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8. Spiny Dogfish in the Pelagic Waters of the Strait of Georgia and Puget Sound

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Abstract.—Spiny dogfish *Squalus acanthias* have been an important commercial species on Canada's Pacific coast for more than 130 years. In this study we show that the spiny dogfish life history results in juveniles remaining in pelagic waters for 10–15 years after birth, with lengths up to about 60 cm. Abundance estimates show that the numbers of these young dogfish, as well as some older dogfish in the pelagic waters, appear to represent a relatively large percentage of the population in these two regions. Dietary analysis shows that while euphausiids and teleosts constitute the major food items, regardless of size/age, dogfish feed on a number of species within the ecosystem. After about 15 years, there is a movement into demersal habitats where individuals eventually mature. Because dogfish are long lived, and because they are found throughout the pelagic zone and demersal habitats, it is probable that they play a key role in the Strait of Georgia and Puget Sound ecosystems.

Introduction

The fishery for spiny dogfish *Squalus acanthias* was one of the first commercial fisheries on the Pacific coast of Canada, dating back to the 1870s (Anderson 1877). Dogfish have been fished using gear set or towed on the ocean bottom (Ketchen 1986). Consequently, the biology of dogfish was described from fish that were collected in these demersal fisheries. It was not until the mid 1970s that it was known that juvenile dogfish remain in the pelagic waters for approximately 10–15 years (Beamish and Smith 1976). In this paper we provide new information about the pelagic residence of dogfish for the Strait of Georgia and Puget Sound as a result of an extensive survey program to study juvenile Pacific salmon (Sweeting et al. 2003; Beamish et al. 2004a; Beamish et al. 2004b). Incidental catches of dogfish in this study provide new information about the size, sex composition, diet, and abundances of dogfish that reside in the water column of these two ecosystems. The surveys also provide information on the response of juvenile dogfish before and after the 1998 regime shift (Beamish et al. 2000a; King 2005). In addition, we report the results of the early studies of the biology of juvenile dogfish in surface waters as they relate to the most recent studies.

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Methods

As part of our juvenile salmon studies, we have conducted surveys in the Strait of Georgia along the same track line since 1997 (Figure 1). There have been 17 cruises and 1,523 sets since 1997 (Table 1). All sets were made using a modified rope trawl, as described in Beamish et al. (2000b). Briefly, depths for each set are randomly assigned within depth strata with about 70% weighted towards the top 30 m of the water column, as this is the stratum that contains most juvenile Pacific salmon in the summer. Each set was 30 min in duration, with a net opening ranging from approximately 14 × 30 m at the surface to approximately 20 × 40 m at 60 m or greater. The net was towed at 5 knots during surface tows, but slightly slower at depth. Because the average net depth is about 15 m, the water column was stratified by 15-m increments for fishing (i.e., 0–15 m, 15–30 m,

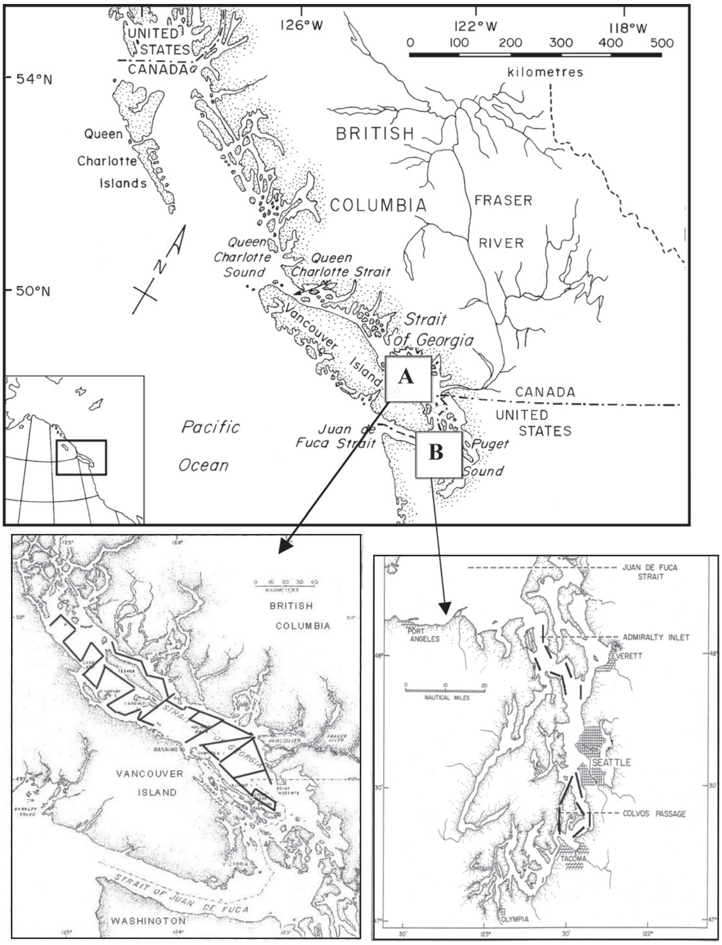

Figure 1. General location of survey sets in (A) Strait of Georgia and (B) Puget Sound.

Table 1. The number of sets in the 1997–2005 July and September surveys in the Strait of Georgia and Puget Sound.

	Strait of Georgia		Puget Sound		
Year	Jul	Sep	Jul	Sep	Total
1997	69	128	14	12	223
1998	95	95	10	9	209
1999	98	85	8	8	199
2000	85	91	3	15	194
2001	89	102	9	17	217
2002	93	78	13	16	200
2003	-	91	-	-	91
2004	105	72	16	16	209
2005	81	66	16	17	180
Total	715	808	89	110	1,722

30–45 m, 45–60 m, etc.). Strata were subsequently combined to facilitate analysis, producing four total strata: 0–29 m, 30–59 m, 60–100 m, and 100 m plus) (Table 2).

There have been 16 cruises and 199 sets in Puget Sound since 1997 and the track lines are also shown in Figure 1. The number of sets (Table 1) and fishing effort (Table 2) have been lower in Puget Sound than for corresponding surveys in Strait of Georgia, in part due to management restraints and in part due to shipping traffic in the narrower Puget Sound. Sets were shorter in duration (10–20 min) than in the Strait of Georgia, but all other factors (vessel, gear, speed, net opening, and depth strata) were as noted for the Strait of Georgia.

At the end of each set, the total catch was emptied into totes and sorted. Spiny dogfish sorted from each catch were counted or numbers were estimated for exceptionally large catches. In smaller sets, all dogfish were sexed and measured whereas in larger sets, random samples were taken. The length of the fish from the tip of the head to the tip of the dorsal part of the caudal fin bent horizontally was recorded to the nearest millimeter. When time permitted, the portion of the gut anterior of the cardiac sphincter and posterior of the pyloric sphincter was opened at sea and contents identified by an expert familiar with plankton and nekton (King and Beamish 2000). The total prey volume and percent contribution of the major diet items were estimated for each dogfish examined. All other dogfish were either returned to the ocean as quickly as possible or allowed to recover in a flow-through tank on deck before being released. Gut contents were not examined for dogfish in Puget Sound, in part owing to lack of sufficient time and in part owing to management and conservation mandates.

Estimates of the number of spiny dogfish in the Strait of Georgia and Puget Sound were made using the swept volume method described in Beamish et al. (2000b) as well as in Palsson (2009, this volume). Basically, the catch of dogfish in the volume of the water fished for each stratum is expanded for the total habitat area for each stratum. For the purposes of this study, the total habitat volume is assumed to be equal for each stratum (i.e., no consideration of slope with depth). Depths from 60 m to 100 m were combined into one stratum. Depths greater than 100 m were not consistently performed in all surveys, thus we used an average catch for all surveys when estimating abundances in a combined stratum below 100 m (Table 3). The 1998 regime shift was first detected as a doubling of euphausiid biomass in 2000 (Beamish et al. 2001). Thus, comparisons were made for the years before 1997–1999 and from 2000 to 2005 (note that no surveys were conducted in the Strait of Georgia in July of 2003 or in Puget Sound in July and September of 2003).

Statistical significance was accepted at the $P \leq 0.05$ level. For comparison of multiple groups (such as average lengths per strata), analysis of variance (ANOVA) was used. The Student Newman Keuls test was subsequently used to identify significance within these group analyses. For comparisons between two groups, standard *t*-tests were used for parametric data and Welch's approximate *t*-test for nonparametric data (INSTAT, GraphPad Software, USA). Regressions and correlations were determined using the data analysis package in Excel 2002 (Microsoft Corporation, Redmond, Washington).

Table 2. Total fishing effort (hours), in 15-m increments, for 1997–2005 Strait of Georgia and Puget Sound surveys.

	Depth strata (m)						
	0–15	15–30	30–45	45–60	60–100	100 +	Total
Strait of Georgia							
Summer	168.1	75.5	53.5	37.7	20.05	9.3	364.15
Fall	206.9	92.4	60.1	22.6	14.25	12.25	408.5
Puget Sound							
Summer	13.4	8.6	3.4	0.8	1.25	3.08	30.53
Fall	23.6	11.4	5.6	0.3	0.9	3.32	45.12
Total	412.0	187.9	122.6	61.4	36.45	27.95	848.30

Table 3. The number of sets and dogfish catch in stratum 60–100 m, and stratum > 100 m. Catches between 60–100 m are combined into a single stratum and used for calculations. Catches greater than 100 m are not used in abundance estimates. Note that no surveys were conducted in July of 2003.

Survey year	60–100 m		>100 m	
	Number of sets	Catch	Number of sets	Catch
1997				
Jul	5	754	1	101
Sep	7	1,039	5	29
1998				
Jul	12	412	5	138
Sep	10	543	2	27
1999				
Jul	11	0	1	0
Sep	4	101	2	58
2000				
Jul	5	27	0	0
Sep	1	1	1	163
2001				
Jul	3	1	2	119
Sep	3	0	1	0
2002				
Jul	2	0	0	0
Sep	0	0	1	0
2003				
July	No survey		No survey	
Sep	4	55	2	33
2004				
Jul	3	11	0	0
Sep	3	0	0	0
2005				
Jul	0	0	0	0
Fall	1	0	0	0
Totals	74	2,944	23	668

Results

A. Strait of Georgia

A total of 31,183 spiny dogfish were captured in our 1997–2005 July and September surveys in the Strait of Georgia, of which 7,885 fish were sampled for length and sex (representing approximately 25% of both July and September surveys). Slightly more than one half (57% overall: 58.9% in July, 54.7% in September) were 60 cm or smaller and only13.3% were larger than 90 cm (12.4% in July, 16.8% in September). Average lengths in July were similar among the four depth strata used (Figure 2A–D), although there were significant differences (ANOVA, $F = 9.55$, $P < 0.01$). There was also a significant trend between strata depth and average length ($F = 16.65$, $P < 0.01$). A similar picture was observed for the September surveys (Figure 3A–D), although the average overall size was significantly larger (622.4 ± 234.88 mm versus 598.0 ± 216.79 mm; *t*-test, $t = 4.48$, $P < 0.01$). As in the July surveys, lengths were similar but significantly different at each strata (ANOVA, $F = 25.83$, $P < 0.01$). There was also a significant linear trend ($F = 71.83$, $P < 0.01$). For both the July and September Strait of Georgia surveys, dogfish captured deeper than 100 m had the smallest average length.

The percentage of males and females for the total sample of 7,885 fish in the Strait of Georgia was 47.0% and 52.2% for July and September surveys, respectively. For a small percentage (0.8%) of fish, sex was either not identified or not recorded. There were slightly more females in the catches from the September cruises than from the July cruises (56.2% versus 52.1%, respectively). Sex ratios among the depth strata and between the July and September samples ranged from 37% to 58% males. There were no clear trends in the ratio of sexes associated with increasing depths (Table 4). There was, however, a slightly greater percentage of females captured during September surveys than during July.

Catch per unit effort (CPUE) for all tows showed no apparent trend with depth (Figure 4A–4B). There were also no similarities in trends between the July and September data, other than the lowest CPUE being observed in the surface tows. Overall, the average CPUE for July surveys was higher than for September (55.2 versus 30.9, respectively), although not significantly so (*t*-test; $t = 0.797$, $P > 0.05$). Abundance estimates from the July surveys through to 2005 indicated a range of 1.54 million

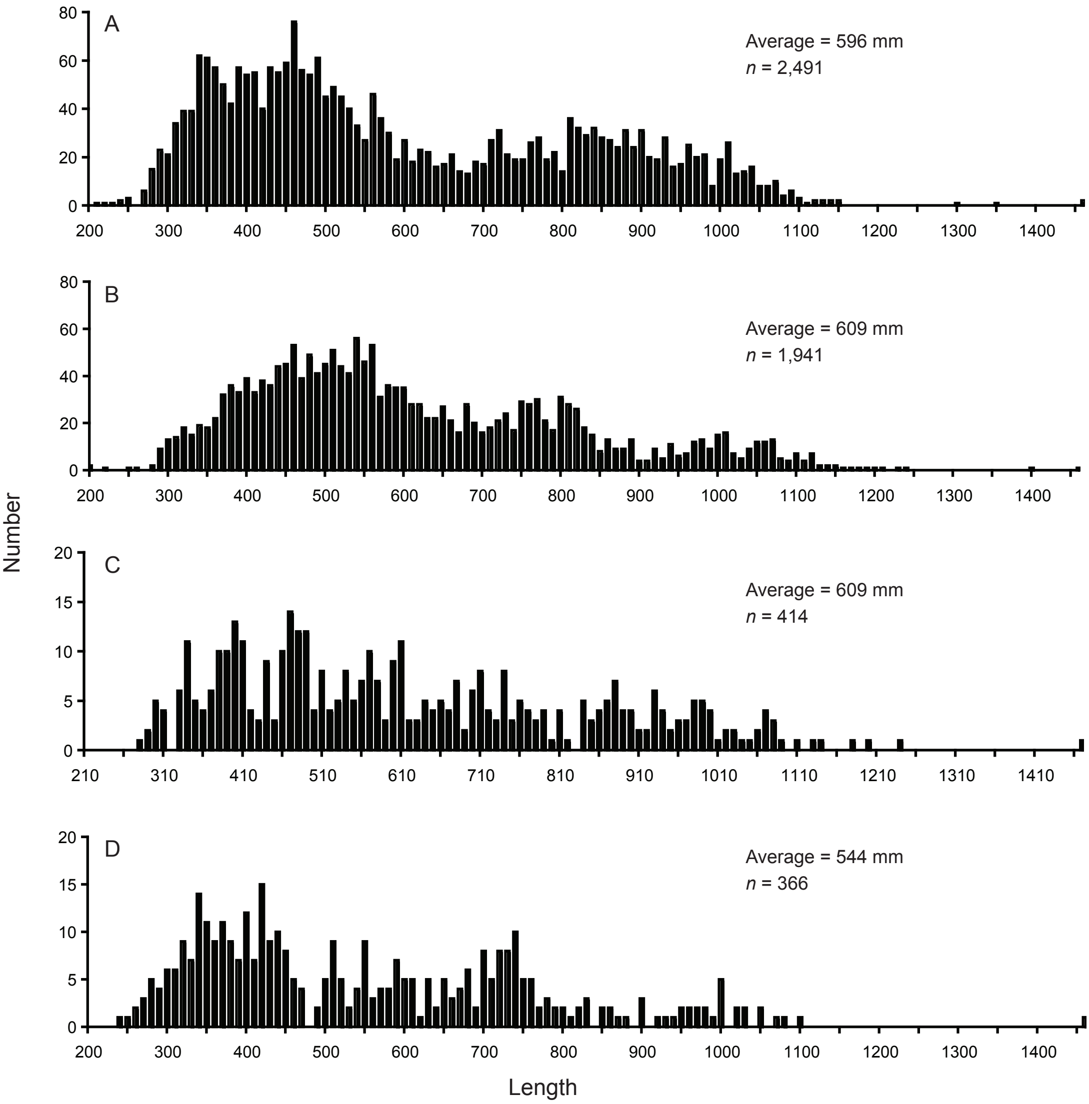

Figure 2. Length-frequency distributions for spiny dogfish captured in the Strait of Georgia in July surveys, 1997–2005. Depth ranges (m): (A) 0–30 m; (B) 30–60 m; (C) 60–100 m; (D) >100 m.

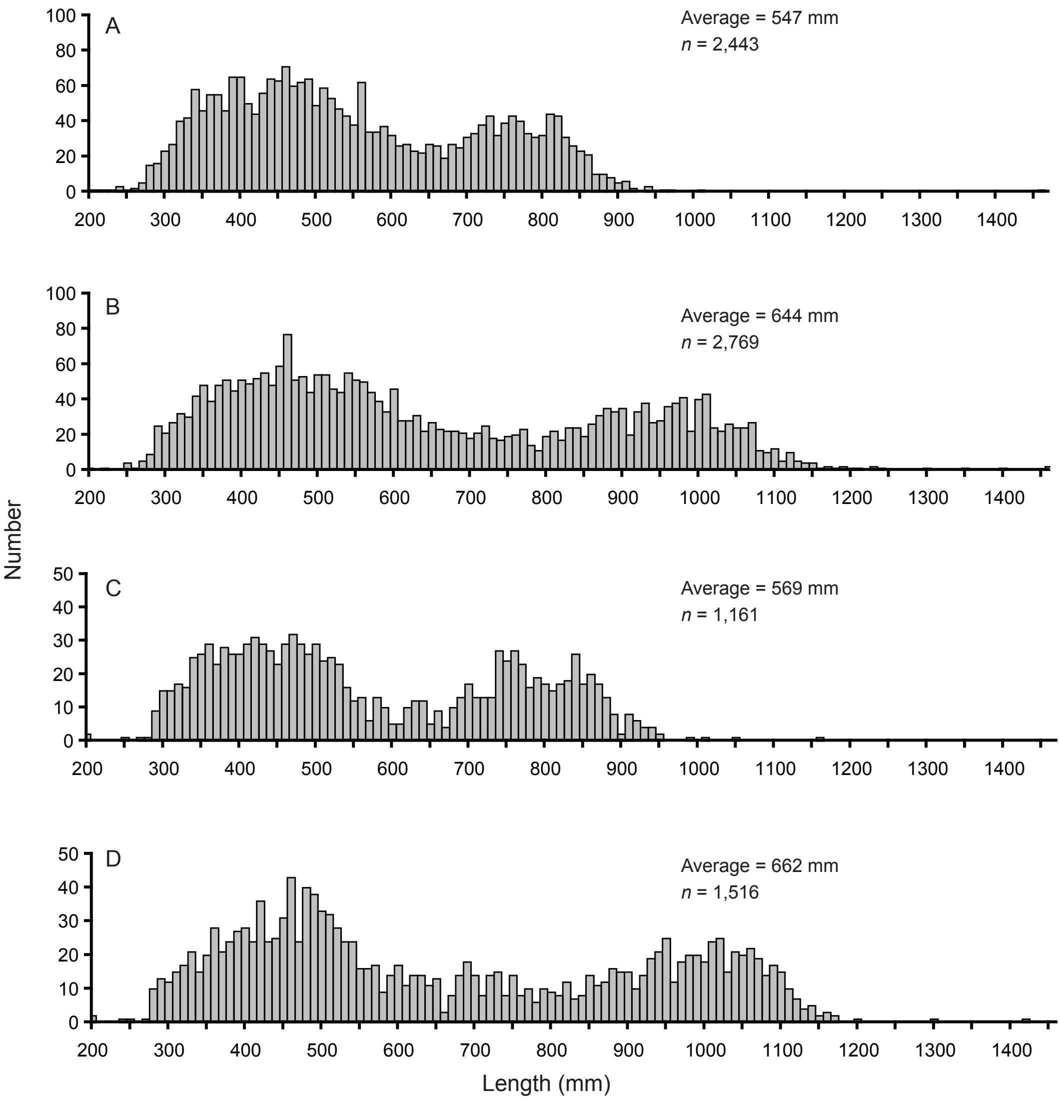

Figure 3. Length-frequency distributions for spiny dogfish sampled from surveys in the Strait of Georgia 1997–2005. (A) July males, (B) July females, (C) September males, (D) September females.

to 6.80 million fish with abundances in most years ranging between 2.0 and 4.0 million (Figure 5A, 5B) and averaging 3.21 million spiny dogfish. In July of 2000, the larger abundance estimated resulted from a single set in which 1,188 dogfish were captured (52% of the total catch). In July 2005, there was also one exceptional catch that was estimated to be approximately 9,000 dogfish. If this set was included in the calculation for the abundance estimate, the estimate would be 24 million fish. Excluding this one set produced an estimate of 2.3 million fish. The abundances in July before 2000 (2.71 million) and from 2000 to 2005 (3.08 million) were similar. Abundances in September declined steadily after 2000 with very few dogfish captured in September 2002, 2003, and 2004 (Figure 5B). In September 2005 there was one set that captured large numbers of dogfish (5,000 individuals). If this set is excluded, the abundance estimate is 0.52 million and is consistent with the reduced catches beginning in 2002.

Table 4. Sex ratios of spiny dogfish, by strata, captured during 1997–2005 July and September surveys in the Strait of Georgia.

		Catch			Percentage		
	Strata	Male	Female	Unknown	Male	Female	Unknown
Jul	0–30 m	1,099	1,048	4	51.1	48.7	0.19
	30–60 m	818	919	47	43.6	51.5	2.63
	60–100 m	155	258	1	37.4	62.3	0.24
	>100 m	211	153	2	57.7	41.8	0.55
	Totals	2,283	2,378	54	48.4	50.4	1.15
Sep	0–30 m	675	1,246	3	35.1	64.9	0.16
	30–60 m	284	295	2	48.9	50.8	0.34
	60–100 m	264	275	3	48.7	50.7	0.55
	>100 m	184	208	4	46.5	52.5	1.01
	Totals	1,407	1,751	12	44.4	55.2	0.38

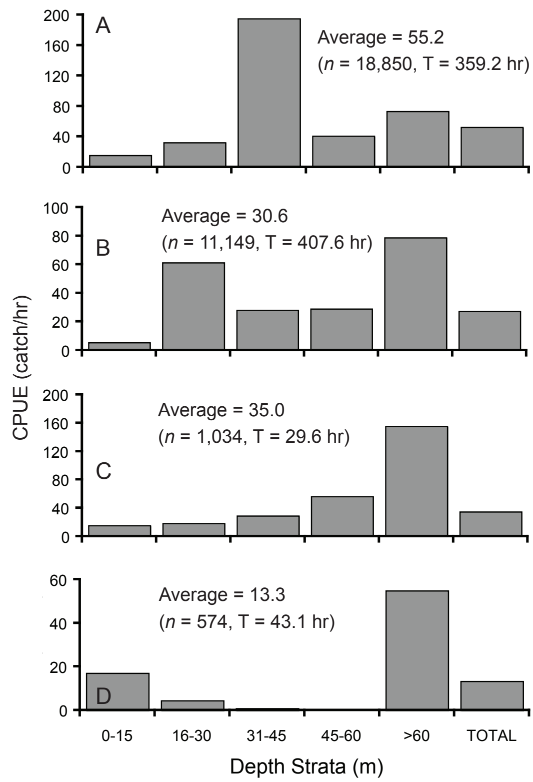

Figure 4. Average catch per unit effort (CPUE, catch per hour) for spiny dogfish captured in 15-m strata from 1997 to 2005 in the Strait of Georgia in the (A) summer and (B) fall, and in Puget Sound in the (C) summer, and (D) fall. Total catch and total time are shown for each group.

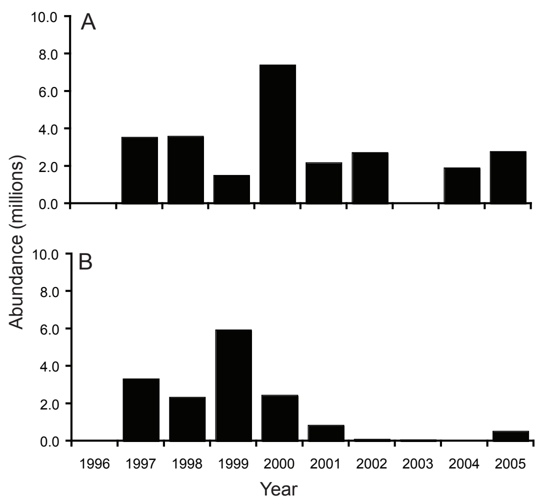

Figure 5. Abundance estimates for (A) July and (B) September surveys in the Strait of Georgia from 1997 to 2005.

The average abundances in September from 1997 to 1999 were 3.87 million, which compares to an average of 2.89 million for the same years in July. The overall average abundance in September was 1.73 million, reflective of decreasing catches after 2000. There was no apparent relationship between July and September abundance estimates.

A total of 1,103 stomachs were examined from surveys in the Strait of Georgia. Of the 493 spiny dogfish stomachs analyzed from July surveys, euphausiids and teleosts were the principal food items in the diets, representing 38.5% and 35.7% of all contents observed, respectively (Figure 6). Ctenophores were the third most common item observed, but the percentage was less than one half of euphausiids and fish. There was an increase in the percentages of fish and ctenophores seen in the July diet beginning in 2000 with a concomitant decrease in consumption of euphausiids (Figure 7A–7B). In July, females had larger percentages of fish and ctenophores in their diet, with a smaller percentage of euphausiids, than males (Figure 8A–8B). There was little difference in the overall September diets, with teleosts and euphausiids continuing as the dominant food items (Figure 9). There were also no major differences between regimes for the September data (Figure 10A–10B), although the proportion of ctenophore and decapods is generally reversed. As in July, there were major differences between male and female diets in September (Figure 11A–11B). Female dogfish in September had more euphausiids and decapods observed in their stomachs and fewer teleosts than did males.

When diet was compared by sizes 60 cm or smaller and larger than 60 cm (Figure 12), euphausi-

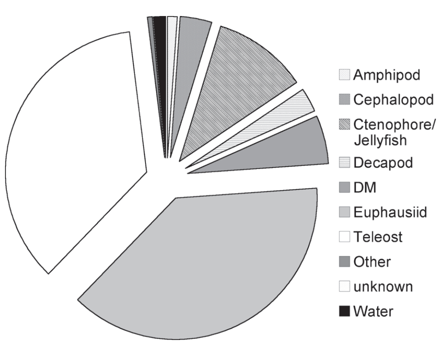

Figure 6. Diet for spiny dogfish captured in Strait of Georgia in July surveys 1997–2005.

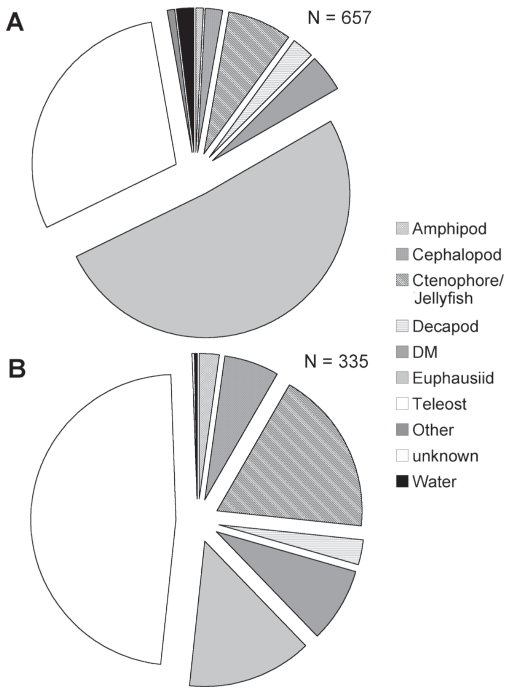

Figure 7. Diet for spiny dogfish captured in Strait of Georgia in July surveys from (A) 1997–1999 and (B) 2000–2005.

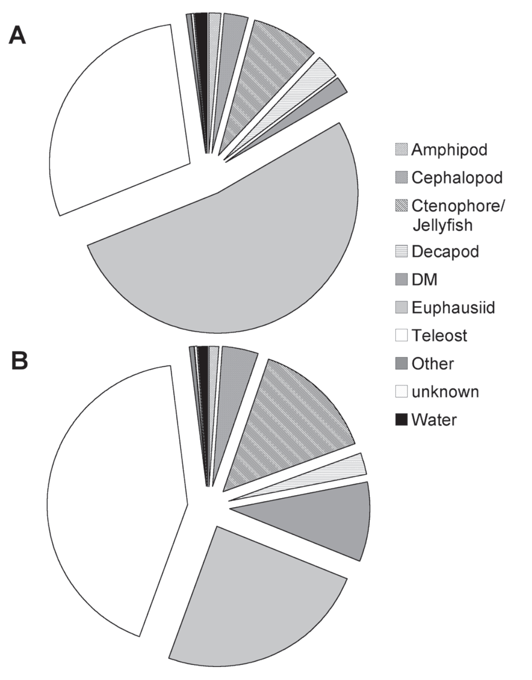

Figure 8. Diet for (A) male and (B) female spiny dogfish captured in Strait of Georgia in July surveys 1997–2005.

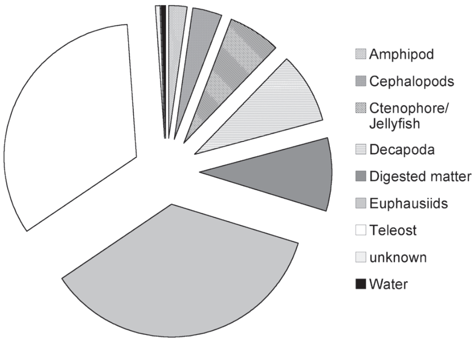

Figure 9. Diet for spiny dogfish captured in Strait of Georgia in September surveys 1997–2005.

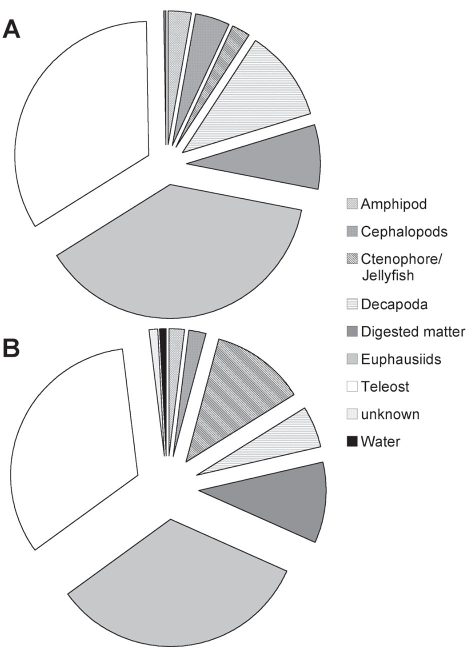

Figure 10. Diet for spiny dogfish captured in Strait of Georgia in September surveys from (A) 1997–1999 and (B) 2000–2005.

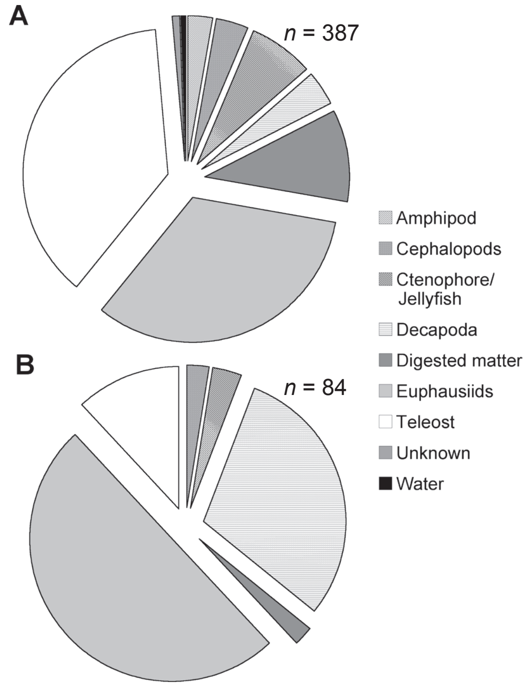

Figure 11. Diet for (A) male and (B) female spiny dogfish captured in Strait of Georgia in September surveys 1997–2005.

ids were the dominant prey in the smaller size group whereas teleosts constituted a greater proportion of the diet of the larger size group. This result was consistent for both the July and September surveys in the Strait of Georgia.

B. Puget Sound

There were 1,863 spiny dogfish sampled from a total catch of 1,982 in Puget Sound from 1997 to 2005 (Table 5, Figure 13). Many of the samples (69%) were 60 cm or smaller and only 1.2% were larger than 90 cm. The length frequencies of dogfish varied slightly among the depth strata (Figure 14). The smallest fish were least abundant in the mid-depths (30–60 and 60–100 m). Sex ratios in the July and September samples were virtually identical (Table 6), ranging between 35% and 63% males within the various strata with no trends. Most dogfish were captured at depths deeper than 45 m in both the July and September samples (61.4% and 62.4%, respectively; Figure 4C–4D). Abundance estimates

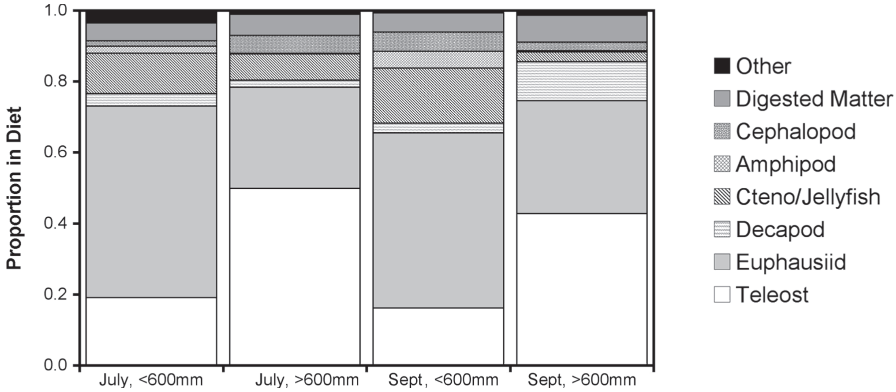

Figure 12. Diet for spiny dogfish captured in Strait of Georgia in July and September surveys in the Strait of Georgia from 1997 to 2005, by size category (<600 mm and >600 mm).

Table 5. Abundance estimates of spiny dogfish for the July and September surveys in Puget Sound, 1997–2005.

Survey	Number of sets	Catch	Abundance
Jul 97	13	99	538,000
Jul 98	10	151	1,592,000
Jul 99	7	283	4,151,000
Jul 00	3	43	1,725,000
Jul 01	9	169	2,061,000
Jul 02	13	4	27,000
Jul 03	–	–	No survey
Jul 04	16	244	2,394,000
Jul 05	16	44	346,000
Sep 97	14	10	54,000
Sep 98	9	15	154,000
Sep 99	8	8	1,373,000
Sep 00	15	22	116,000
Sep 01	16	402	2,114,000
Sep 02	14	20	192,000
Sep 03	–	–	No survey
Sep 04	15	0	0
Sep 05	17	1	6,000

in July ranged from 27,000 to 4.15 million fish and in September from 5,900 to 2.11 million fish (Figure 15). These estimates include only sets down to 100 m, as habitat volume estimates were not available below 100 m. The standardized data show extreme variation but, recognizing the relatively small amount of effort, there is some consistency in CPUE (Figure 16). (Also see Palsson 2009.)

C. *Previous studies*

Studies from 1974 to 1976 identified the existence of large numbers of juvenile spiny dogfish in the pelagic waters of the Strait of Georgia (Beamish and Smith 1976; Beamish et al. 1982). The results of these studies have not been published in the primary literature and are relevant to the results of our studies beginning in 1997. In these studies, dogfish were measured to the nearest centimeter and examined for sex and maturity. Spines from the second dorsal fin were collected, cleaned, and air-dried in envelopes for age determination as described by Ketchen (1975). Annuli were defined as elevated ridges of enamel that were complete on both anterior and lateral surfaces of the spine.

In July–August of 1974 and in July–September of 1975, 20 and 164 purse seine sets, respectively, were made in the surface waters of the Strait of Georgia from the M/V *Caligus*. The purse seine was 402 m long, 33 m deep with mesh sizes that varied from 6.4 cm in the lead to 0.6 cm in the bunt end. The principal study area for the purse seine surveys was the main body of the Strait of Georgia from the

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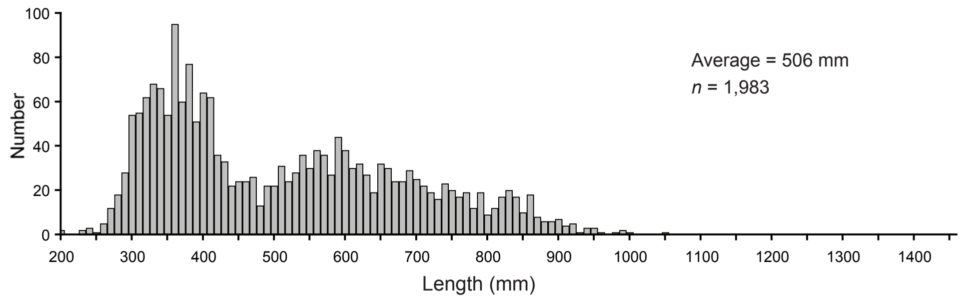

Figure 13. Length-frequency distribution of spiny dogfish from July and September surveys conducted in Puget Sound from 1997 to 2005.

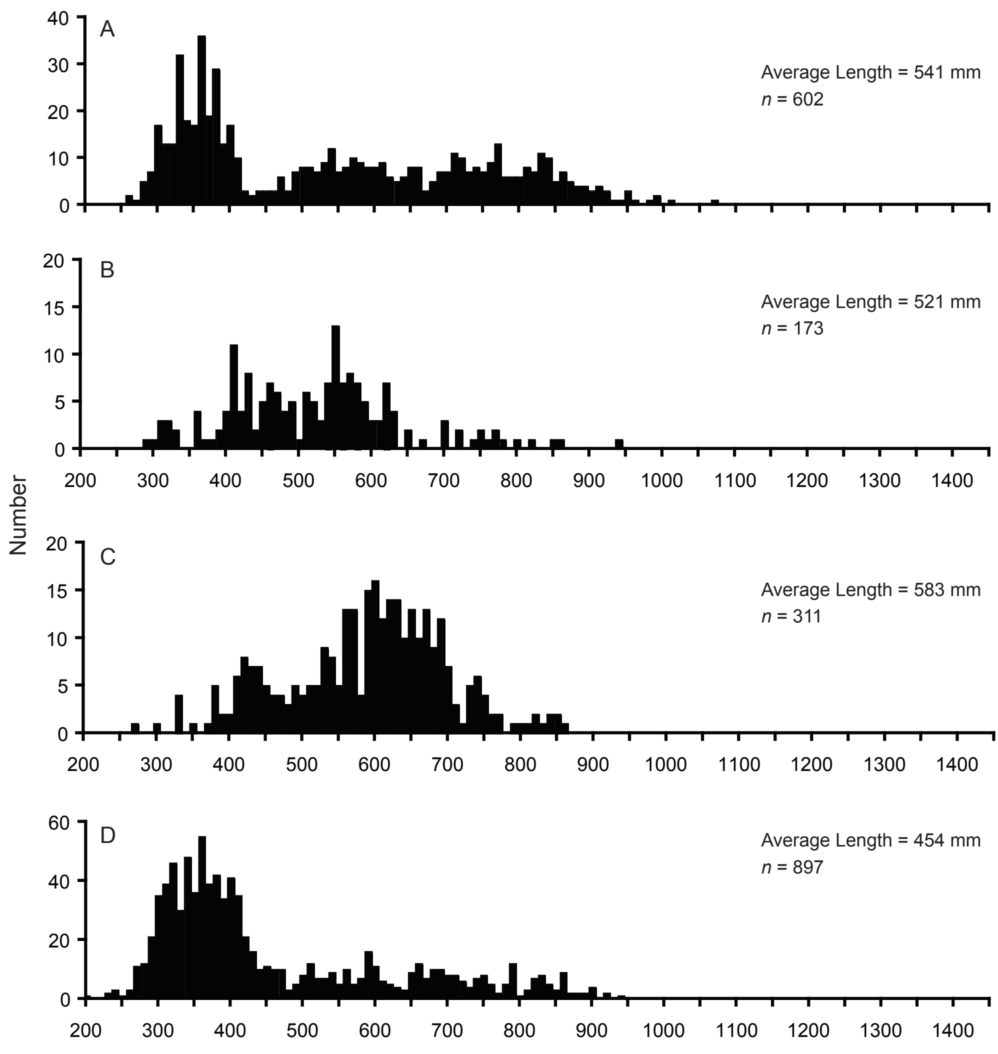

Figure 14. Length-frequency distributions of spiny dogfish captured in the Puget Sound surveys from 1997 to 2005. (A) 0–30 m depths, (B) 30–60 m depths, (C) 60–100 m depths, (D) >100 m.

Table 6. Sex ratios of spiny dogfish, by 30-m strata, captured during 1997–2002 and 2004–2005 July and September surveys in Puget Sound (no surveys in 2003).

		Catch			Percentage		
	Strata	Male	Female	Unknown	Male	Female	Unknown
Jul	0–30 m	218	125	1	63.4	36.3	0.29
	30–60 m	59	109	0	35.1	64.9	–
	60–100 m	132	179	0	42.4	57.6	–
	>100 m	131	137	1	48.7	50.9	0.37
	Totals	540	550	2	49.5	50.4	0.18
Sep	0–30 m	117	141	0	45.3	54.7	–
	30–60 m	3	2	0	60.0	40.0	–
	60–100 m	0	0	0	–	–	–
	>100 m	267	240	0	52.7	47.3	–
	Totals	387	383	0	50.3	49.7	–

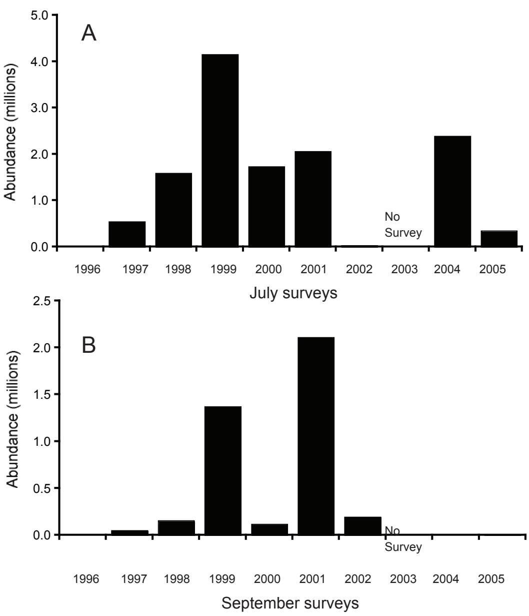

Figure 15. Abundance estimates for (A) July and (B) September surveys in Puget Sound from 1997 to 2005.

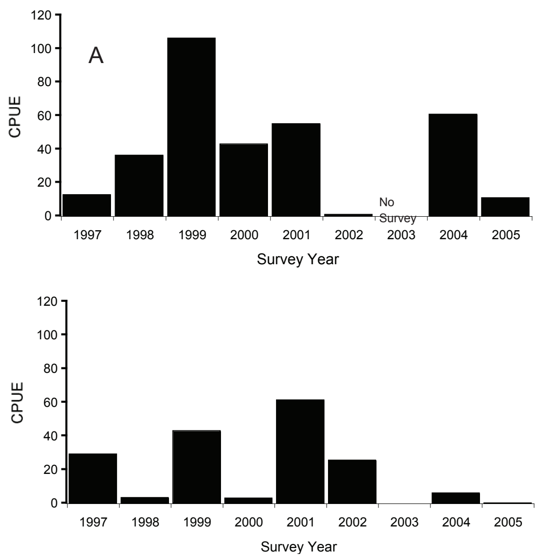

Figure 16. Catch per unit effort (CPUE; catch per hour) for dogfish in the (A) July and (B) September surveys conducted in Puget Sound from 1997 to 2005. (Note that no surveys were conducted in 2003.)

international boundary in the south to Cape Mudge in the north, including the Gulf Islands (Figure 1). A total of 4,540 spiny dogfish of 60 cm or smaller were captured in these two surveys (Table 7).

Also in 1975, an Engel 434 midwater trawl with a 25-mm cod end liner was fished from the *G. B. Reed* in three cruises, January 6–February 21, March 17–March 24, and June 16–June 27. In 1976 a Canadian Diamond 5-b midwater trawl with a 43.4 m headrope was fished by the *Arctic Harvester*. In the initial 29 tows by the *Arctic Harvester*, the cod end had a 3.8 stretched-mesh layer; in latter tows, the mesh was 2.5 cm stretched mesh layer. The study area for the trawl surveys included the Strait of Georgia, Juan de Fuca Strait, west coast of Vancouver Island, and the coasts of Washington and Oregon. These midwater trawl surveys in 1975 and 1976 conducted 129 sets, resulting in the capture and sampling of 3,919 dogfish 60 cm and smaller (Table 7).

The smallest fish in the combined 1974 and 1975 purse seine and trawl samples was 20 cm, with most fish ranging from 29 cm to 38 cm (57% of the sample) for a mean size of 43.1 cm ± 6.5 (Figure 17). A sub-sample of 153 fish from the June 1975 midwater trawl sample was aged. No annuli were worn off the distal portion of the spine; thus it was not necessary to attempt to estimate missing annuli. Fish ranged from 0+ to 11+ years old (Figure 18). The mean annual growth increments indicate that average growth declined each year from 4.6 cm between June of the first summer (age 0+) and June of the second summer (age 1+) to approximately 1 cm after about 4 years. Sample sizes for fish age 8+ and older were small and probably not representative of average annual growth.

Table 7. The number of sets in surveys conducted in the Strait of Georgia during 1974–1975.

		Number of dogfish sampled	
	Number of sets	≤60 cm	>60 cm
Purse seine			
Jul–Aug 1974	20	368	5
Mid-water trawl			
Jan–Feb 1975	55	2,582	444
Mar 1975	20	179	163
Jun 1975	54	1,158	62

In the 1976 midwater trawl surveys, no dogfish were captured off the coasts of Washington and Oregon. In the Strait of Georgia, most juvenile dogfish were in the size range of about 32 cm to 42 cm, while most juvenile dogfish caught in Juan de Fuca Strait and off the west coast of Vancouver Island ranged from 29 cm to about 35 cm (Figure 19). Samples for age determination were collected from the total catch of 13 consecutive sets in the Strait of Georgia, except for one set in which the catch was 533 individuals. In this set, the first 200 fish were sampled, resulting in a total sample of 944 fish. There were 53% male and 47% female fish in the sample. Annuli that were characterized by ridges and dark pigmentation were easily identified. Less easily distinguished annuli were not elevated from the spine base and formed weakly pigmented bands. There was some wear on the distal ends of the spines of some fish older than age 14, which required the estimation of lost annuli using the method described by Ketchen (1975). Most fish (87%) were age 10+ years or younger. Fish with an average age of up to 16 years had average lengths of 60 cm or smaller. The mean annuli increments were approximately 2 cm for the first 5 years of growth and less for subsequent years up to age 14 (Figure 20). Only 5% of the sample was determined to be older than 15 years; thus the mean size at age for fish older than 15 years is unlikely to be representative of average lengths within the population and is not shown in Figure 20. There was no trend in the mean sizes at age for male or female fish that indicated that growth up to age 15 was different for a particular sex.

Discussion

The studies in the 1970s and our recent surveys indicate that spiny dogfish commonly occur in the pelagic waters of their ocean habitat for ages up to about 15 years and lengths of 50–60 cm. Larger dogfish also occur in the pelagic waters but they are less numerous than younger individuals. The majority of dogfish in the commercial dogfish fisheries range from about 60–90 cm in the Strait of Georgia (Figure 21A) and from about 50 cm to 80 cm in Puget Sound (Figure 21B). These fisheries capture dogfish on the bottom using baited hooks and would be expected to be selective for larger fish (as seen in Figure 4A-D). It is apparent that there is a major difference between the size distributions of dogfish stocks in the pelagic waters and those of dogfish retained by

—*Text continues on page 116*

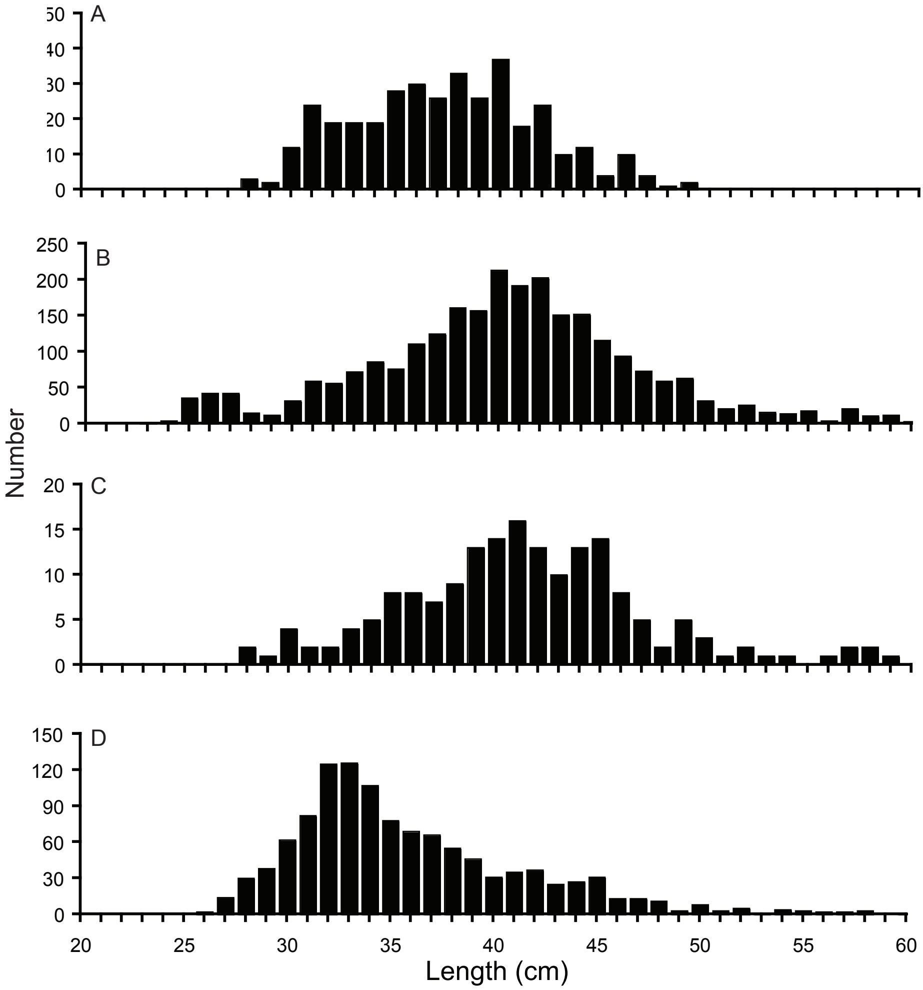

Figure 17. Length-frequency distributions of all spiny dogfish < 60 cm examined in (A) January–February 1975, (B) March 1975, (C) June 1975, and (D) July–August 1974 and July–September 1975.

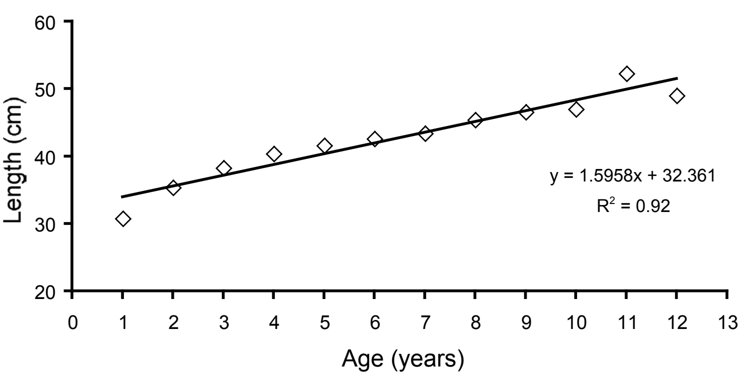

Figure 18. Ages of dogfish (determined from dorsal spine analysis) captured by midwater trawl in the Strait of Georgia in June of 1975.

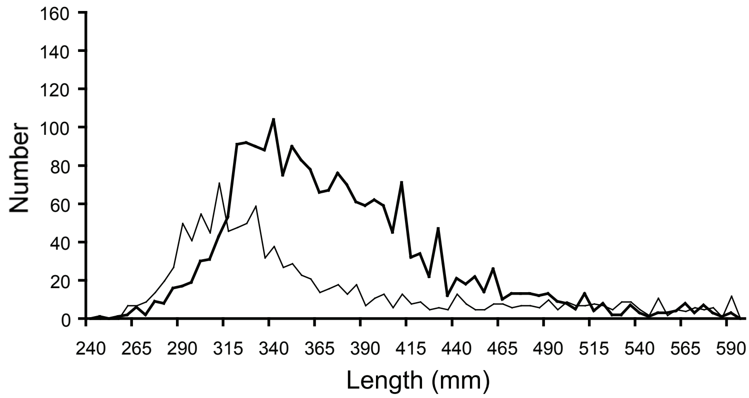

Figure 19. Length-frequency distribution of spiny dogfish from the Strait of Georgia (bold line) and combined sets from Juan de Fuca Strait and southwest Vancouver Island (thin line) in July 1976.

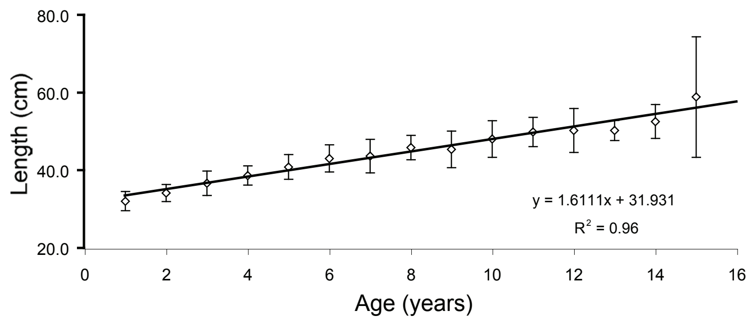

Figure 20. Growth curve estimates for spiny dogfish from combined midwater and purse seine catches from the Strait of Georgia in July 1976.

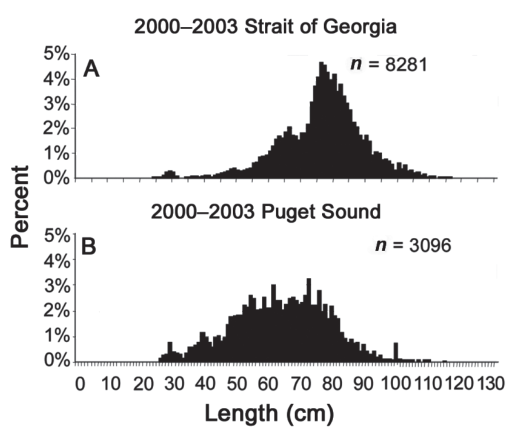

Figure 21. Length-frequency distributions of spiny dogfish in the commercial catch from (A) the Strait of Georgia and (B) Puget Sound from 2000 to 2003. (From McFarlane et al. 2004).

the commercial fisheries. Ages determined from the samples collected in the 1970s indicates that most of the smaller dogfish were age 10+ or younger with fish that averaged 16+ years having an average size of about 60 cm or smaller. Annual growth of these juvenile fish is only a few centimeters a year. The diet of juvenile fish consists mainly of plankton. Dogfish larger than 60 cm have diets consisting of about equal amounts of fish and plankton. Our study was primarily in the Strait of Georgia and Puget Sound. However, we observed in the 1970s that juvenile dogfish were common in the pelagic waters of Juan de Fuca Strait and off the west coast of Vancouver Island. Thus we conclude that the pelagic behavior is common to dogfish in general.

Estimates of the abundances of spiny dogfish in the pelagic waters and on bottom are needed to assess the relative importance of the pelagic habitat in the life history of dogfish. Our estimates of abundance are approximate as there are some assumptions that have major impacts on the calculations. For example, our estimation method does not have an accurate estimate of "catchability" of the net and assumes conservatively that all dogfish in front of the net opening are captured. Also, the estimates do not include dogfish in the pelagic waters deeper than 100 m. The abundance estimates for July and September in the Strait of Georgia could be about 4 million individuals for comparative purposes. (See also King and McFarlane 2009, this volume.)

Spiny dogfish are long lived and dogfish in the Strait of Georgia can be considered resident because tagging studies have shown only a small amount of movement out of the strait (McFarlane and King 2003; Beamish et al. 2006; King and McFarlane 2009). Thus our abundance estimates are probably approximate indicators of the importance of the pelagic habitat in the early life history of dogfish. To place a perspective on these estimates, we also estimated the total abundances of dogfish in the Strait of Georgia. We averaged the estimate of 40,000–60,000 mt used by Wood et al. (1979) for Puget Sound and the Strait of Georgia for an estimate of 50,000 mt. We divided this estimate equally between the two areas resulting in an estimate of 25,000 mt for the Strait of Georgia. If an average weight of 3.4 kg is used for each fish (based on the average weight in the commercial fishery 2000–2005), there would be 7.4 million dogfish in the demersal areas in the Strait of Georgia in the 1970s. The abundance estimates for dogfish in the pelagic waters of Puget Sound would be even more approximate than estimates for the Strait of Georgia as the sampling effort was substantially less. The average estimate for July is approximately 1.6 million fish, which could also indicate that dogfish in pelagic waters are a significant component of the total population in both areas.

Ketchen (1975) reported that the average age and size at maturity for spiny dogfish in the Strait of Georgia was 23 years and 93 cm for females and 14 years and 72 cm for males. Saunders and McFarlane (1993) applied the results of the age validation study of Beamish and McFarlane (1985) to determine the age and length of female dogfish in the Strait of Georgia. They determined an average age at maturity of 35.5 years or about 12 years older than estimated by Ketchen. The lengths at maturity determined by Ketchen (1975) and Saunders and McFarlane (1993) were similar at 93 cm and 94 cm, respectively (see also Tribuzio et al. 2009, this volume). Although fish in the size ranges reported for mature males and females by Ketchen (1975) and Saunders and McFarlane (1993) were in the pelagic waters, they could be considered to be much less abundant than would be found demersally.

Dense concentrations of juvenile spiny dogfish occurred in the northern Strait of Georgia, in the Mittlenatch Island area (Figure 1), in January and February. We first observed this behavior in 1975 (Beamish and Smith 1976) and confirmed the occurrence of juvenile dogfish in this area at this time of year in a number of cruises over the past 30 years. Included in these catches were juvenile dogfish that were aged as 0+ (since birth) with a modal size of 26–27 cm (Beamish and Smith 1976), which is identical to the length Ketchen (1975) identifies as the size at birth. Thus, we concluded that these age-0 dogfish were recently born and that they were born in this general area, perhaps in the late fall or early winter. In other surveys occurring later in the year in this same area, pregnant female dogfish with unborn pups are often captured (R. Beamish and R. Sweeting, unpublished data).

A comparison between the length distribution of spiny dogfish within the water column (Figure 3) and the length distribution of fish caught in the on-bottom longline fishery (Figure 21) indicates that juveniles up to about 60 cm are commonly found in the water column. We subsequently showed that fish at this size are approximately 15–20 years old (Figures 18 and 20) (Beamish et al. 1982). Catches of dogfish larger than about 60 cm in the water column decreased as lengths increased, while catches of these larger fish occurred in the bottom fisheries. Thus, we concluded that at an age of 15–20 years and a size of about 60 cm, many dogfish begin a predominantly demersal existence by changing their habitat preference from the pelagic zone to the demersal zone.

We observed a change in behavior in the Strait of Georgia after the regime shift in 1998 (Beamish et al. 2001). In 2000, September catches decreased dramatically, indicating that many dogfish had moved out of the main body of the Strait of Georgia. However, catches in July continued at approximately the same levels, indicating that the behavior observed in September was seasonal and probably related to changes in the Strait of Georgia associated with the climate event of 1998 (McFarlane et al. 2000).

Our studies showed that spiny dogfish commonly occur throughout the pelagic waters of the Strait of Georgia and Puget Sound. There were some differences in standardized catches among depths, but in general dogfish were distributed throughout the water column. Female dogfish give birth to 2–16 babies ranging in size from about 23–30 cm (Ketchen 1986) after a pregnancy of almost 2 years (Ford 1921; see also Tribuzio et al. 2009). In the Strait of Georgia, we observed that juveniles are released in the late fall. Our study showed that juveniles remain and grow slowly in the pelagic waters for many years. The reasons why these young dogfish occupy a habitat that is separate from the larger and mature fish are not known. It is tempting to speculate that this separation reduces mortality that could be associated with sharing the habitat of older, larger dogfish. It is not known what regulates the population size of dogfish. Wood et al. (1979) proposed a density-related process resulting in the reduced production of offspring when abundances were large. It may also be possible that direct mortality occurs through an association of these very young juveniles with much larger individuals.

It is important to consider the role of spiny dogfish in the Strait of Georgia and Puget Sound ecosystems. This is a species that is found in virtually all habitats in these areas and is mostly resident. All ecosystems support species that are scavengers, such as dogfish. Scavengers "clean up" ecosystems and thus presumably help to keep ecosystems healthy and stable. It is possible that dogfish benefit the Strait of Georgia and Puget Sound ecosystems in this way. While this is speculation, it is beyond speculation to conclude that an important part of the life history strategy of dogfish is to spend their first 10–15 years in the pelagic waters. Furthermore, the health of dogfish populations may be an indicator of the overall health of the ecosystem.

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