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Pacific sardine (*Sardinops sagax*) biomass and migration rates in British Columbia

Biomasse et taux de migration de la sardine du Pacifique (*Sardinops Sagax*) en Colombie-Britannique

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ABSTRACT

The Pacific sardine (*Sardinops sagax*) is a transient visitor to Canadian waters, annually migrating northward from spawning grounds off southern California. As the sardine population has rebuilt over the past few decades, the abundance of fish migrating into British Columbia waters has increased, as has interest in harvesting them. The difficulty in developing a harvest policy for sardines in Canadian Pacific waters is the uncertainty in the annual migration rate of the coastwide stock into British Columbia. Ware (1999) estimated the migration rate of sardine into Canadian waters based on the catches taken in the historical fishery and proposed a harvest policy based on the United States assessment model and assuming an annual 10 percent migration. A trawl survey has been conducted off the west coast of Vancouver Island since 1997 to monitor sardine abundance and distribution in Canadian Pacific waters with an objective of providing updated estimates of sardine distribution and migration rate. Based on our re-analysis of the available information on the sardine abundance in Canada from the trawl survey conducted on the west coast of Vancouver Island, we believe that the currently assumed harvest rate is conservative and should be updated. Based on the five years for which a comprehensive survey was conducted the average migration rate estimate is18.3 percent. Given that the survey region does not cover the known distribution of sardines in Canadian waters (such as the inlets of the west coast of Vancouver Island and Queen Charlotte Sound), this provides a precautionary estimate of migration for determining allowable harvest.

RÉSUMÉ

La sardine du Pacifique (*Sardinops sagax*) visite chaque année dans les eaux canadiennes lorsqu'elle quitte les aires de frai au large de la Californie pour migrer vers le nord. La population de sardine s'étant reconstituée au cours des dernières décennies, l'abondance des individus migrant dans les eaux de la C.-B. a augmenté, tout comme l'intérêt pour l'exploitation de cette ressource. La difficulté associée à l'élaboration d'une politique sur la pêche à la sardine dans les eaux canadiennes réside dans l'incertitude entourant le taux de migration annuelle du stock côtier en Colombie-Britannique. Ware (1999) a estimé le taux de migration des sardines dans les eaux canadiennes selon les prises réalisées dans le cadre de la pêche historique et a proposé une politique de pêche fondée sur le modèle d'évaluation américain, d'après un taux de migration annuelle de 10 %. Depuis 1997, on effectue un relevé au chalut au large de la côte ouest de l'île de Vancouver afin de surveiller l'abondance et la répartition des sardines dans les eaux canadiennes et ce, dans le but d'établir des estimations à jour de la répartition de l'espèce et du taux de migration. Selon notre nouvelle analyse de l'information concernant l'abondance des sardines au Canada dérivée du relevé au chalut effectué sur la COIV, nous croyons que le taux d'exploitation actuel est conservateur et qu'il pourrait être mis à jour. Selon les relevés détaillés effectués au cours des cinq dernières années, on estime le taux de migration moyen à 18,3 %. Étant donné que ces relevés ne couvrent pas l'ensemble de l'aire de répartition connue des sardines dans les eaux canadiennes, tels que les bras de mer de la COIV et le détroit de la Reine-Charlotte, l'estimation de la migration pour établir le niveau de prélèvement autorisé est prudente.

INTRODUCTION

The Pacific sardine (*Sardinops sagax*) is a transient visitor to Canadian waters, migrating northward from spawning grounds off southern California in the spring to the rich feeding grounds off Vancouver Island and returning south in the fall. Sardines were fished extensively in the Pacific Northwest during the first half of the 20th century, disappearing entirely from this area by the late 1940s. After an absence of almost 50 years, sardines reappeared in Canadian waters in 1992 (Hargreaves *et al*., 1994, McFarlane and Beamish 2001). As a result, there has been some debate about sardine spawning in Canadian waters and the possible existence of a northern sardine stock. Hart (1973) reports observations of sardines with "loose eggs" in Canadian waters, however spawning was not observed. A more recent survey (1997) reports the collection of "ripe females" near Vancouver Island along with juvenile sardines (McFarlane and Beamish 2001). Both historically (Hart 1937) and in recent years (McFarlane *et al*., 2005; Schweigert, pers.obs.), there has been evidence of sardines over-wintering in waters off the west coast of Vancouver Island rather than migrating south in the fall. Wintering fish have been found in inlets and some schools appear to have been trapped in warm water cells exhibiting subsequent die-offs as conditions cooled. This was observed in 1998, while at the same time, quantities of healthy sardine were observed offshore where water temperatures were warmer (McFarlane and MacDougall 2001). Consequently, there is no apparent evidence of distinct sardine stocks in Canadian waters and available data suggest that the annual northward migration is constrained by the 12C isotherm (Ware 2001).

In the past few decades, abundance of the California sardine population has increased, resulting in greater migration into British Columbia (BC) waters and a renewed interest in the fishery. The annual sardine quota for fisheries in BC is tied to the estimate of sardine migration and uncertainties in this estimate present a challenge for developing a harvest policy. Ware (1999) estimated the average migration rate of sardines into Canadian waters to be 10% based on the catches taken from 1917-1945 in the United States (US) and Canadian fisheries (Figure 1) and proposed a harvest policy based on the US assessment model that has been adopted since 2000. A trawl survey has been conducted off the west coast of Vancouver Island since the mid -1990s to monitor sardine abundance and distribution in Canadian waters with an objective of providing updated estimates of migration. This report briefly describes the trawl survey results and proposes an updated estimate of the sardine migration rate into Canada.

METHODS

Surface Trawl Survey

Surveys employing mid-water trawls towed near the surface have been conducted on the west coast of Vancouver Island from 1997 to present to examine the distribution and relative abundance of sardines in Canada (McFarlane and MacDougall 2001). Abundance estimates were calculated using representative catches from the surface to 30 m depth, collected during cruises in late June, July and August. The July cruises have generally been most indicative of the relative sardine biomass in Canadian offshore waters. For estimating abundance, the west coast of Vancouver Island was partitioned into 6 regional areas or sampling strata (Figure 2), 5 of which were sampled in most survey years. Sampling effort was considered to be "complete" when sampling occurred in Areas 2-6, whereas when regions were omitted due to time constraints (i.e. Areas 2 and 3), sampling was considered "incomplete" and not representative of distribution and abundance. Page 1 of 17

- 2 -The total surface volume of each region was estimated using the maximum depth fished (30m):

Total surface volume (km^3) = Regional area (km^2) * 0.030 km

Each region contained 3-5 transects with 2-51 tows or "sets" per transect. Transects were run parallel or perpendicular to the shore, depending on weather, tides and currents, out to a bottom depth of 500 m. Tows of 20-60 minutes duration were conducted sequentially along the length of each transect (i.e., constant fishing).

The swept volume of each tow was determined by multiplying the area of the opening of the trawl net by the distance travelled:

Swept Volume (km^3) = Net height (km) * Net width (km) * Distance (km)

From each tow, total sardine catch was recorded by piece count or by weight. If sardine catch was only recorded by weight, the total number of fish caught was estimated by dividing weight (in kg) by the average individual sardine weight for that region. Using estimates of swept volumes for tows from the same region, estimates of average swept volumes and 95% confidence intervals were calculated for each region.

Day/ Night Calibration

From 1997 to 2004 all sets were conducted during daytime hours. In July 2005, day/night catch comparisons were conducted off Nootka Sound and Barkley Sound to estimate day/night catch ratios. In these areas, all sets were completed during 2 days and 2 nights of fishing. In 2006 and 2008, all tows were conducted at night and the calibration factor from the 2005 day/night catch ratios was applied to results from these 2 years to represent daytime catches.

Abundance

Biomass estimates were calculated from data collected during cruises from 1997 to 2008 (Table 1). Biomass estimates were calculated according to the method described in Beamish *et al*. (2000) assuming a stratified random sampling design. For each regional stratum, total abundance was estimated as the number of sardines per swept volume times the total swept volume:

$$C_h = \frac{V_h}{\bar{v}_h} \bullet \bar{c}_h$$

where

h = regional stratum (Areas 2 to 6)

C_h = estimated number of sardines in stratum h

$\bar{c}_h$ = average number of sardines caught in stratum h

V_h = estimated surface volume of stratum h

$\bar{v}_h$ = average swept volume of all sets in stratum h

$N_h = V_h/\bar{v}_h$, or the total number of possible samples of size $\bar{v}_h$ in stratum h

The corresponding variance estimator for abundance in the h th stratum is:

$$\mathrm{var}(C_h) = \sum_h N_h (N_h - n_h) \bullet \frac{S_{ch}^2}{n_h}$$

where catch sample variance by stratum is represented by:

$$S_{ch}^2 = \frac{\sum_i^{n_h} (c_{hi} - \bar{c}_h)^2}{(n_h - 1)}$$

c_{hi} = number of sardines caught in sample *i* in stratum *h*
c_h = average number of sardines caught in stratum *h*
n_h = number of samples taken in the h^{th} stratum

Abundance in number of sardines was converted to weight (kg) by multiplying abundance in numbers by average weight (kg) of an individual sardine by stratum:

$$B_h = \frac{V_h}{\bar{v}_h} \bullet \bar{c}_h \bullet \bar{w}_h$$

where

$\bar{w}_h$ = average sardine weight (kg) in stratum *h*

For 1997, 1999, and 2001, the average sardine weight in all strata was estimated as 0.165 kg because fish sizes were similar.

The corresponding variance estimator for abundance (weight) in the *h* the stratum is:

$$\mathrm{var}(B_h) = \sum_h N_h (N_h - n_h) \bullet \frac{S_{bh}^2}{n_h}$$

where catch sample (weight) variance by stratum is represented by:

$$S_{bh}^2 = \frac{\sum_i^{n_h} (\bar{w}_h \bullet c_h - \bar{w}_h \bullet \bar{c}_h)^2}{(n_h - 1)}$$

Minimum and maximum biomass estimates were determined using an approximate 95% confidence interval determined as the average biomass plus or minus twice the standard error (square root of the estimated sample weight variance).

Migration Rates

Estimates of the annual migration rate for each survey year were developed by calculating the ratio of estimated biomass off the west coast of Vancouver Island and the total biomass estimate for the coastwide population, as presented in the annual United States sardine assessment (Hill *et al*., 2008).

RESULTS

Abundance

Sardine biomass estimates for the west coast of Vancouver Island from complete surveys (Areas 2-6) were calculated for years:1997, 1999, 2000, 2001, 2004, 2006 and 2008; whereas biomass estimates from incomplete surveys were calculated for 2002 and 2005, and no surveys occurred in 1998, 2003 and 2007 (Tables 1-4, Figure 3). A summary of the number of sets conducted in each region each survey year is presented in Table 1. In 2000 and 2004, sardine trawl catch distributions were especially patchy, which was thought to be partly attributed to gear avoidance and high variability in daytime school densities and depths. Consequently, sampling data for these two years are not considered representative of distribution and abundance and are treated as anomalous (Tables 3 and 4).

The results of the 2005 day/night calibration trials showed average day time catch rates to be higher than night time rates by approximately 21%. Therefore, this calibration factor that was applied to the 2006 and 2008 catches to calculate an adjusted biomass estimate. The adjusted estimates are presented in Table 3.

For the entire time period, average annual estimates of biomass range from 14,793 t (2002) to 258,702 t (2006) with considerably high peak years in 2006 and 2008 (Figure 3). Sardine biomass estimates for 1997 and 1999 were 88,626 and 79,398 tonnes respectively, and similar to the 2000 and 2001 surveys, the majority of sardines were found in the southern 3 strata (Areas 4-6) . There were anecdotal reports of large quantities of sardines in inshore waters in 2000 and 2001, particularly the inlets along the west coast of Vancouver Island and these fish would not have been detected by the trawl survey

Migration Rates

Migration rates are calculated as the ratio of biomass estimated off the west coast of Vancouver Island and the total coastwide biomass of Pacific sardine as presented in the annual United States stock assessment document (Hill *et al*., 2008, Table 4). Based on all annual estimates of average biomass from the trawl survey time series, migration rates range from 1.9% to 34.7%, or 12.9% over all years (Table 4a). When calculation of migration rate is limited to survey data for years with representative survey coverage (omitting years with incomplete effort and anomalous catch distributions), estimated migration ranges from 5.0% to 34.7%, corresponding to an overall average rate of 18.3% (Table 4b). As with the abundance estimates, the 2006 (27.2%) and 2008 (34.7%) migration rate estimates are the highest on record.

DISCUSSION

During the early 20th century, the Canadian fishery took on average about 10% of the combined US and Canadian sardine catch in the Pacific Northwest (Figure 1). Assuming the Canadian and US fisheries harvested the available supply of sardines at about the same rate, then on average about 10% of the sardine population migrated to BC in the summer. This was the basis for the procedure proposed by Ware (1999) for determining the probable biomass of Pacific sardine in Canada and for proposing a harvestable surplus, which is also based on annual US stock assessment results (Hill *et al.,* 2008, Appendix A). The procedure proposed by Ware has been used to make harvest recommendations to fisheries management since it was adopted by PSARC for 2000. Compared to historical estimates, recent scientific catch data from the trawl survey suggest increased levels of migration into Canadian waters; consequently, there has

been increasing interest in the fishery for harvesting opportunities. Based on our analysis of trawl survey data from the west coast of Vancouver Island and on other recent observations of sardines in Canadian wasters, we suggest that the currently assumed average migration rate of 10 % from Ware (1999) is conservative and should be updated to take into consideration the more recent information.

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 waters off the west and northeast coasts of Vancouver Island, Queen Charlotte Sound, and in inlets surrounding Vancouver Island in both research surveys and commercial fisheries. From 1997 to 1999, sardines were found in the Strait of Juan de Fuca, in the Strait of Georgia, along the west coast of Vancouver Island, Hecate Strait, and off southeast Alaska. Sardine distribution in 2000 was concentrated on the west coast of Vancouver Island and ranged as far south as Barkley Sound and as far north as the mainland of British Columbia, north of Vancouver Island. From 2001 to 2003, sardine distribution became progressively concentrated near shore along the southwest coast of Vancouver Island and progressively less prevalent in research cruises. By 2004, sardines were rarely captured offshore or along the research grid; however, large commercial catches of sardines were made in inlets and the shallows along the west coast of Vancouver Island. In 2004, sardines were also commercially caught in inlets of Queen Charlotte Sound.

In 2005, part of the survey was directed at developing a relationship between day and night sampling. The calibration trials were done to explore catch efficiency and sampling representivity since daytime behaviour of fish schools was suspected to have higher gear avoidance and patchier vertical and horizontal distributions. Sampling by night was subsequently determined to be more conducive to estimating sardine biomass by surface trawl gear. For similar reasons, night trawl sampling for sardines is applied in Oregon (Emmett *et al*., 2005). While night trawl sampling was conducted in 2006 and 2008, the distribution of sardine catches extended along the entire west coast of Vancouver Island and relatively high catches of sardine occurred. Future work should explore an optimal sampling design for the trawl survey, and review the calibration of day and night catches.

The trawl surveys conducted off the west coast of Vancouver Island sampled sardines in offshore waters, which did not include inlets, other inshore areas, nor areas north of Vancouver Island, all known to have contained significant quantities of sardine in recent years. Consequently, the average biomass estimate from the trawl surveys can be assumed to provide a minimal approximation of the total biomass of sardines in Canadian waters. The average migration estimate from all of the available west coast of Vancouver Island survey years, including those with incomplete coverage is 12.9 % while for the five years for which survey coverage was considered to be representive, the average migration rate estimate is 18.3 %. Given that these surveys do not cover the entire known distribution of sardines in Canadian waters, we feel that a migration rate estimate based on the average of the trawl survey estimates for the complete surveys of 18.3 % is conservative and precautionary and recommend that this approach be used for determining harvest levels in the short term. Future analysis should be undertaken to investigate the application of a running average migration rate or other decision rules for providing precautionary harvest guideline for sardines in Canadian waters.

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Table 1. Summary of the number of sets and survey areas sampled from 1997 to 2008. Number of sets with sardine catches are also shown.

Year	Survey Area	Number of sets	Sets with sardines
1997	2	4	3
	3	6	5
	4	4	4
	5	11	11
	6	23	8
1999	2	11	2
	3	15	8
	4	15	1
	5	17	11
	6	49	10
2000	2	6	0
	3	12	4
	4	12	6
	5	9	2
	6	10	4
2001	2	6	0
	3	6	0
	4	11	4
	5	10	6
	6	14	5
2002	2	-	-
	3	-	-
	4	10	2
	5	19	9
	6	15	4
2004	2	9	0
	3	18	2
	4	20	4
	5	13	3
	6	20	3
2005	2	-	-
	3	-	-
	4	29	11
	5	9	6
	6	13	10
2006	2	7	6
	3	6	6
	4	12	11
	5	15	14
	6	5	5
2008	2	7	5
	3	15	14
	4	11	11
	5	11	3
	6	11	7

Year	Area	Volume of area	Swept Volume (km3)	Swept volume 95%	Average kg	Average number of fish	Biomass (Mt)		
							Minimum (ave - 95%CI)	Average	Maximum (ave + 95% CI)
1997	2	66.6	0.0042	0.0009	801	3,509	7,499	9,172	11,838
	3	119.7	0.0031	0.0016	107	645	2,673	4,069	8,522
	4	83.9	0.0032	0.0012	2,154	12,696	39,454	54,853	89,965
	5	71.8	0.0028	0.0006	202	1,222	4,234	5,176	6,658
	6	127.7	0.0021	0.0004	239	1,521	12,902	15,355	18,961
						1997 Biomass Totals:	66,762	88,626	135,944
1999	2	66.6	0.0019	0.0002	195	1,186	6,146	6,744	7,472
	3	119.7	0.0020	0.0001	71	430	4,127	4,345	4,588
	4	83.9	0.0019	0.0002	92	559	3,774	4,159	4,632
	5	71.8	0.0017	0.0006	216	1,307	6,487	8,690	13,157
	6	127.7	0.0020	0.0005	877	5,262	44,122	55,459	71,123
						1999 Biomass Totals:	64,656	79,398	100,972
2000	2	66.60	0.0019	0.0006	0	0	0	0	0
	3	59.85	0.0020	0.0002	87	433	3,819	4,296	4,910
	4	41.92	0.0018	0.0001	1	4	54	57	61
	5	71.76	0.0017	0.0002	954	6,369	38,961	43,452	49,113
	6	127.65	0.0020	0.0002	2	14	130	141	155
						2000 Biomass totals:	42,964	47,947	54,239
2001	2	66.6	0.0020	0.0001	0	0	0	0	0
	3	119.7	0.0015	0.0003	0	0	0	0	0
	4	83.9	0.0017	0.0005	1	4	13	16	22
	5	71.8	0.0017	0.0002	1	4	22	25	29
	6	127.7	0.0017	0.0005	597	3,616	33,804	43,824	62,285
						2001 Biomass Totals:	33,839	43,865	62,336
2002	2	119.7	no fishing						
	3	83.9							
	4	83.9	0.0019	0.0002	193	1,087	7,688	8,720	10,072
	5	71.8	0.0018	0.0002	108	559	3,973	4,403	4,937
	6	127.7	0.0020	0.0002	1	3	36	39	42
						2002 Biomass totals:	11,696	13,161	15,051
2004	2	119.7	0.0014	0.0002	0	0	0	0	0
	3	83.9	0.0014	0.0002	103	515	7517.80	8689.28	10293.24
	4	83.9	0.0015	0.0002	160	730	7,995	8,917	10,078
	5	71.8	0.0017	0.0001	296	1,692	12,050	12,867	13,802
	6	127.7	0.0014	0.0002	0	2	28	31	36
						2004 Biomass totals:	27,591	30,504	34,210
2005	2	119.7	no fishing						
	3	83.9							
	4	83.9	0.0018	0.0002	303	2,008	15,498	16,097	16,745
	5	71.8	0.0017	0.0001	511	3,885	22,547	23,710	25,001
	6	127.7	0.0017	0.0001	907	5,275	69,710	71,949	74,336
						2005 Biomass totals:	107,755	111,757	116,083
2006	2	66.6	0.0019	0.0001	228	1,577	7,865	8,216	8,599
	3	119.7	0.0018	0.0002	176	1,422	10,595	11,741	13,165
	4	83.9	0.0015	0.0003	1,510	11,035	69,730	85,477	110,410
	5	71.8	0.0012	0.0002	1,154	9,193	58,381	66,905	78,344
	6	127.7	0.0019	0.0003	632	4,328	36,512	41,464	47,971
						2006 Biomass Totals:	183,083	213,803	258,489
2008	2	66.6	0.0018	0.0002	213	1,476	7,254	8,029	8,989
	3	119.7	0.0013	0.0002	1,398	9,149	108,391	127,569	154,992
	4	83.9	0.0015	0.0002	726	5,005	34,003	39,412	46,869
	5	71.8	0.0012	0.0002	3	24	167	201	252
	6	127.7	0.0016	0.0002	186	1,329	13,390	14,641	16,151
						2008 Biomass Totals:	163,204	189,852	227,253

Table 3. Pacific sardine biomass estimates for all years including those adjusted using the night/day conversion factor (2006 and 2008). Note the partial surveys in two years (2002 and 2005).

Year	area	Survey description	Average biomass (mt)	Maximum biomass (mt)
1997	2	Complete Survey	9,172	11,838
	3		4,069	8,522
	4		54,853	89,965
	5		5,176	6,658
	6		15,355	18,961
		Total:	88,626	135,944
1999	2	Complete Survey	6,744	7,472
	3		4,345	4,588
	4		4,159	4,632
	5		8,690	13,157
	6		55,459	71,123
		Total:	79,398	100,972
2000	2	Anomalous distribution	0	0
	3		4,296	4,910
	4		57	61
	5		43,452	49,113
	6		141	155
		Total:	47,947	54,239
2001	2	Complete Survey	0	0
	3		0	0
	4		16	22
	5		25	29
	6		43,824	62,285
		Total:	43,865	62,336

Year	area	Survey description	Average biomass (mt)	Maximum biomass (mt)
2002	2	Incomplete Survey	-	-
	3		-	-
	4		8,720	10,072
	5		4,403	4,937
	6		39	42
		Total:	13,161	15,051
2004	2	Anomalous distribution	0	0
	3		8689.28	10293.24
	4		8,917	10,078
	5		12,867	13,802
	6		31	36
		Total:	30,504	34,210
2005	2	Incomplete Survey	-	-
	3		-	-
	4		16,097	16,745
	5		23,710	25,001
	6		71,949	74,336
		Total:	111,757	116,083
2006	2	Night survey adjusted to day	9,941	10,405
	3		14,207	15,930
	4		103,427	133,596
	5		80,955	94,796
	6		50,172	58,045
		Total:	258,702	312,772
2008	2	Night survey adjusted to day	9,715	10,877
	3		154,358	187,541
	4		47,689	56,711
	5		243	305
	6		17,716	19,543
		Total:	229,721	274,977

Table 4. Percentage of the coastwide Pacific sardine biomass estimated to be in the Canadian zone. Estimates representing total biomass in US and Canadian waters are from Hill et al., 2008. Biomass for 2006 and 2008 adjusted to daytime catch rates.

a) All survey years.

year	Average biomass (mt)	Maximum biomass (mt)	Total biomass (mt) (US and Canada)	Proportion in Canadian waters Average Abundance	Proportion in Canadian waters Maximum Abundance
1997	88,626	135,944	559,613	15.8	24.3
1999	79,398	100,972	887,809	8.9	11.4
2000	47,947	54,239	1,002,330	4.8	5.4
2001	43,865	62,336	878,841	5.0	7.1
2002	13,161	15,051	785,200	1.7	1.9
2004	30,504	34,210	730,489	4.2	4.7
2005	111,757	116,083	847,585	13.2	13.7
2006	258,702	312,772	949,717	27.2	32.9
2008	229,721	274,977	662,886	34.7	41.5
			Overall:	12.8	15.9

b) Survey years 1997, 1999, 2001, 2006 and 2008 (excludes years with incomplete survey coverage or believed to have anomalous sardine distribution).

year	Average biomass (mt)	Maximum biomass (mt)	Total biomass (mt) (US and Canada)	Proportion in Canadian waters Average Abundance	Proportion in Canadian waters Maximum Abundance
1997	88,626	135,944	559,613	15.8	24.3
1999	79,398	100,972	887,809	8.9	11.4
2001	43,865	62,336	878,841	5.0	7.1
2006	258,702	312,772	949,717	27.2	32.9
2008	229,721	274,977	662,886	34.7	41.5
			Overall:	18.3	23.4

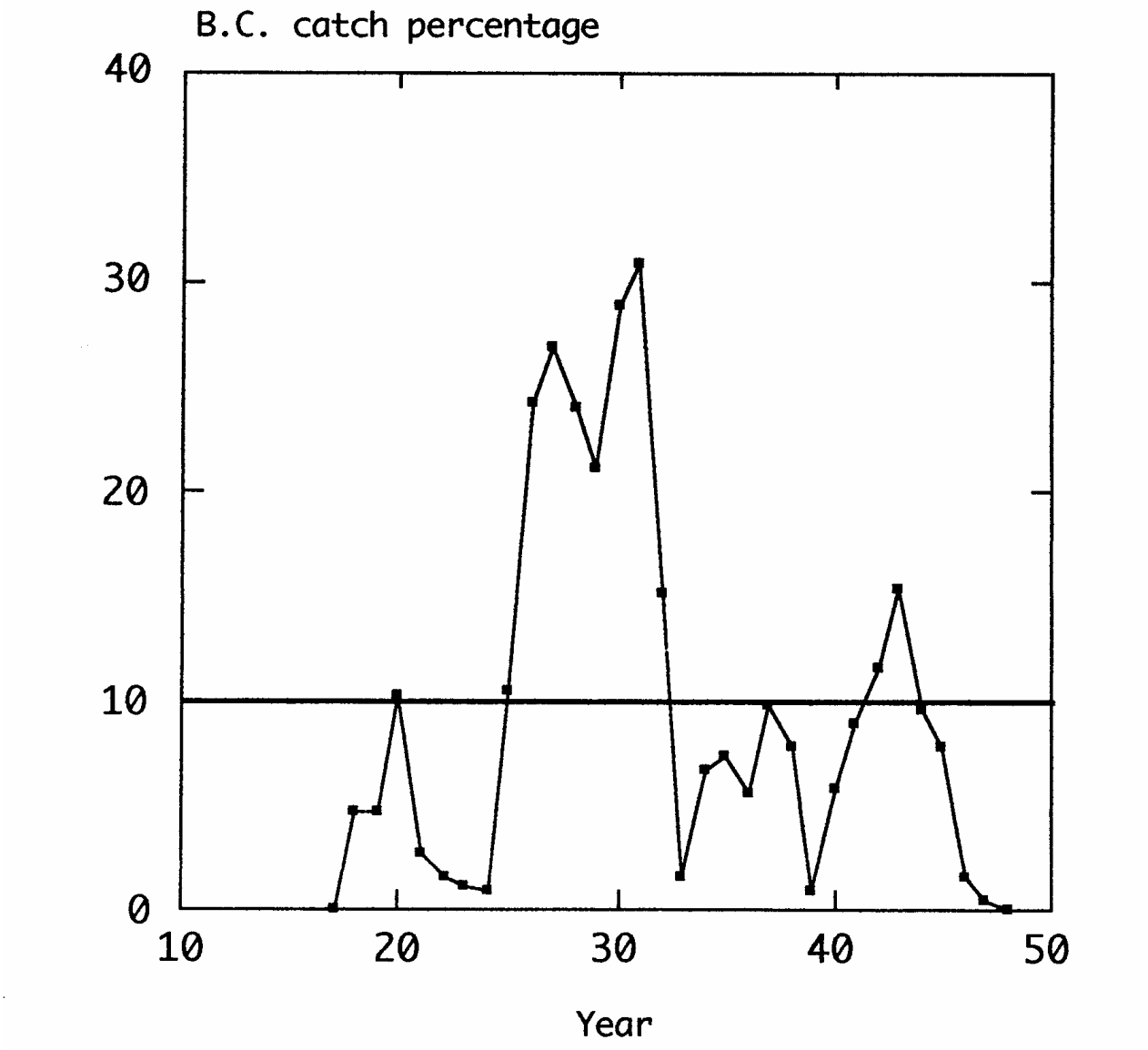

Figure 1. Percentage of the combined United States and Canadian sardine catch landed in British Columbia. The average is 10%. However, there were extended periods where the fraction was appreciably higher (e.g. 1926 to 1932), and lower (e.g. 1933 to 1941), taken from Ware (1999).

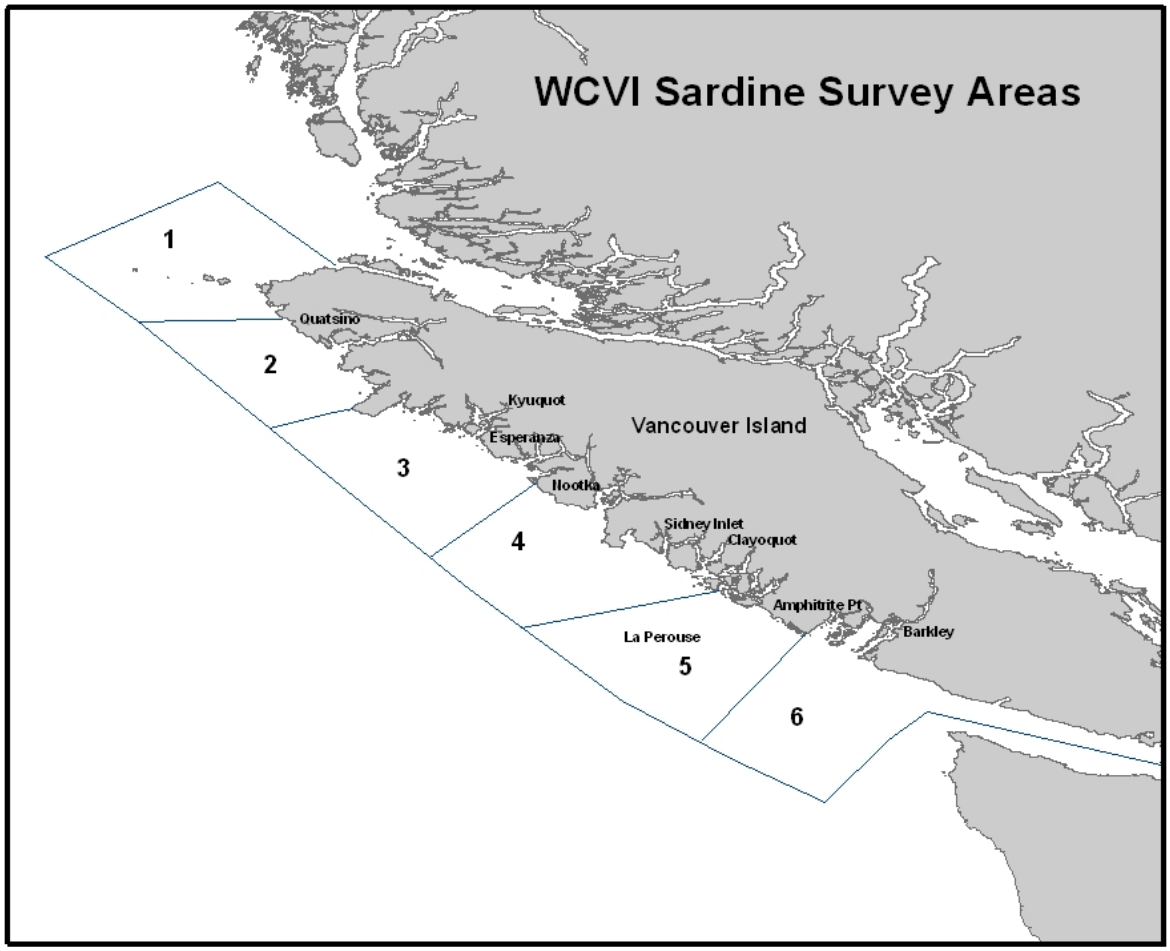

Figure 2. Pacific sardine survey areas for the west coast of Vancouver Island delineating the sampling regions.

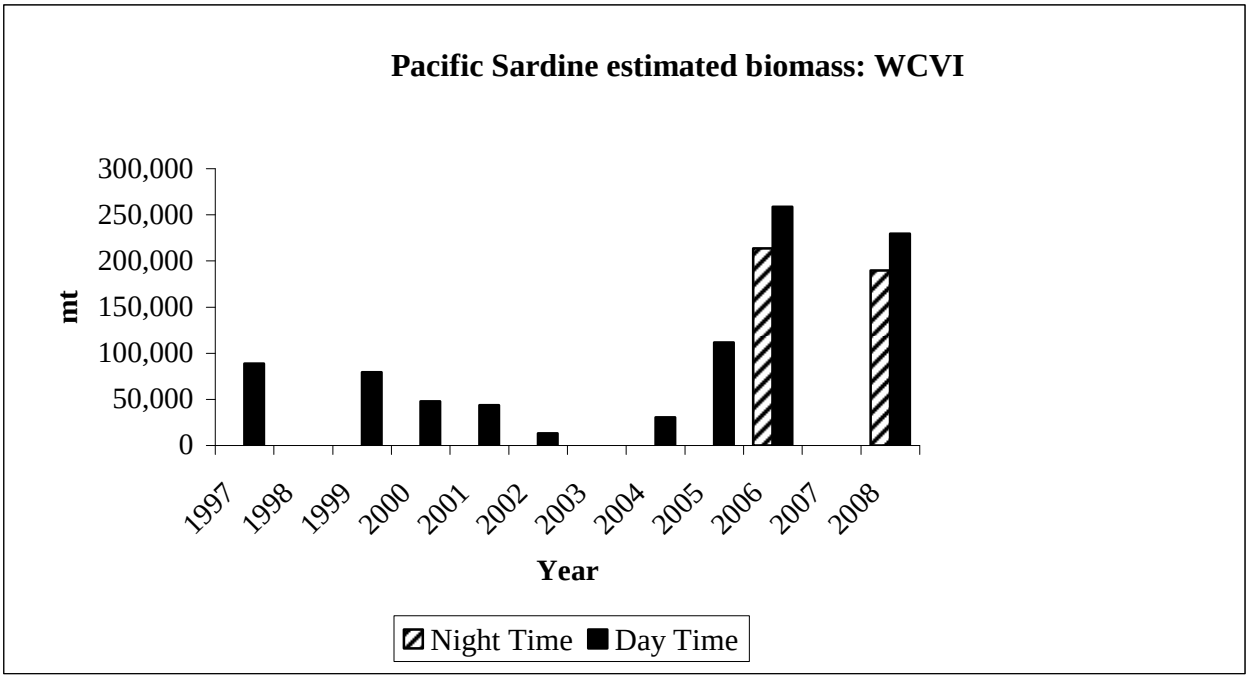

Figure 3. Estimated Pacific sardine biomass estimates in the Canadian zone from WE Ricker sardine trawl surveys on the west coast of Vancouver Island conducted from 1997 to 2008. Surveys in 2002 and 2005 were incomplete. Results for night time surveys in 2006 and 2008 adjusted to day time. Catch distributions in 2000 and 2004 are considered anomalous.

Appendix A: Procedures For Recommending Pacific Sardine Harvests

The US formula (Hill *et al*., 2008):

$$H = (\text{Total Biomass}_{2008} - \text{Cutoff}) \times \text{Fraction} \times \text{Distribution}$$

where

H = total US harvest (California, Oregon, Washington);
Biomass = total biomass of age 1 and older fish at the beginning of season;
Cutoff = lowest biomass where harvest is allowed (currently 150,000 tonnes);
Fraction = MSY control rule for proportion of stock to be harvested;
Distribution = fraction of stock biomass in US Waters (87% in 2008).

Fraction is a proxy for F_{msy}, which is the fishing mortality rate to achieve MSY and is the environmental-based percentage of the biomass above the Cutoff that can be harvested by the fishery. Fraction depends on ocean temperatures because F_{msy} and sardine productivity are both higher at warmer water temperatures:

$$\text{Fraction or } F_{msy} = 0.249\ T^2 - 8.19\ T + 67.46,$$

where T is the average sea surface temperature at Scripps Pier, California during the preceding three seasons but F_{msy} is constrained to range between 5 and 15%. Based on the current ocean conditions the exploitation fraction for 2009 will remain at 15%.

On this basis, the United States assessment assumes a very small migration rate of only 13% that is actually targeted by the Mexican fishery and makes no consideration for the fish in Canada.

The BC Formula (Ware, 1999):

The following relationship represents the estimate of sardine biomass that will potentially migrate to BC the following season:

$$\text{BC Biomass (tonnes)} = \text{Total Coastwide Biomass (tonnes)} \times \text{BC Migration rate}$$