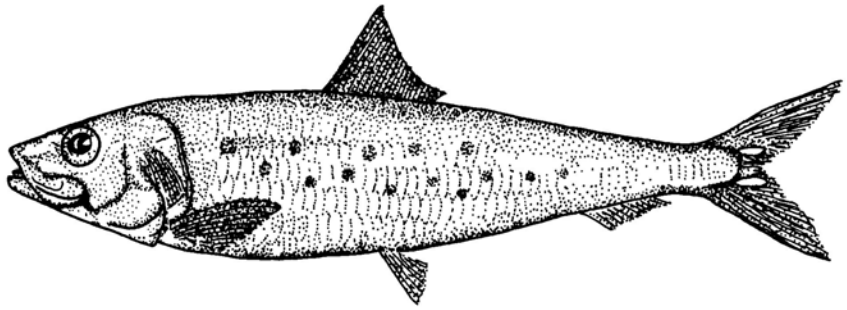
COSEWIC
Assessment and Update Status Report

on the

Pacific Sardine
Sardinops sagax

in Canada



NOT AT RISK
2002

COSEWIC
COMMITTEE ON THE STATUS OF
ENDANGERED WILDLIFE
IN CANADA

COSEPAC
COMITÉ SUR LA SITUATION DES
ESPÈCES EN PÉRIL
AU CANADA

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Pacific sardine – Figure redrawn from Hart (1973).

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COSEWIC
Assessment Summary

Assessment Summary – May 2002

Common name
Pacific sardine

Scientific name
Sardinops sagax

Status
Not at risk

Reason for designation
The sardines in Canadian waters apparently migrate from breeding areas near California, USA. Individuals in British Columbia do not appear to be self-recruiting and apparently lack local genetic differentiation. Numbers are increasing and the Canadian portion of the population is being managed in concert with US managers.

Occurrence
Pacific Ocean

Status history
Designated Special Concern in April 1987. Status reexamined in May 2002 and de-listed (Not at Risk) in May 2002. Last assessment based on an update status report.

COSEWIC
Executive Summary

Pacific Sardine
Sardinops sagax

Species information

The Pacific sardine *(Sardinops sagax)* resides seasonally in Canadian waters. It migrates northward from California in the spring to the rich feeding grounds off Vancouver Island and returns south in the fall. The evidence from tagging and other studies indicates that sardines venture progressively further north as they age during their annual migration from spawning to feeding areas. The recent consensus on stock structure supports the existence of a single panmictic population in the eastern north Pacific. Intermittent spawning probably occurs in the Pacific Northwest, including British Columbia, but self-sustaining populations are unlikely in this area. Sardines disappeared from Canadian waters in the late 1940s as the entire stock collapsed and only re-appeared in 1992 as the range of the resurgent California population has again expanded.

Distribution

Sardines as a group are classified into three genera and about 18 species world-wide. They are found in the waters of every continent, although they are fundamentally a warm water species whose global distribution is restricted within the latitudes of 60° N and 50° S. The Pacific sardine occurs from northern Mexico to southeastern Alaska, although the main concentration is from southern California - northern Baja to the southern portions of British Columbia.

Habitat

Little is known about specific habitat requirements for the Pacific sardine. In California, sardine schools have been found in temperatures ranging from 7° C to 28° C. The water temperature for spawning is thought to range from 13° to 22° C. Virtually all eggs are found in water between 12.5° and 16° C. The food of the sardine is primarily copepods and diatoms. A combination of water temperatures and favourable feeding conditions may account for the northward migration of adults each summer. Little is known about the requirements of juveniles during their first summer, when they are moved passively inshore and southward by the prevailing currents.

Biology

There are presently two main spawning areas off southern California and Baja California. The major and northern spawning area is between Point Conception and Ensenada. It is about 400 km long and extends up to 325 km offshore. The smaller spawning area, about half the size, is off central Baja California. There is also a smaller spawning area within the Gulf of California. Spawning occurs both in the spring and fall. Adult sardine with ripe eggs have been reported in Canadian waters and juveniles have recently been collected. This is evidence of local spawning. However, the successful recruitment of these juveniles into the population appears to be limited. The Pacific sardines are batch spawners with larger fish (21 cm) releasing up to 65,000 eggs per spawning and up to 200,000 eggs per spawning season. The eggs are pelagic, about 1.6 mm in diameter, and hatch in two to four days. The larvae are about 3.5 mm in length and resorb the yolk sac after four to seven days. Sardines grow rapidly, reaching 115 mm by the end of the first year. The maximum length is 31 cm for a fish 10 to 12 years of age, and females grow faster and larger than males. Young sardines move inshore as they grow and congregate in schools near beaches. Each year, beginning in their second summer, the fish migrate northwards early in summer and travel south again in the fall. The migration extends further north with age. Northward migration may also be affected by oceanographic conditions.

Population sizes and trends

Population sizes and trends in Canada are due to the population dynamics off California and local environmental conditions. Pacific sardines reappeared in Canadian waters in 1992, and are increasing in number. It appears from historical catch records and recent trawl surveys that, on average, about 10% of the US Pacific sardine population migrates into Canada each year. If the US population continues to increase, abundance of sardines in British Columbia should increase proportionately.

Limiting factors and threats

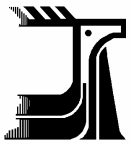
The primary limiting factors and threats to sardine are overfishing and environmental conditions. It is accepted that the collapse of the sardine population in the 1940s was a result of overfishing in combination with unfavourable environmental conditions for sardine survival. The current objective of the US management regime is to harvest only after a minimum spawning stock of 150,000 tonnes exists. A harvest rate of between 5-15%, depending on water temperature, which has been found to relate directly to sardine survival, is presumed to be sustainable. Canada has adopted the US harvest rate and has an interest in expanding the fishery in British Columbia. Without adverse environmental regimes similar to those of the last century, the sardine fishery along the Pacific coast should be sustainable. It has been shown from analyses of sediment cores and scale deposition that this sardine population has collapsed and recovered at least 9 times over the past two millennia, with each period of collapse or recovery lasting about 30 years.

Special significance of the species

Commercial harvesters take sardine as a food and bait species. They have also been an important food source, when available, for Nuu-chah-nulth First Nations people (west coast of Vancouver Island). Sardines are a critical component of ecosystem integrity. They are an important forage species for many other fishes, such as tunas, yellowtail, barracuda, bonito, marlin, hake, and mackerel. During their peak abundance in the 1930s and 1940s, sardines were the dominant prey species for chinook and coho salmon in the Pacific Northwest. The wide distribution of sardine make them readily available prey for mammals such as sea lions, porpoises, whales and birds such as cormorants, gulls, and pelicans.

Existing protection or other status designations

The Pacific sardine is managed in the US under the auspices of the Pacific Fisheries Management Council. The allowable harvest is a function of ocean conditions and stock abundance above a minimum biomass (150,000 mt). The harvest target is believed to be the maximum sustainable yield that is a function of ocean conditions, and is constrained to be between 5 and 15% of the stock forecast to be in US waters. The Pacific sardine in Canadian waters is currently listed by COSEWIC as a species of special concern. It has been managed under an experimental licence by Fisheries and Oceans Canada since 1997, with a harvest of about 1450 tonnes annually. There is commercial interest in British Columbia to increase this harvest.



COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) determines the national status of wild species, subspecies, varieties, and nationally significant populations that are considered to be at risk in Canada. Designations are made on all native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fish, lepidopterans, molluscs, vascular plants, lichens, and mosses.

COSEWIC MEMBERSHIP

COSEWIC comprises representatives from each provincial and territorial government wildlife agency, four federal agencies (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biosystematic Partnership), three nonjurisdictional members and the co-chairs of the species specialist groups. The committee meets to consider status reports on candidate species.

DEFINITIONS

Species	Any indigenous species, subspecies, variety, or geographically defined population of wild fauna and flora.
Extinct (X)	A species that no longer exists.
Extirpated (XT)	A species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A species facing imminent extirpation or extinction.
Threatened (T)	A species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A species of special concern because of characteristics that make it particularly sensitive to human activities or natural events.
Not at Risk (NAR)**	A species that has been evaluated and found to be not at risk.
Data Deficient (DD)***	A species for which there is insufficient scientific information to support status designation.

* Formerly described as “Vulnerable” from 1990 to 1999, or “Rare” prior to 1990.
** Formerly described as “Not In Any Category”, or “No Designation Required.”
*** Formerly described as “Indeterminate” from 1994 to 1999 or “ISIBD” (insufficient scientific information on which to base a designation) prior to 1994.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list.

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Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

Update
COSEWIC Status Report

on the

Pacific Sardine
Sardinops sagax

in Canada

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2002

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SPECIES INFORMATION

Name and classification

The current nomenclature for the Pacific sardine, *Sardinops sagax* (Family Clupeidae), was adopted by the American Fisheries Society in 1960 (Parrish et al. 1989). Sardines as a group are classified into three genera and about 18 species world-wide (Culley 1971). In British Columbia, the historical common name is the pilchard. The term sardine is increasingly prevalent. The French common name is sardine.

Description

The Pacific sardine *(Sardinops sagax)* is a schooling pelagic species that dominated the fisheries along the west coast of North America in the early 1900s. Vast quantities were taken for food or were reduced to oil. It is an active fish, which avoids nets so it is most easily captured at night when there is little moonlight. It is similar in size and appearance to the Pacific herring *(Clupea pallasi)* with which it is coincident in the Pacific Northwest. Both fish are silvery on the sides and belly with a dark blue or green dorsal surface. The sardine (Figure 1) may be distinguished from the herring by fine striae on the operculum, specialized flaps on the tail fin, and black spots on the side of the body visible through the scales. The sardines averaged 250 mm total length (TL) in the British Columbia fishery and were smaller as one progressed southward. The largest specimen was 394 mm long and weighed 486 grams (Hart 1973). The maximum age was 14 years (Marr 1960). Currently, in the Canadian fishery, few fish are older than age 9, and most are 3-7 years old.

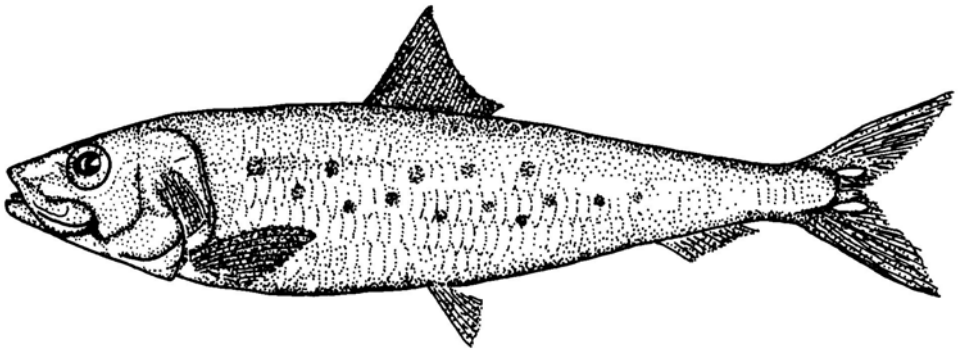

Figure 1. Pacific Sardine, *Sardinops sagax,* redrawn from Hart (1973).

DISTRIBUTION

Global range

The Pacific sardine is distributed from northern Mexico to southeastern Alaska, although the main centres of concentration range from southern California - northern Baja to the southern portions of British Columbia (Figure 2). Prior to the early 1900s' collapse of the California sardine, it was generally accepted that there were three stocks within the California Current system: a northern stock [from northern Baja California (30N) to Alaska (55N)], a southern stock [off the coast of Baja (23-30N)], and a Gulf of California stock (23-31N). This classification was based on spawning ground distribution, growth rates, tagging studies, and serological evidence (Culley 1971, Felin 1954, Hart 1943a, Janssen 1948, Marr 1957, 1960, Murphy 1966, Vrooman 1964). Radovich (1962) postulated the existence of an additional far northern population in the Pacific Northwest based on differing growth rates and scale patterns. However, other researchers questioned this (Marr 1960, Murphy 1966) and recent studies suggest that variation in life history traits is more likely the effect of environmental variation than of genetic differences (Hedgecock et al. 1989). They also suggest a single genetic stock of sardine in the California current system (Parrish et al. 1989, Hedgecock et al. 1989). For instance, Hedgecock et al (1989) found similar allozyme frequencies throughout the spawning distribution of the Pacific sardine, and the same rare alleles in widely separated localities. This suggests that there has been substantial gene flow among populations and does not provide evidence of the genetic differentiation that would support the existence of discrete stocks.

Canadian range

The Pacific sardine resides seasonally in Canadian waters, migrating northward from California in the spring to the rich feeding grounds off Vancouver Island and returning south in the fall. It was fished extensively in the Pacific northwest during the first half of the 20th century, and disappeared entirely from this area by the late 1940s. Some sardines over-wintered in inlets along the west coast of Vancouver Island rather than migrating south in the fall (Hart 1938, 1943a). Hart (1943a) concluded that "some of the tag recoveries indicate that these pilchards [fish taken in inlets] are a part of the general population cut off from participation in the general movement by local conditions rather than a special local population". After an absence of almost 50 years, sardines re-appeared in Canadian waters in 1992 (Hargreaves et al. 1994). As in the past, sardines have been found over-wintering in the inlets along the west coast of Vancouver Island and the Central Coast of British Columbia. This has been most pronounced during the 1997 and 1998 warm water years. These occurrences may represent schools of sardines trapped in warm water cells since they were coincident with large die-offs of fish that occurred in these areas in the winter (personal communication - G. Traxler, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, B.C. 14 November 2001). At this time there is no evidence to support the existence of reproducing resident populations of Pacific sardine in Canada.

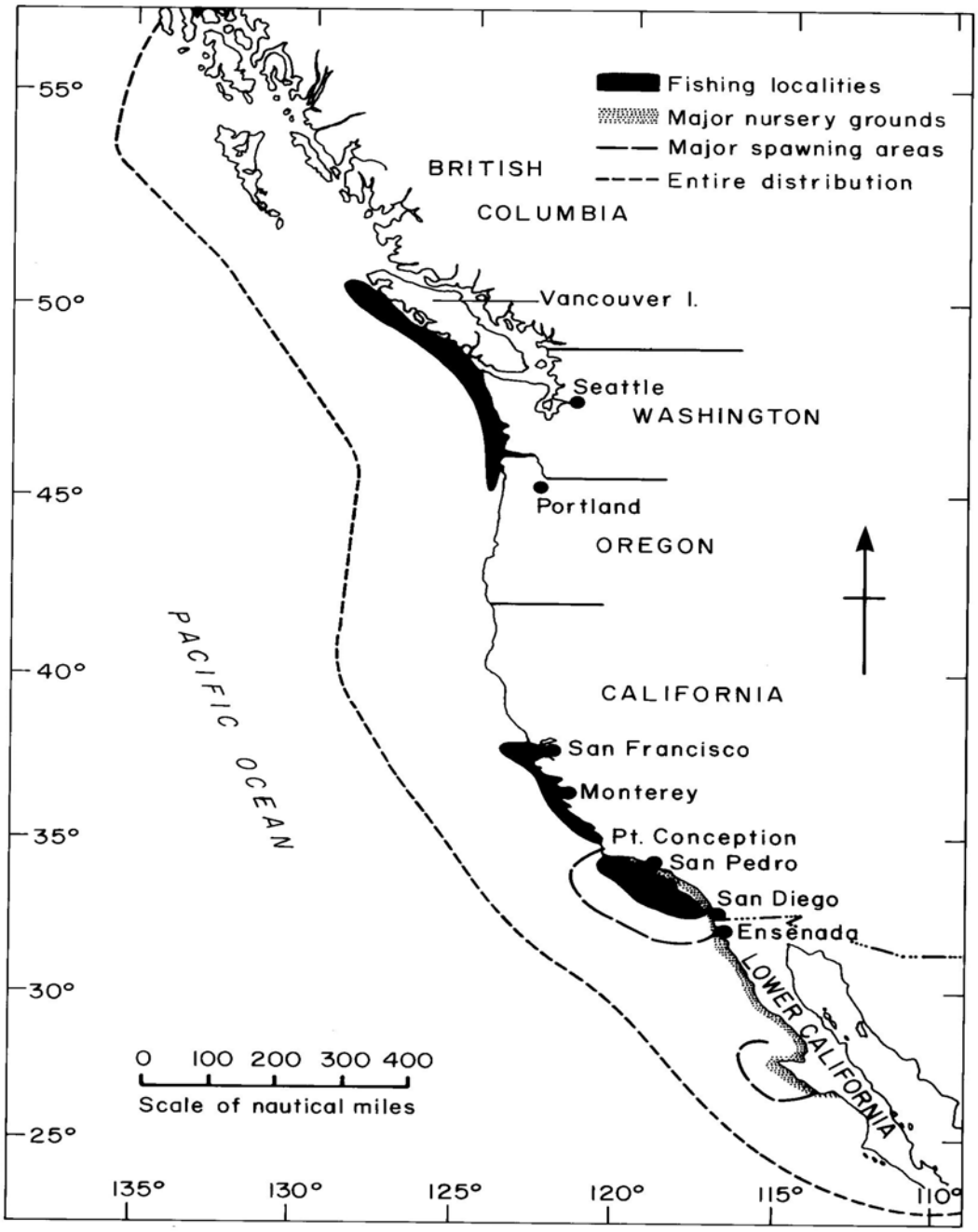

Figure 2. Distribution of the Pacific sardine, its major spawning grounds, nursery areas, and major fishery localities prior to 1950 (redrawn from Culley 1971). Spawning also occurs in the Gulf of California but locations are unknown.

HABITAT

Habitat requirements

Little is known about specific habitat requirements for the Pacific sardine. Although they are found in the waters of every continent, they are a warm water species whose global distribution is restricted to 60° N and 50° S latitude. In California, sardine schools have been found in temperatures ranging from 7° C to 28° C, but spawning is thought to be restricted to 13° to 22° C (Ahlstrom 1960). The temperature range for eggs is even more restricted, with all eggs being found only in water between 12.5° and 16° C (Culley 1971). The diet of the sardine varies regionally, but as an omnivorous filter feeder it includes copepods, diatoms, a variety of other zooplankton, and occasionally fish larvae (Ahlstrom 1960). A combination of water temperatures and favourable feeding conditions may account for the annual northward migration of adult Pacific sardine stocks each summer (Ware 2001). Little is known about the requirements of juvenile sardines during their first summer when they are moved passively inshore and southward by the prevailing currents (Culley 1971).

BIOLOGY

General

There are presently two main spawning areas off southern California and Baja California. The major and northern spawning ground is between Point Conception and Ensenada (Figure 2). It is about 400 km long and extends up to 325 km offshore (Culley, 1971, Marr 1960). The other main spawning area, about half the size, is off central Baja California. In addition, there is an inshore fall spawning area off central Baja and a winter-early spring spawning area within the Gulf of California (Marr 1960). In the southern California offshore area, spawning occurs between April and May at temperatures of 13° to 16.5° C. In the lower California area, spawning is from March to April at similar temperatures. The fall spawning in this area occurs from August to September at temperatures of about 18° to 23° C. The Gulf of California fish spawn from February to March.

The evidence for sardine spawning in Canadian waters is largely circumstantial. Hart (1973) reported that sardines with ripe eggs have been found in Canadian waters, but no spawning was known to occur here. Williamson (1930) noted that in June and July some schools of ripening sardine were taken off the west coast of Vancouver Island. He also reports that “at different times, but not every year, small-size pilchards (3 inches long) have been reported in Clayoquot Sound, Hesquiat and Malksope Inlet, and they are recorded as having been taken at Nootka this year”. More recently, Ware (1999) reported evidence of eggs and larvae being taken in Canadian waters during 1992 and 1993 and again in 1997, all unusually warm years. McFarlane and Beamish (2001) also reported that ripe females were collected on the west coast of Vancouver Island in July 1997 and age 0 juveniles (mean=10 mm) were collected the following March and April, suggesting successful spawning in the area. It is known that sardines have spawned off the coast of Oregon just

to the south in recent years (Bentley et al. 1996). Thus, it appears that in warm periods, such as during strong El Niño events, environmental conditions may be conducive to sardine spawning in Canadian waters. However, this does not appear to be an annual event, thus it is unlikely that a self-reproducing population exists in these waters.

Pacific sardines are batch spawners; large fish (21 cm) release 30-65,000 eggs per spawning (Hart 1973). A single large female can spawn about three batches, releasing almost 200 000 eggs per spawning season. Small fish (13-15 cm) appear to spawn about 30 000 eggs per season. Most spawning occurs during the first part of the night. Spawning behaviour differs from the usual schooling and consists of fish darting about and leaping out of the water (Culley 1971). The eggs are about 1.6 mm in diameter and take two to four days to hatch at 16° to 14° C. The eggs are deposited and fertilized in mid-water, and remain pelagic until hatching. Most of the eggs are found in the upper 25 m of the water column (Culley 1971). The larvae are about 3.5 mm in length and resorb the yolk sac after four to seven days. By the end of two to three months they are about 34 mm in length, and by the end of the first year they reach 115 mm. The length is about 31 cm for a fish 10 to 12 years of age. Females grow faster and larger than males (Culley 1971). The instantaneous natural mortality rate has been estimated from age composition and tagging information at about 0.40 (Murphy 1966). The age of maturity is variable and appears to be a function of stock biomass. In large stocks, only some of the two-year-olds are mature, while in small stocks all of the two-year-olds appear to mature (MacCall 1979). The young sardines move inshore as they grow and congregate in schools near beaches. Each year, beginning in their second summer, the fish migrate northwards early in summer and travel south again in the fall. Hart (1938, 1973) suggests that with increasing age the migration becomes farther with the oldest fish being found farthest to the north. The migrations appear to be complex, with timing and extent of movements being affected by oceanographic factors.

Physiology

Pacific sardine have been reported to over-winter in inlets of the British Columbia coast. Co-incidentally, there have been reports of mass mortalities (Hart 1943b). Foerster (1941) speculated that this was caused by a dietary deficiency. However, Hart (1943b) noted that the mortalities tended to occur at the heads of inlets where fresh water inflow could result in reduced water temperature. He also suggested that lack of plankton availability could be responsible for these mortalities. Hart's (1943b) description is similar to recent observations in the Central Coast and Queen Charlotte Strait areas of British Columbia where sardines succumbed to VHS (viral hemorrhagic septicemia). From November 1998 to February 1999, large numbers of sardines were reported dying at numerous locations in the Queen Charlotte Strait. Samples collected from Beaver Cove were found to be infected with VHS virus. The strain of VHS virus appears to be identical to that commonly observed in Pacific herring (*Clupea pallasi*) from the British Columbia coast (personal communication - G. Traxler, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, B.C. 14 November 2001). VHS has also been found in sardines off the California coast but it is unknown whether this is the identical strain to that found in the B.C. samples.

The mass die-offs occurred during strong El-Niño events and warmer water conditions, which appear to favour greater sardine migration into Canadian waters (Ware 2001). While the proximate cause of death of these sardines was probably VHS infection, it seems likely that stress from reduced water temperature and possibly from food limitation triggered the disease outbreak. Water temperatures observed during an earlier die-off in the Central Coast (Smith Inlet) in February, 1998 were measured at 7° and 8.5° C (personal communication - D. Kieser, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, B.C. 10 March, 1998). Ahlstrom (1960) reported that the lower temperature at which sardine can live is approximately 7° C.

Movements/dispersal

Tagging of sardines in British Columbia waters and off California demonstrated the annual migration patterns of sardines to be northward in the spring and back to California in the late fall (Hart 1943a, Janssen 1948). Recent analysis of historical fisheries shows that rate of movement into Canadian waters is influenced by water temperatures during the spring and early summer (Ware, 2001). The extent and speed of the annual northward migration of sardines is directly related to the location of the 12° C isotherm. As a result, in warm El Niño years there are more extensive migrations into Canadian waters. Other factors, such as local environmental conditions and food availability, also play roles in the dispersal of sardines. Estimates of the proportion of the total annual Pacific sardine catch that were taken in Canadian waters, from 1917-1948, suggest that on average about 10% of the sardine population migrates into British Columbia (Ware, 1999, 2001).

Nutrition and interspecific interactions

Pacific sardine feed extensively on copepods while young and switch to diatoms as they mature (Hart 1938, 1973; McFarlane and Beamish 2001). Ahlstrom (1960) noted that sardines are opportunistic and consume fish larvae and other zooplankton when available. Sardines are prey to a wide variety of predators including commercially important fish species, seabirds, and marine mammals (Bargmann 1998, Culley 1971, Ahlstrom 1960). Pritchard and Tester (1944) reported that sardines were the dominant prey item for chinook (*Oncorhyncus tshawytscha*) and coho (*O. kisutch*) salmon during the 1930s when they were abundant off the British Columbia coast. It is expected that if the sardine population continues to increase, they will again become an important food item for salmonids in the Pacific northwest.

The dramatic collapse and disappearance of the sardine from the west coast of North America during the mid-20th century stimulated research into a better understanding of the dynamics of this and other pelagic species that exhibit large fluctuations in abundance. Studies of sediment cores in the Santa Barbara Basin (California) have used fish scale deposition to reconstruct the relative abundance of pelagic species for the past two millenia. These data reveal cycles of approximately 60 years' duration in the abundance of both sardine and northern anchovy *(Engraulis mordax)*; moreover, during sardine absence, anchovy tend to be more abundant and vice versa (Soutar and Isaacs 1969,1974). Because the negative associations are only weakly correlated, the mechanism driving the

fluctuations remains unclear. There may be a parallel response to large-scale environmental change or competition for food or other biological interaction (Baumgartner et al. 1992). Baumgartner et al. (1992) found nine major recoveries and nine subsequent collapses of the sardine population in the past 1700 years. The recoveries range from 20 to 70 years, with an average of 36 years, while the collapses range from 20 to 50 years, averaging 30 years in length. Thus, the recent collapse and recovery of sardines in the California Current system appears to be a recurring biological phenomenon that may be mediated by both climatic factors and biological interactions, and can be expected to recur in the future despite human intervention.

POPULATION SIZES AND TRENDS

Traditional ecological knowledge

Researchers and historicans (Drucker 1951; Sapir and Swadesh 1939) as well as the historical account of Jewitt (Stewart 1987) have documented the pre- and post-contact importance of sardines (Sardinops sagax) along the west coast of Vancouver Island in Nuu-chah-nulth communities. Archeological evidence recovered from sites in Nuu-chah-nulth territories has conclusively revealed the use of sardines pre-dating modern-day commercial fisheries. Research indicates that sardines were highly valued when the fall salmon runs were low in abundance. During these times, Nuu-chah-nulth gathered both sardines and herring to supplement their diet. Interestingly, Williamson (1930) noted that “the indians knew these fish, which they called “seetons”: they did not find them palatable”. The Nuu-chah-nulth word for sardines is "Tsee'pin".

Recent stock status

The history of the Pacific sardine fishery has been extensively documented by Murphy (1966), Culley (1971) and Radovich (1982). The fishery began in California in 1916-17 with a catch of about 25 000 tonnes. It was primarily used as a canned product to compete in the European markets where domestic production had been curtailed by the war (Figure 3). Thereafter, catches for reduction to meal and oil increased substantially, peaking in 1936-37 at 718 000 tonnes. The fishery remained stable at about the 500 000 tonne level until 1945-46, when it declined markedly to catches of 20 to 40 000 tonnes annually. The fishery remained at this level until 1967, when legislation was introduced to limit pressure on the depleted stocks (Radovich 1982). A moratorium on landings was instituted in California until the spawning population recovered to 20 000 short tonnes (1 short ton = 2000 lbs.). The moratorium was lifted in 1986 when the biomass exceeded this level.

The major reduction fishery began in 1925, which is coincident with the exponential growth in landings. In British Columbia, this fishery began in 1917-18 at 70 tonnes and increased rapidly to 44 000 tonnes by 1926-27. This level was surpassed and sustained until 1947-48, when the population was collapsing and only 444 tonnes were landed in Canadian waters (Radovich 1982).

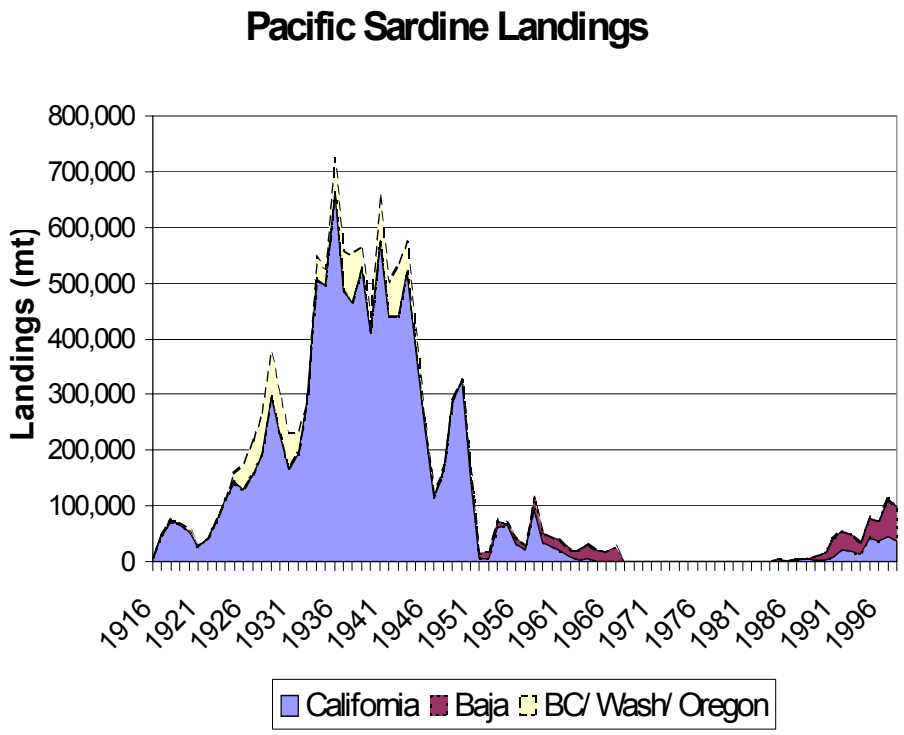

Figure 3. History of catches in the Pacific sardine fishery from 1916 to present.

The factors causing the demise of the California sardine stocks appear to have been a combination of overfishing and unfavourable environmental conditions for sardine survival (Radovich 1982, Murphy 1966, 1978, MacCall 1979). As the stock collapsed the range of the population contracted and fewer and fewer fish migrated to the Pacific northwest (Radovich 1982). Around this time, the northern anchovy populations were beginning to increase in abundance, and it remains uncertain whether interspecific competition with the anchovy was responsible for, or accelerated, the decline of the Pacific sardine stocks (Murphy 1966, 1978; Radovich 1982).

Murphy (1967) estimated that the stock would require 24 years to recover to maximum productivity in the presence of moderate fishing. In the mid- to late 1980s, there were indications that the sardine population was increasing rapidly. In 1986, it was estimated that the tonnage off California had exceeded 20000 short tons, which provided the opportunity for a small, directed quota of 1000 short tons for the California fleet. The fishery in the United States has continued to expand as the sardine population increases (Figure 4). The entire sardine population is estimated to exceed one million metric tonnes, a level approaching that of the 1930s. The recent dramatic increase in abundance is largely a function of strong recruitment (Figure 5) that appears to be related to recent elevated sea-surface temperatures (Conser et al. 2001).

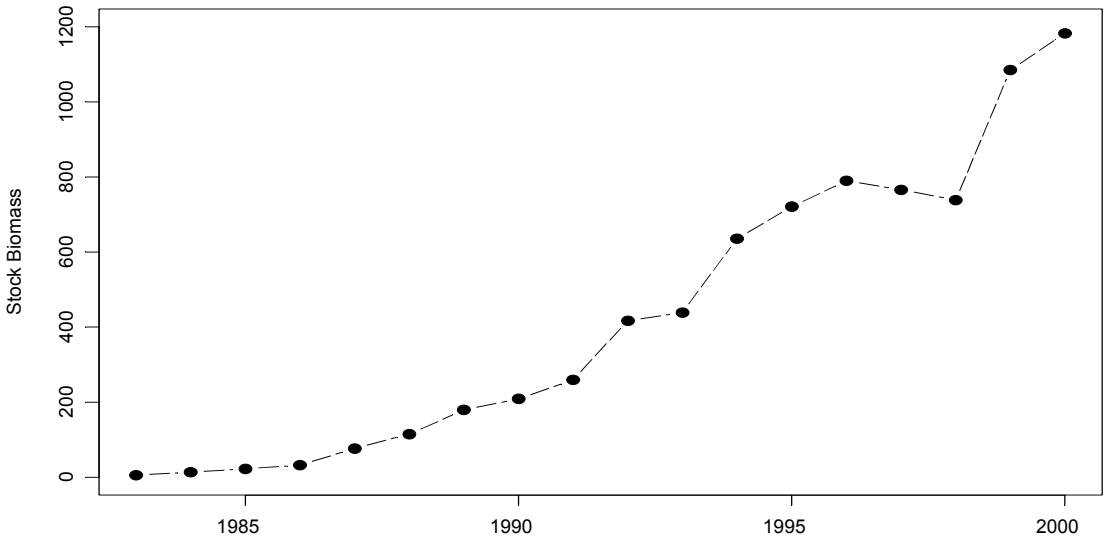

Figure 4. Recent Pacific sardine stock biomass (x1,000 mt) of age 1 and older fish, estimated from an age-structured stock assessment model (see Conser et al. 2001). The assessment is for the entire North American population, the majority of which (~90%) resides in US waters.

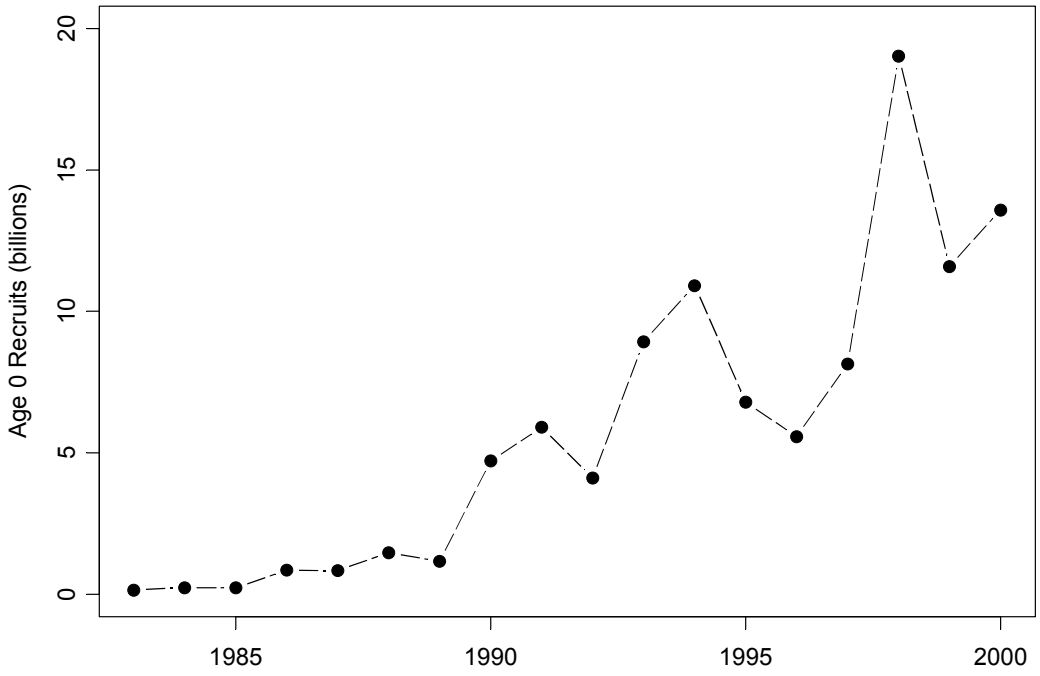

Figure 5. Recent Pacific sardine recruitment (billions of 0 age fish) estimated from an age-structured stock assessment model (see Conser et al. 2001). The assessment is for the entire North American population, the majority of which (~90%) resides in US waters.

As the California sardine population increases it continues to expand its range. As a result, the sardine re-appeared in British Columbia waters in 1992 (Hargreaves et al. 1994). The abundance of sardine in Canadian waters has increased through the 1990s and may be approaching historical levels of 10% of the coastwide biomass (McFarlane and Beamish 2001, Ware 1999, 2001, Schweigert and McFarlane, 2001).

Rate of increase

The rate of increase of the sardine population was calculated from Figure 4 using formulae provided by COSEWIC (http://www.cosewic.gc.ca/COSEWIC/authors/). It indicates a 322% increase in abundance during the past 10 years, which suggests an annual rate of increase of 14%. In other words, the population has more than tripled during the past decade.

LIMITING FACTORS AND THREATS

The factors determining the abundance of the sardine are not well understood. It is known that reproductive success or survival to recruitment is linked to water temperature (Conser et al. 2001). Historically, an intensive fishery had dramatic effects on the abundance of sardines. Additionally, there have been speculations about the interrelationships of the sardine and anchovy populations both on short and long time scales from examinations of sediment cores (Soutar and Isaacs 1969, 1974). These data suggest that anchovy have been present in the offshore California area for at least the past 200 years at a more uniform level of abundance than the Pacific sardine (Soutar and Isaacs 1974). During this time period, the sardine appears to have had periods of great abundance interspersed with almost complete absence. It is possible that the sardine is locally adapted to a narrower range of temperature for spawning, and subsequent egg and larval development and survival, than the anchovy. Thus, long-term changes in ocean temperature regimes would affect the success of reproduction and ultimately stock size to the extent that the sardine would be a successful competitor with anchovy in restricted areas, as the latter appears to be more tolerant of a wider range in temperature. The limiting factor to the current expansion of the sardine population may be the availability of spawning habitat and food, as the population begins to saturate its available resource base.

The fishery management regime currently in place in the United States for sardines allows for a maximum 15% harvest rate. This rate may vary between 5-15 % and is linked to recent water temperature, which directly determines reproductive success and productivity of the species. This harvest rate policy is thought to be precautionary and approximates the maximum sustainable harvest rate estimated for this species. In addition, the harvest policy includes the requirement for a spawning reserve of 150,000 metric tonnes that is protected prior to considering any fisheries (Conser et al. 2001).

At present, there is only an experimental fishery for sardine in British Columbia but there is interest in its expansion. The proposed Canadian harvest rate is fixed at the

United States rate and the harvest would be based on the US assessment of the population size (Schweigert and McFarlane, 2001). Since the Canadian fishery is based on northward migrants from California, a very limited portion of the population is susceptible to exploitation here, and at the proposed harvest rate would amount to only 1-2% of the entire stock. This assumes that 10% of the population migrates into Canadian waters and 5-15% of these fish are captured.

SPECIAL SIGNIFICANCE OF THE SPECIES

The sardine and the sardine fishery have played an instrumental role in the economic development and expansion of western North America, particularly Monterey, California. It has been popularized in Steinbeck's novel *Cannery Row* (Hemp 1986) and so has cultural significance in the United States. Sardines have also been an important source of food for Nuu-chah-nulth First Nations people (west coast of Vancouver Island). Sardine is a highly prized food fish worldwide and is used extensively for bait wherever it occurs. Biologically, the sardine is an important forage species that supports a variety of predators and plays a pivotal role in the marine ecosystem. Since the mid-1990s, sardine have dominated the commercial fish biomass landings in California (see http://swr.ucsd.edu/fmd/bill/landings.htm). Aside from squid, they appear to be among the most abundant species on the coast. As a result, they provide prey for most marine fish predators including other fishes (tunas, yellowtail, barracuda, bonito, marlin, hake, and mackerel), sharks, seabirds (pelicans, gulls, cormorants), and marine mammals (sea lions, seals, porpoises, and whales) (Culley 1971). During their peak abundance in the 1930s and early 1940s, sardine was the dominant prey species for chinook and coho salmon in the Pacific northwest (Pritchard and Tester 1944, Bargmann 1998).

EXISTING PROTECTION OR OTHER STATUS

International: Beginning in 1928 until collapse, California primarily regulated their fishery by season limits. Some regulations consisted of net and mesh size limits. Considerable controversy revolved about the quantities of sardines which were reduced to oil and meal versus the amount canned for human consumption (Ahlstrom and Radovich 1970; Culley 1971). A permit system was introduced to limit the quantities reduced but this system was circumvented, such as through reduction ships operating outside the three-mile territorial limit. Quotas were suggested, beginning in about 1931, but met limited success (Radovich 1982). In 1967, the California Legislature imposed a moratorium on landings of Pacific sardines for any purpose, including bait. It was recommended that fishing be suspended until the stocks rebuilt to at least 20 000 tons. In 1986, the state lifted its 18-year moratorium on sardine harvest based on evidence that the spawning biomass exceeded 20,000 tons. An annual directed quota of 1,000 tons was established from 1986-1990, increasing to 12,000 tons in 1991 and to 20,500 tons in 1992. Subsequently, quotas have increased as the stock continues to grow at a rapid rate. The US quota is restricted to a maximum 15% harvest rate as long as the biomass exceeds 150,000 tonnes. The harvest rate is constrained between

5-15% based on a three-year running mean water temperature that reflects recent stock productivity.

National: In British Columbia there was no restriction on the quantities of sardines that could be used for reduction. The fishery was seasonal and variable, and minor regulations were imposed from time to time on size and mesh of purse seine gear and season of fishing (Ahlstrom and Radovich 1970). The recent re-appearance of sardines in Canadian waters has resulted in renewed interest in harvest, primarily as food and bait. An experimental fishery has been in operation since 1997, with seven licensees participating. The experimental nature of the fishery has restricted the harvest to 1600 tons in 2001, with substantial interest in expanding the fishery in the future. The quota proposed for the fishery in British Columbia in 2002 is based on the current United States harvest rate of 15% and the coastwide biomass estimated to be in Canadian waters. The result would be a harvest of approximately 1-2% of the total Pacific population (assuming 10% of the population migrates into Canada and the harvest rate is 15%; see Schweigert and McFarlane, 2001). The Canadian assessment and quota is based on the US sardine assessment which samples and surveys the major spawning areas off California. Canada currently and historically provided catch and sampling data from British Columbia as part of a coastwide sardine database.

The current status of the Pacific sardine in British Columbia is listed by COSEWIC as vulnerable or a species of special concern, based on a previous review prior to population recovery (Schweigert 1988).

TECHNICAL SUMMARY

Sardinops sagax (Jenyns 1842)
Pacific sardine (sardine Pacifique)
California sardine
British Columbia

Extent and Area information	
• *extent of occurrence (EO)(km²)*	1.250 million km^2 extending from Alaska to Mexico
• *specify trend (decline, stable, increasing, unknown)*	Increasing
• *are there extreme fluctuations in EO (> 1 order of magnitude)?*	Yes, but on a scale of decades
• *area of occupancy (AO) (km²)*	Perhaps 36,000 km^2 within Canadian waters
• *specify trend (decline, stable, increasing, unknown)*	Increasing
• *are there extreme fluctuations in AO (> 1 order magnitude)?*	Yes, but on a scale of decades
• *number of extant locations*	Gulf of California and seasonally from Baja to Alaska
• *specify trend in # locations (decline, stable, increasing, unknown)*	Increasing
• *are there extreme fluctuations in # locations (>1 order of magnitude)?*	Yes, but on a scale of decades
• *habitat trend: specify declining, stable, increasing or unknown trend in area, extent or quality of habitat*	Increasing
Population information	
• *generation time (average age of parents in the population) (indicate years, months, days, etc.)*	2-3 years
• *number of mature individuals (capable of reproduction) in the Canadian population (or, specify a range of plausible values)*	Billions of individuals in total population, on average about 10% migrate into Canadian waters but only occasionally reproduce here.
• *total population trend: specify declining, stable, increasing or unknown trend in number of mature individuals*	Increasing
• *if decline, % decline over the last/next 10 years or 3 generations, whichever is greater (or specify if for shorter time period)*	
• *are there extreme fluctuations in number of mature individuals (> 1 order of magnitude)?*	Yes, on a scale of decades
• *is the total population severely fragmented (most individuals found within small and relatively isolated (geographically or otherwise) populations between which there is little exchange, i.e., ≤ 1 successful migrant / year)?*	No
• *list each population and the number of mature individuals in each*	Only one panmictic population
• *specify trend in number of populations (decline, stable, increasing, unknown)*	N/A
• *are there extreme fluctuations in number of populations (>1 order of magnitude)?*	N/A
Threats (actual or imminent threats to populations or habitats)	
- No threats at this time.	

Rescue Effect (immigration from an outside source)	
• *does species exist elsewhere (in Canada or outside)?*	Yes
• *status of the outside population(s)?*	Increasing
• *is immigration known or possible?*	Yes
• *would immigrants be adapted to survive here?*	N/A
• *is there sufficient habitat for immigrants here?*	N/A
Quantitative Analysis	Extensive annual stock assessment and other analyses are conducted by U.S. scientists

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