume in each stomach (tab. 5). Twelve prey items were identified at very low volumes. Copepods (%RI = 18%) were the most important, found in 95% of the stomachs, and diatoms (%RI = 12%) were also important (tab. 6; fig. 8d). In 2002, a total volume of identifiable contents of 90.10 cc was collected from 80 stomachs. Thirteen prey items were identified, characterized by a high frequency of occurrence and small volume contributions similar to 2001. Copepods and diatoms dominated the sardine diet (%RI of 33% and 30% respectively), were found in nearly every stomach, and were substantially more important than other prey items (fig. 8e).

In general, the majority of identifiable stomach contents consisted of five prey items: phytoplankton (diatoms), euphausiids, euphausiid eggs, copepods, and oikopleurids (larvaceans). The relative contribution by each of the prey items varied considerably (fig. 9). The categories of prey items found most often in our study are consistent with major food items found by Hand and Berner (1959), Radovitch (1952), and Ahlstrom (1960). For example, euphausiids were the most important prey item in 1997 but were virtually absent in 1999 and 2001. In contrast, phytoplankton (mainly diatoms) were absent in 1997 but were the most important prey item in 1998 (figs. 9 and 10). Copepods were important in 1999

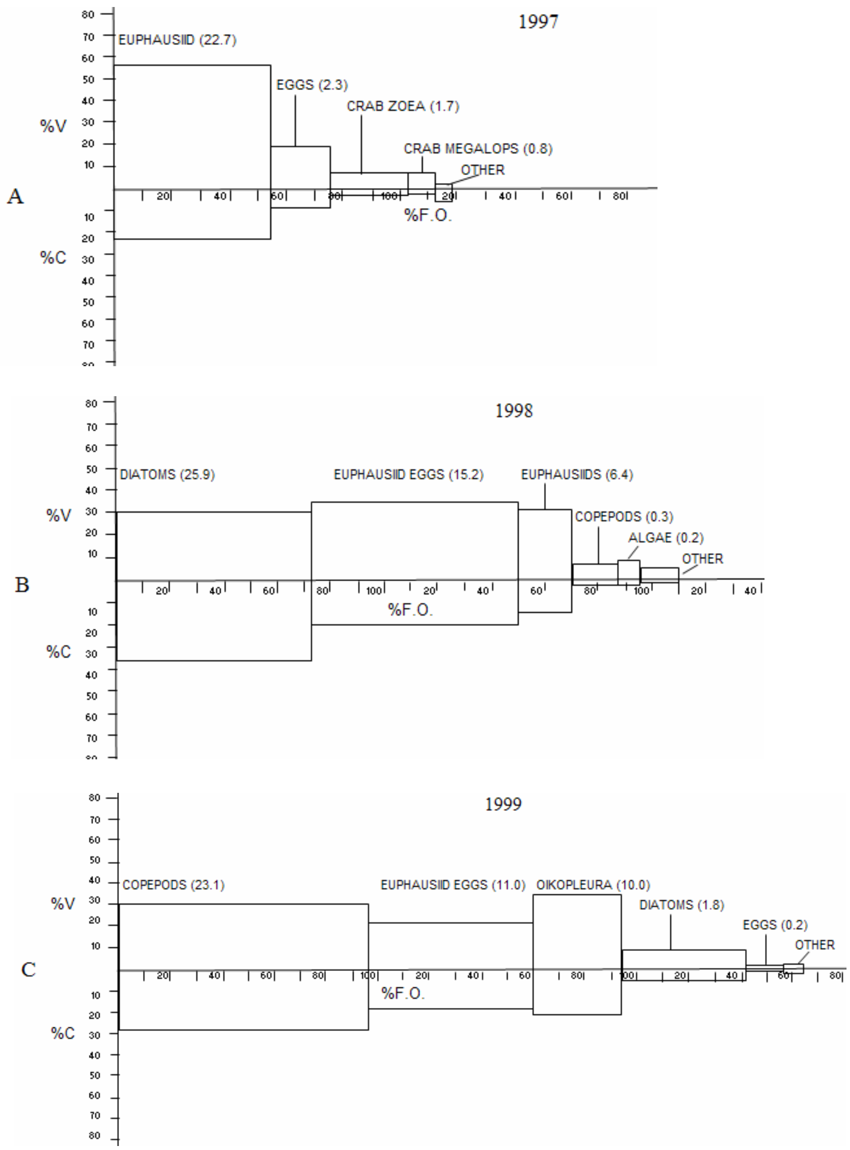

Figure 8. Three-way boxplots illustrating Relative Importance (%RI) values for prey items from Pacific sardine (*Sardinops sagax*) stomachs collected in (A) 1997, (B) 1998, and (C) 1999. Other category contains items with %RI values less than 0.1 for that year and may include: amphipod, barnacle nauplii and cyprids, chaetognath, cladoceran, copepod, crab megalops and zoea, cyclopoid, euphausiid, fish eggs and larvae, gastropod, oikopleura, and shrimp zoea.

and 2001 but were rarely consumed in 1997 and 1998. The absence of copepods in the sardine diet in 1997 may be coincident with a marked decrease in total copepod abundance in the North Pacific (Ocean Station Papa) in the spring of 1997 (Goldblatt et al. 1999) and illustrates the opportunistic feeding behavior of sardines.

Temperature The apparent change in the distribution of sardines in Canadian waters from offshore waters to inshore waters since 2002 was investigated by analyzing recent SST data from lighthouses and ocean buoys (fig. 11). We examined recent trends in SST for June, July, and August; the likely period of arrival of sardines in British Columbia waters. It is evident from the lighthouse data that in most years, with the exception of the 1992–93 and 1997–98 El Niño years, that surface waters did not reach 12°C until July (fig. 12). Similarly, the inshore buoys 46132 off Brooks Peninsula and 46185 in Hecate Strait did not reach 12°C until July. Only buoy 46206 on La Perouse bank consistently experienced SSTs above 12°C in all years in June (fig. 12). The offshore buoys consistently indicated colder conditions than the inshore buoys with SSTs in some years not reaching 12°C until August (i.e. 1999; fig. 13). In fact, buoy 46207 off the north end of Vancouver Island also indicated a declining trend in SST during June. The SST data from this region suggest that conditions in the offshore areas

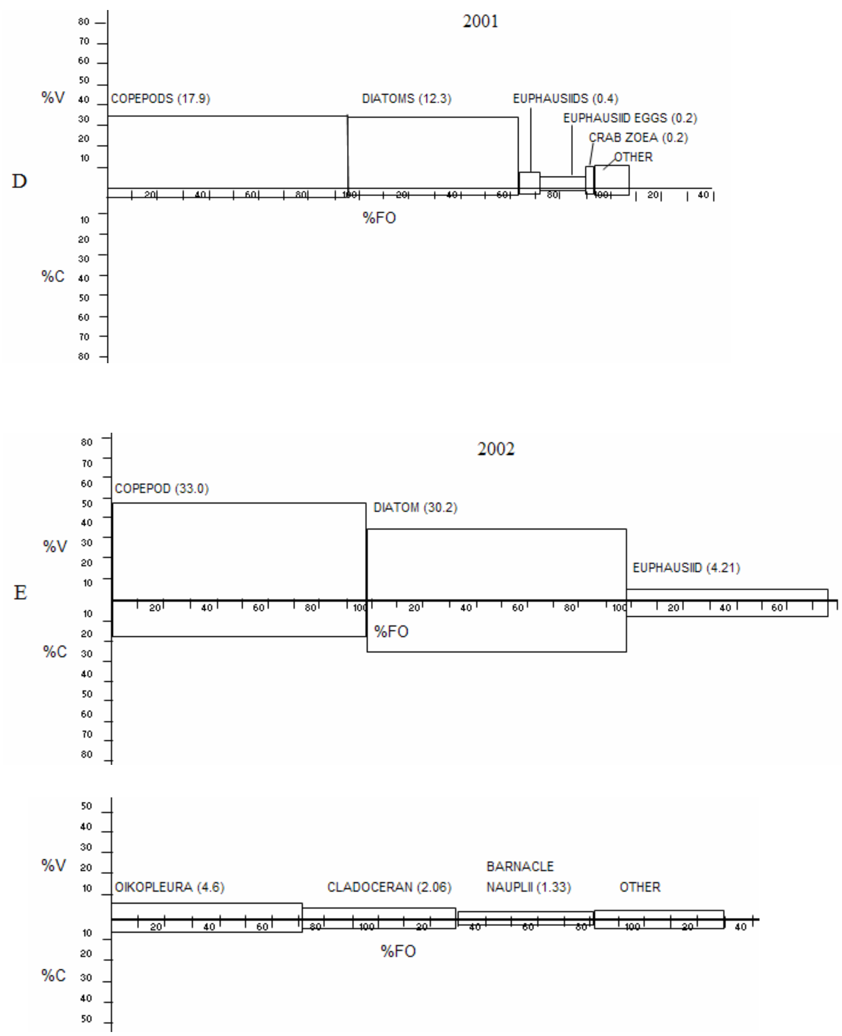

Figure 8 (continued). Three-way boxplots illustrating Relative Importance (%RI) values for prey items from Pacific sardine (*Sardinops sagax*) stomachs collected in (D) 2001, and (E) 2002. Other category contains items with %RI values less than 0.1 for that year and may include: amphipod, barnacle nauplii and cyprids, chaetognath, cladoceran, copepod, crab megalops and zoea, cyclopoid, euphausiid, fish eggs and larvae, gastropod, oikopleura, and shrimp zoea.

have been less favorable to sardines than in the inshore waters and that in recent years the highest water temperatures have occurred in the inshore areas near the mouth of Barkley Sound early in the year.

DISCUSSION

The management of the sardine fishery in Canada is based on the presumption that a portion of the population will continue to migrate north and be accessible to local fishers. The estimate of the migration rate of sardines into Canadian waters is based on the historically observed catch of sardines in Canada relative to that in the United States. From 1916 to 1947, the Canadian catch amounted to about 10% of the combined catch, suggesting on average a 10% annual northward migration rate. From the mid-1990s to 2001, sardines were widely distributed in the offshore areas near Vancouver Island, and their relative abundance could be determined by a standardized trawl survey. These surveys supported the 10% annual migration rate. However, more recently it appears that the bulk of the sardine migration has contracted shoreward and into the inlets along the WCVI where they are less accessible to trawling. The regional pattern of sardine distribution in recent years appears to be broadly consistent with observed local SST patterns.

The annual Canadian harvest is based on the United States assessment of coast-wide stock abundance, an assumed 10% migration rate, and the harvest rate adopted for the United States fishery. To date, 50 licensees have been allocated 300 t individual quotas, of which half were dedicated to First Nations fishers. Relatively few of these have been accessed. Further expansion of the fishery will be contingent on the development of markets and the continued northward migration and avail-

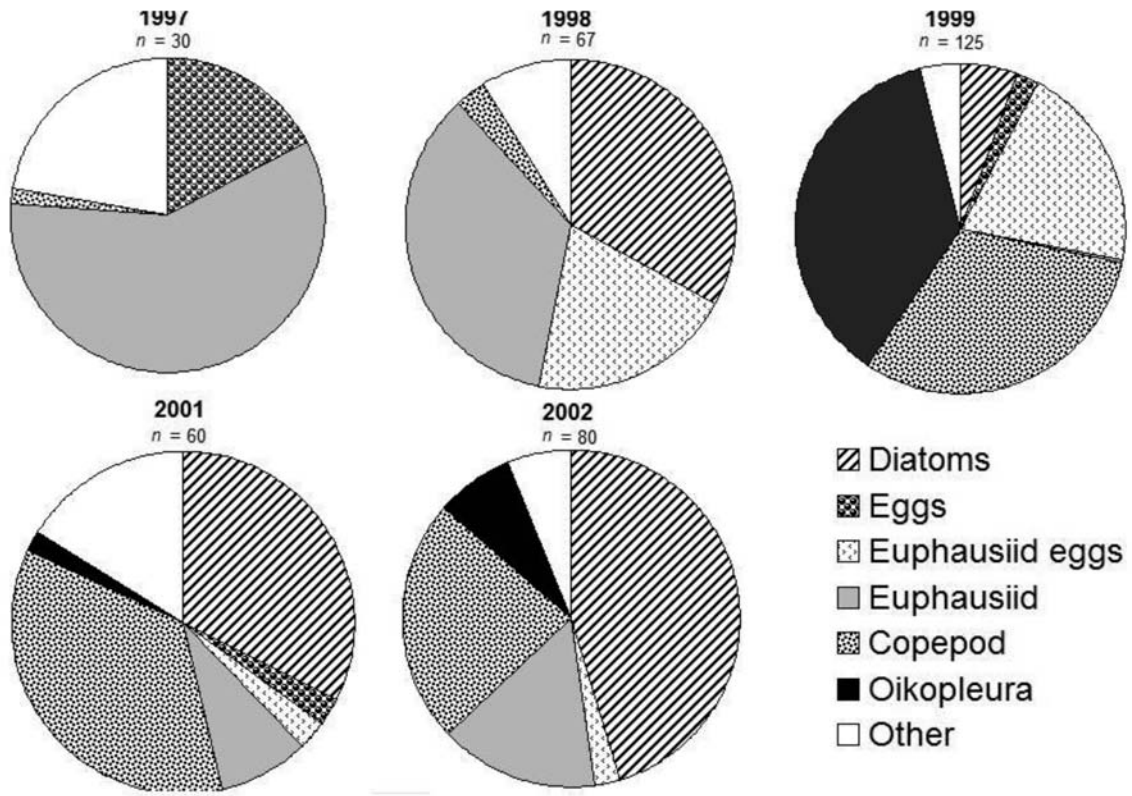

Figure 9. Major prey items by average % volume per Pacific sardine (*Sardinops sagax*) stomach, 1997–2002.

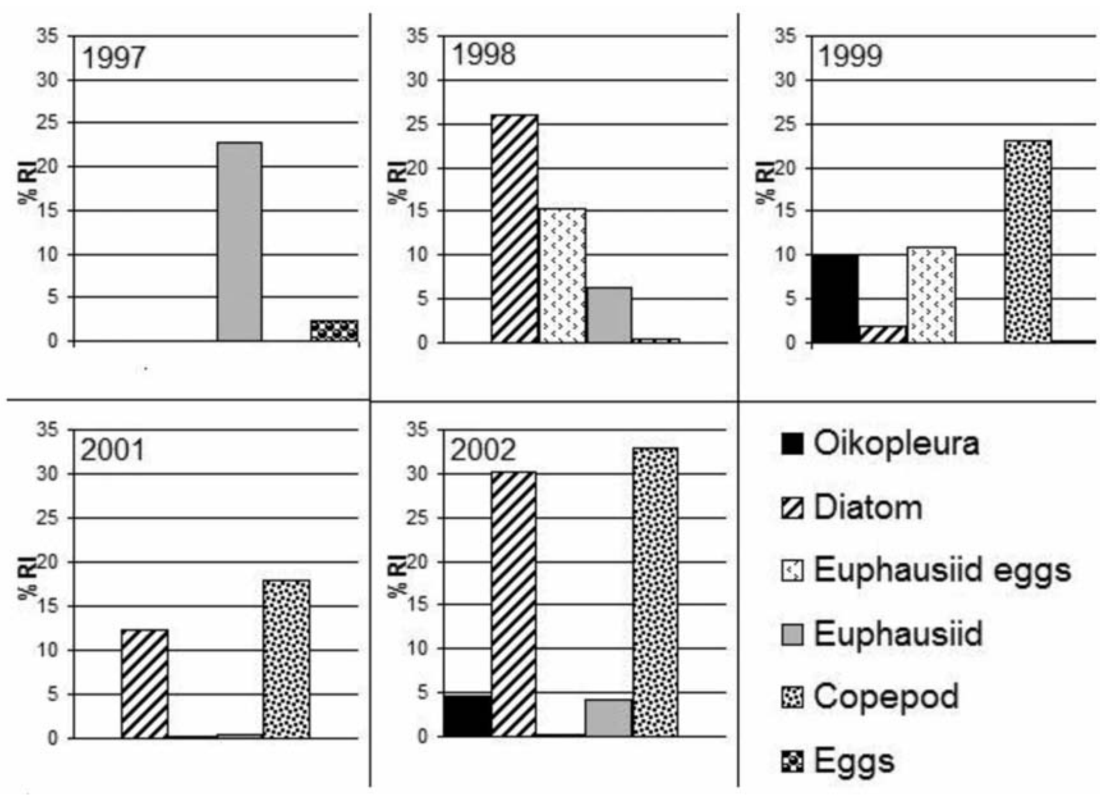

Figure 10. Major prey items of Pacific sardine (*Sardinops sagax*) by Relative Importance (%RI) value, 1997–2002.

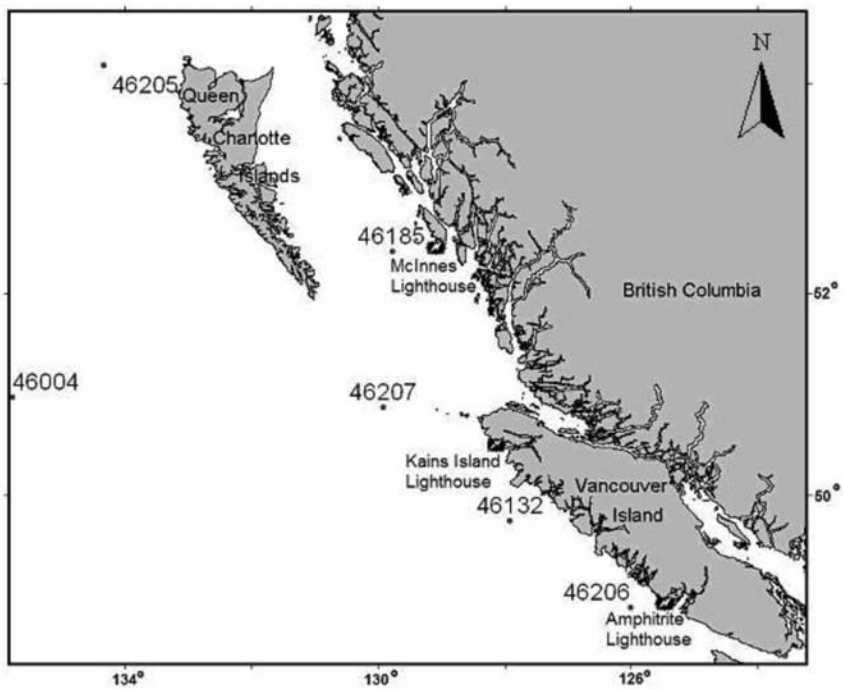

Figure 11. Location of ocean buoys (inshore and offshore) and lighthouse stations providing temperature data, 1990–2003.

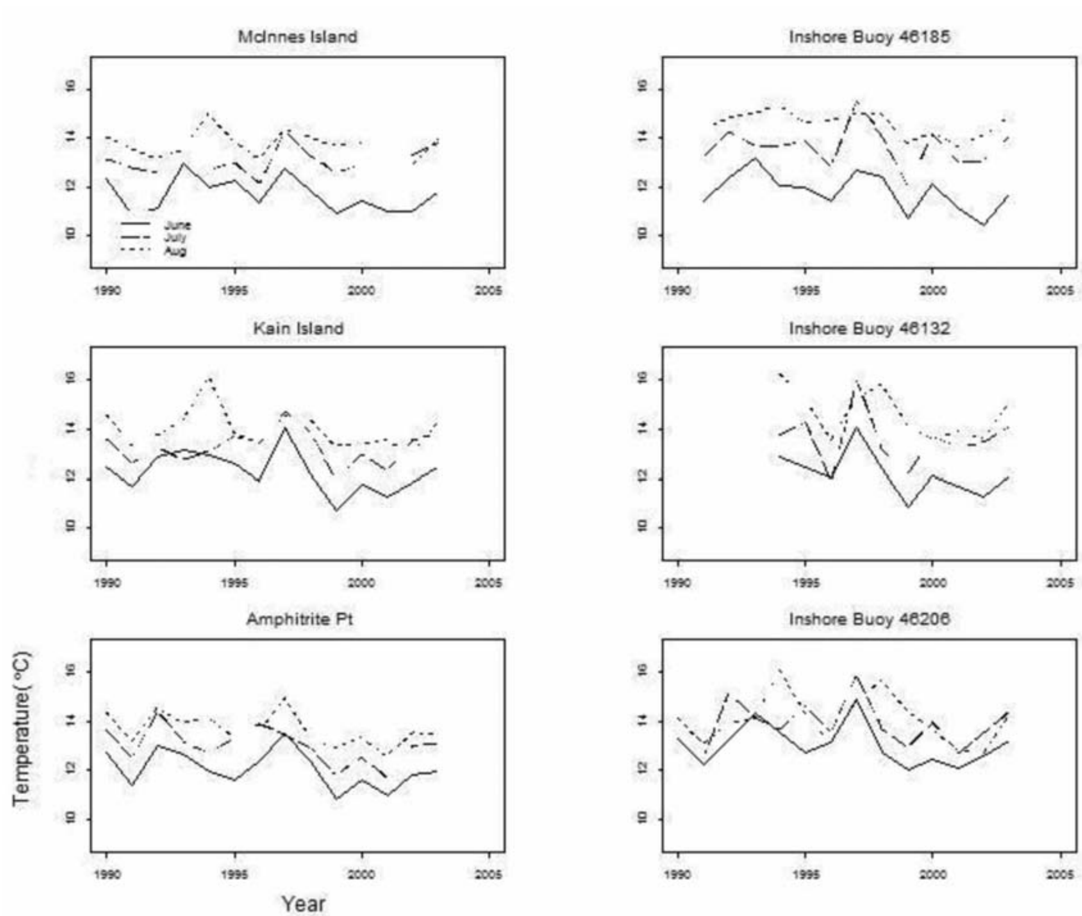

Figure 12. Sea surface temperature conditions during June–August for lighthouse stations and inshore buoys from 1990–2003 off the west coast of British Columbia.

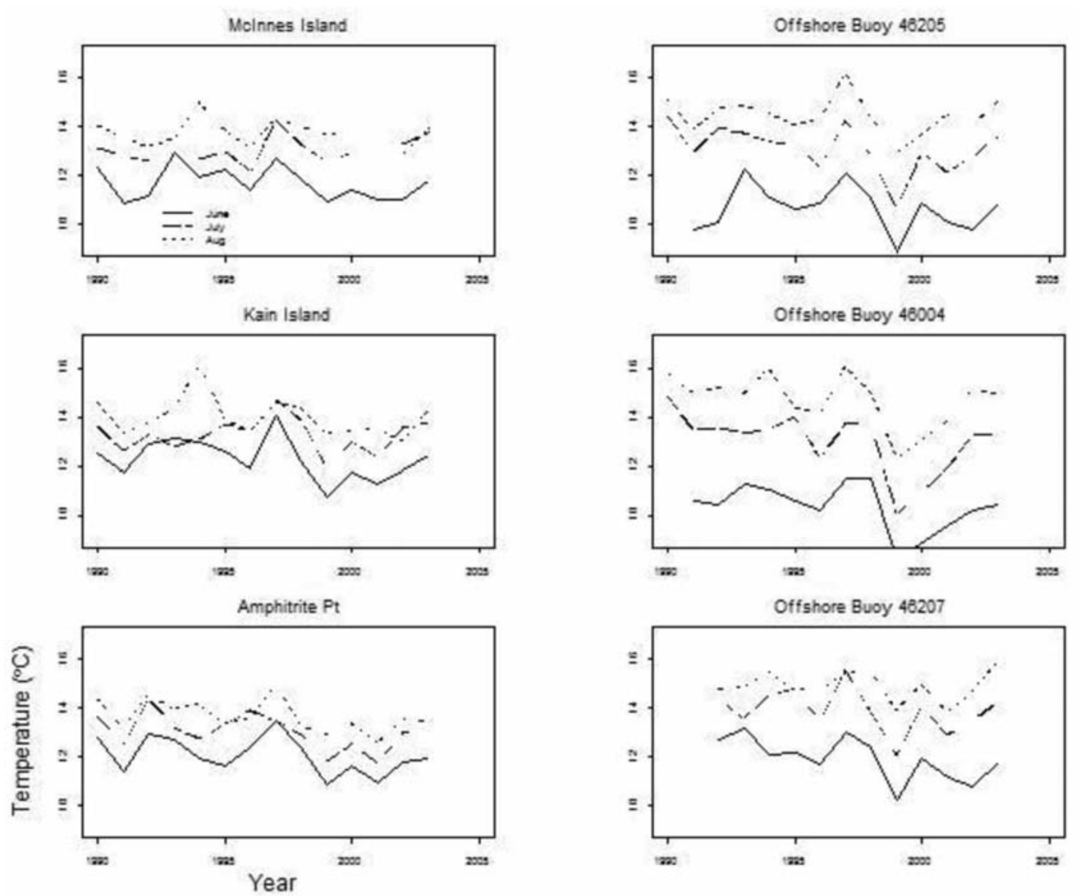

Figure 13. Sea surface temperature conditions during June–August for lighthouse stations and offshore buoys from 1990–2003 off the west coast of British Columbia.

ability of sardines in Canada. A better understanding of the biological and oceanographic factors that determine the migration timing and relative abundance or availability of sardines to Canadian fishers will be crucial to the longer-term viability of this fishery.

Historically, sardines entered British Columbia waters in mid-June and returned to southern spawning grounds (California) in mid-October. Most spawning occurred from April to June in the southern California Bight. It was primarily the older, larger sardines which migrated north to feed off British Columbia. Hart (1943) noted that in some years some sardines remained in the inlets off the WCVI throughout the winter. In 1992, sardines reappeared in British Columbia waters (Hargreaves et al. 1994) after a total absence of over 40 years. They have increased in abundance in Canadian waters and now are a dominant species in the surface waters. As in the 1930s and 1940s, it is primarily the older, larger sardines which enter Canadian waters to feed. The unexpectedly large increase in the abundance of sardines has radically changed our ideas about the causes of the collapse of sardine populations in the 1940s. The traditional explanation of overfishing being the principal cause for the collapse is no longer tenable and needs to be re-examined. It is now clear that large-scale fluctuations in oceanic conditions affected their distribution, spawning behavior, and survival. Fishing pressure undoubtedly may have affected the rate of change, but the population dynamics were reflecting the new dynamics of their ecosystem.

Dominant prey groups found in sardine diet each year match groups identified by Mackas and Tsuda (1999) as major contributors to the zooplankton biomass throughout the oceanic subarctic Pacific, both locally and at a basin scale. Mackas et al. (2001) found most zooplankton taxa underwent large year-to-year variations in abundance during the study period (1985–99) off the WCVI. For example, the euphausiids *Euphausiida pacifica* and *Thysanoessa spinifera* were low in abundance before 1987, increased in abundance in the late 1980s through the early 1990s, then levelled off or declined by the late 1990s (Mackas et al. 2001). Our diet data indicate that *E. pacifica* and *T. spinifera* were important prey items in 1998 but declined in importance thereafter. The calanoid copepod *Acartia longiremis* has been increasingly important in stomach contents since 1999 but was not identified from contents in 1998. This may also be an indication of species assemblage shifts, as Mackas et al. (2001) report a population recovery of "boreal" copepod species (*Acartia longiremis*, *Calanus marshallae*, *Pseudocalanus mimus*) in 1999 following low levels through the 1990s.

A number of biotic and abiotic factors have been examined to explain the expansion and contraction of sardine populations in the North Pacific Ocean (reviewed in McFarlane et al. 2002). Answering the question as to why sardines shifted their range northward in the early 1990s may be key to understanding the mechanism controlling their abundance changes. McFarlane and Beamish (2001) suggested that these fluctuations in abundance and northern distribution may initially be related to changes in the species composition and availability of phytoplankton in northern waters. Whatever the mechanism, it is generally recognized that the expansion and contraction of sardine populations are likely to continue in response to large-scale changes in ocean conditions. This will require assessments and management strategies that are responsive to trends in climate/ocean systems. Canadian and U.S. assessment and management strategies do not, at present, recognize these trends. However, current studies along the west coast of North America, from Canada to Mexico, are now collecting the information needed to develop future strategies which will incorporate large-scale regime changes. The information in this paper should be useful in the future development of ecosystem approaches to the management of sardines.

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