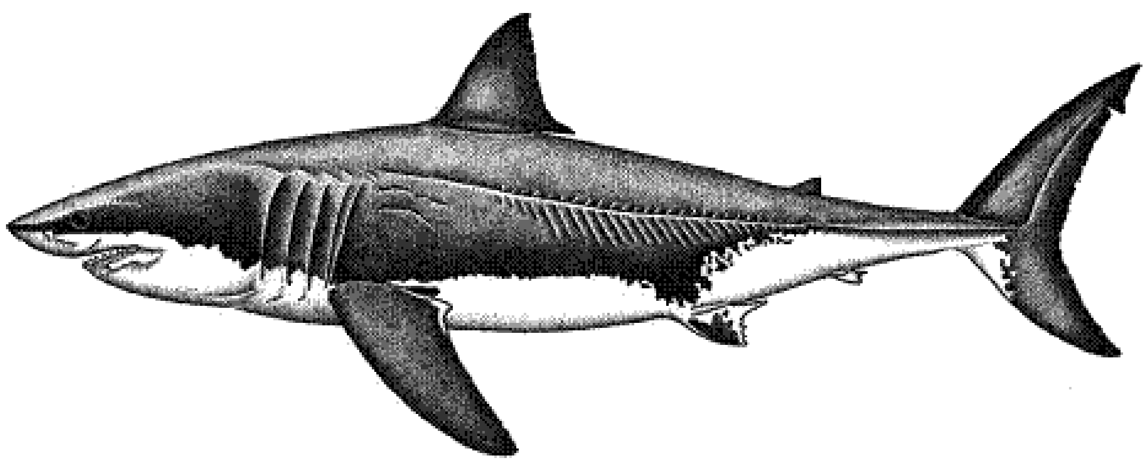
COSEWIC
Assessment and Status Report

on the

White Shark
Carcharodon carcharias

Atlantic population

in Canada



ENDANGERED
2021

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

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Previous report(s):

COSEWIC 2006. COSEWIC assessment and status report on the White Shark *Carcharodon carcharias* (Atlantic and Pacific populations) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 31 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

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White Shark — by R. Aidan Martin.

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COSEWIC
Assessment Summary

Assessment Summary – April 2021

Common name
White Shark - Atlantic population

Scientific name
Carcharodon carcharias

Status
Endangered

Reason for designation
This highly mobile species is a seasonal migrant in Atlantic Canada and considered to be part of a widespread Northwest Atlantic population. The status of the Canadian population is considered to be the same as that of the broader Northwest Atlantic population. That broader population is estimated to have declined by >70% over the past 1.5 generations (since the 1960s) because of incidental mortality from fishing. However, the population appears to have remained stable since the 1990s and is projected to remain stable or increase slightly. Although measures to improve fishing practices have been introduced, the primary threat continues to be mortality from incidental capture in fisheries. The species is still vulnerable to this threat because of its long generation time (42 years) and low reproductive rate.

Occurrence
Atlantic Ocean, New Brunswick, Newfoundland and Labrador, Nova Scotia, Prince Edward Island, Québec

Status history
Designated Endangered in April 2006. Status re-examined and confirmed in May 2021.

COSEWIC
Executive Summary

White Shark
Carcharodon carcharias

Wildlife Species Description

White Shark (*Carcharodon carcharias* (Linnaeus, 1758)) is the only species of this genus. In French it is called grand requin blanc. Genetic evidence combined with satellite tracking information clearly shows that this species is wide-ranging in the Pacific and Atlantic oceans. Gene flow among populations across ocean basins is restricted based on high site fidelity and reproductive philopatry of females (returning to same spawning site). There is no known genetic distinction across the Canadian and U.S. population in the Atlantic Ocean. As such, the entire Northwest Atlantic population should be considered a single designatable unit.

Cultural Significance

All species are significant and are interconnected and interrelated. As part of COSEWIC status assessments, Aboriginal Traditional Knowledge (ATK) reports are prepared by the Aboriginal Traditional Knowledge subcommittee (ATK SC) based on publicly documented ATK compiling and summarizing the relevant ATK to the status assessment. There is no ATK report for White Shark.

Distribution

White Shark is widely distributed, from 60°N to 60°S, but is most frequently observed in temperate waters over the continental shelves of the western North Atlantic Ocean, Mediterranean Sea, the North Pacific Ocean, and off the coasts of southern Africa, southern Australia, and New Zealand. On the Atlantic coast of Canada, White Shark is known from fewer than 100 confirmed or probable records since 1874, in addition to tracking of White Shark tagged in the Atlantic waters of both the U.S. and Canada. White Shark occur throughout Atlantic Canada and are seasonal migrants in the late summer and early fall. Tracking shows that the White Shark uses most of Canada's Exclusive Economic Zone (EEZ) south of 52°N but occasionally ranges off the continental shelf northward to waters near Greenland.

Habitat

White Shark range widely in coastal and oceanic waters. Juveniles are common in coastal habitat but move off the continental shelf seasonally as adults. Bathymetric range is from near the surface to just above the bottom, to a depth of at least 1,128 m but predominately in waters from <50 m to 500 m. White Shark is most common in water temperatures between 14-25°C but can be found in waters from 1.6 to 30.4°C.

Biology

White Shark are ovoviviparous with gestation period estimated from 10-20 months. Litter size averages seven pups. The Mid-Atlantic Bight is a likely pupping area, with the New York Bight being a nursery area. Length of the reproductive cycle is estimated at up to two years and may be more than three years. Maximum lifetime reproductive output has been estimated to be 45 pups. In the Northwest Atlantic, males are estimated to reach sexual maturity at 26 years and a length of ~3.8 m while females likely reach maturity at an age of 33 years and a length of 4 to 5 m. Lifespan in this population is estimated to be 40-73 years based on limited sampling, particularly for females. Generation time has been estimated at about 42 years, with a low natural mortality of 0.063-0.125/year. Intrinsic rate of population increase is also low and estimated at 0.035-0.056/year.

Population Sizes and Trends

There are no estimates of population size in Canadian Atlantic waters. There are only around 100 records of White Shark off the Atlantic coast of Canada since 1874, although sightings are increasing, with more than 40 since 2009. Abundance in Canada has likely always been much lower than in adjacent U.S. waters, given the low encounter rate in commercial and recreational fisheries in Canada and apparent seasonal presence. The White Shark population trend in the Northwest Atlantic is uncertain but is likely stable or increasing. While all analyses agree on the major decline of the White Shark population from the 1960s to the 1990s, there is substantial uncertainty about any subsequent increase.

Threats and Limiting Factors

Human activity is the most significant threat to White Shark, which is taken as sport fish, commercial bycatch, and for international trade of their body parts. In the Northwest Atlantic White Shark occur as bycatch in commercial fisheries in USA waters. Recorded incidental capture in Canada is rare. Their late age at maturity, small litter sizes, and longevity make White Shark highly vulnerable to even low levels of mortality. Their position as top predators and ovoviviparous reproduction also make them vulnerable to pollution by environmental toxins, particularly organochlorines.

Protection, Status, and Recovery Activities

At the start of 2005, the *Convention on International Trade in Endangered Species of Flora and Fauna* (CITES) listed White Shark in Appendix II. In 2009, the International Union for the Conservation of Nature listed White Shark globally as 'Vulnerable'. The species was protected in 1997 in U.S. waters under the federal Fisheries Management Plan. In Canada, the species has been listed as Endangered under the SARA since 2011. Under the provisions of section 32 (1) of the Act it is illegal to kill, harm, harass, capture, or take White Shark, and under section 32(2) it is illegal to possess, collect, buy, sell, or trade White Shark. All sharks captured must be released with minimal harm in U.S. and Canadian fisheries but release mortality is unknown for most fisheries.

TECHNICAL SUMMARY

Carcharodon carcharias

White Shark, Atlantic population

Grand requin blanc, population de l'Atlantique

Range of occurrence in Canada (province/territory/ocean): Atlantic Ocean, New Brunswick, Newfoundland and Labrador, Nova Scotia, Prince Edward Island, Québec

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines(2011) is being used)	42 years. New information on age of maturity suggests the previous generation time estimate of 23 years is likely an underestimate (see **Life Cycle and Reproduction**).
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	No
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Estimated decline of 73-79% over 1.5 generations.
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Estimated decline of 73-79% over 1.5 generations.
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future.	Estimated decline of 73-79% over 1.5 generations but stable to slightly increasing trend for future years, based on projected abundance under current management regime (DFO 2017).
Are the causes of the decline a.clearly reversible and b.understood and c. ceased?	a. Likely b. Yes c. No, greatly reduced
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence (EOO)	Estimated 1,062,590 km², (1,346,138 km² including land area)
Index of area of occupancy (IAO) (Always report 2x2 grid value).	Unknown, greater than 2,000 km²
Is the population "severely fragmented" i.e., is >50% of its total area of occupancy in habitat patches that are (a) smaller than would be required to support a viable population, and (b) separated from other habitat patches by a distance larger than the species can be expected to disperse?	a. No b. No

Number of "locations"* (use plausible range to reflect uncertainty if appropriate)	Not applicable
Is there an [observed, inferred, or projected] decline in extent of occurrence?	No
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	No
Is there an [observed, inferred, or projected] decline in number of subpopulations?	No
Is there an [observed, inferred, or projected] decline in number of "locations"*?	No
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	No
Are there extreme fluctuations in number of subpopulations?	No
Are there extreme fluctuations in number of "locations"*?	No
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each subpopulation)

Subpopulations (give plausible ranges)	**N Mature Individuals**
	Unknown
Total	

Quantitative Analysis

Is the probability of extinction in the wild at least [20% within 20 years or 5 generations, or 10% within 100 years]?	Not undertaken

Threats (direct, from highest impact to least, as per IUCN Threats Calculator)

Was a threats calculator completed for this species? Yes, July 9, 2020

5.4 Fishing and harvesting aquatic resources

i. Bycatch in fisheries – Low impact

What additional limiting factors are relevant? Late maturity, low fecundity.

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	U.S. Atlantic population (same DU) has possible increase

* See Definitions and Abbreviations on COSEWIC website and IUCN (Feb 2014) for more information on this term

Is immigration known or possible?	Yes
Would immigrants be adapted to survive in Canada?	Yes
Is there sufficient habitat for immigrants in Canada?	Yes
Are conditions deteriorating in Canada?[+]	No
Are conditions for the source population deteriorating?[+]	No
Is the Canadian population considered to be a sink?[+]	No
Is rescue from outside populations likely?	Unlikely

Data Sensitive Species

Is this a data sensitive species? No

Status History

COSEWIC Status History: Designated Endangered in April 2006. Status re-examined and confirmed in May 2021.

Status and Reasons for Designation:

Status: Endangered	**Alpha-numeric codes:** A2bd
Reasons for designation: This highly mobile species is a seasonal migrant in Atlantic Canada and considered to be part of a widespread Northwest Atlantic population. The status of the Canadian population is considered to be the same as that of the broader Northwest Atlantic population. That broader population is estimated to have declined by >70% over the past 1.5 generations (since the 1960s) because of incidental mortality from fishing. However, the population appears to have remained stable since the 1990s and is projected to remain stable or increase slightly. Although measures to improve fishing practices have been introduced, the primary threat continues to be mortality from incidental capture in fisheries. The species is still vulnerable to this threat because of its long generation time (42 years) and low reproductive rate.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Meets Endangered A2bd. The number of mature individuals is estimated to have declined by 73-79% over 1.5 generations based primarily on incidental mortality from past fishing practices.
Criterion B (Small Distribution Range and Decline or Fluctuation): Not applicable. EOO of >1,000,000 km^2 and IAO >2000 km^2 exceeds thresholds.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable. Absolute number of mature individuals is unknown. Most recent analyses indicate some increase in relative population indices.
Criterion D (Very Small or Restricted Population): Not applicable. Absolute number of mature individuals is unknown; criteria not applied but effective population size analysis suggests population numbers may be <1000 though this analysis is highly uncertain.
Criterion E (Quantitative Analysis): Not applicable. Analyses not done.

[+] See Table 3 (Guidelines for modifying status assessment based on rescue effect)

PREFACE

Since the writing of the 2006 COSEWIC status report there have been new studies on the genetics, life history, movement, and abundance of White Shark in the Northwest Atlantic, although there is little indication of major changes to bycatch mortality, the main threat to the population. Recent global genetic analyses suggest the Northwest Atlantic population is demographically isolated from other populations, even in the Mediterranean, and may be inbreeding, having recently experienced a genetic bottleneck. New aging studies have updated the maximum ages, age at maturity, productivity, and susceptibility to bycatch mortality. Recent tagging and tracking work expanded understanding of movement between the U.S. and Canada.

New studies of this population's relative abundance suggest a decline of 73-79% from the 1960s to the 1990s. One of these recent studies estimated trends up to 2010 using three standardized indices and suggests a gradual increase since the 1990s; however, there is substantial uncertainty about the magnitude of this increase. The absolute population size of White Shark in the Northwest Atlantic is not known.

COSEWIC HISTORY

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. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2021)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* 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. Definition of the (DD) category revised in 2006.

Environment and Climate Change Canada
Canadian Wildlife Service

Environnement et Changement climatique Canada
Service canadien de la faune

Canada

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

COSEWIC Status Report

on the

White Shark
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in Canada

2021

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

White Shark (*Carcharodon carcharias* (Linnaeus, 1758)) is the only living species of this genus. Over the years, there have been proposals to name separate regional populations, but to date morphometry, meristics, colouration, and skeletal anatomy from different 'centres of abundance' are not recognizably separable. The accepted French name for the White Shark is grand requin blanc.

Morphological Description

The following description is taken primarily from Compagno (2001).

The snout is bluntly conical (Figure 1a). The interior teeth are enlarged and the anterior, intermediate, and lateral teeth are compressed and form a continuous cutting edge. The intermediate teeth are enlarged and are over two-thirds the height of adjacent anteriors. The total tooth count is 44 to 52. The body is usually stout with the dorsal fin origin usually over the pectoral inner margins. The origin of the anal fin is under or slightly posterior to second dorsal fin insertion. The total vertebral count is between 170 and 187 with total length of adults between 3.8-6 m and possibly longer. Typically, there is a black axillary spot at the insertion point of the pectoral fin; and the pectoral fin tips are usually abruptly black on their ventral surfaces.

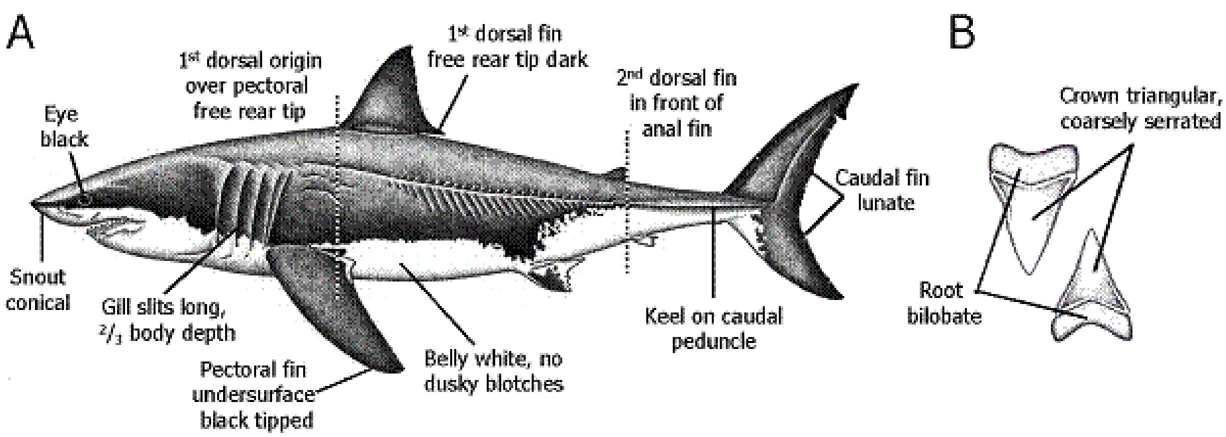

Figure 1. Field characters useful for identifying White Shark (*Carcharodon carcharias*), A. Lateral view, B. detail of upper and lower anterior teeth. Diagrams by R. Aidan Martin.

Field Marks: Heavy spindle-shaped body with a moderately long conical snout. The teeth are large, flat, and triangular with serrated edges. The gill slits are long. The first dorsal fin is large with a dark, free rear tip; the second dorsal and the anal fins are minute; the caudal peduncle has a strong horizontal keel; and the caudal fin is large and shaped like a crescent.

The dorsal surface is a grey or brownish-grey to blackish above and the ventral surface of body is white. The margin between the dark dorsal and white ventral surfaces is sharply delimited. The iris of the eye is conspicuously black.

Population Structure and Variability

No genetic work has been conducted on White Shark in Canadian waters but there has been one recent genetic analysis in U.S. waters. White Shark in the Northwest Atlantic are relatively genetically isolated from the South African population (O'Leary *et al.* 2015). Based on mitochondrial DNA (mtDNA), two distinct lineages and three distinct haplotypes have been identified in global White Shark populations: the Mediterranean/Indo-Pacific lineage and the Northwest Atlantic and Indian Ocean/South Africa lineage, with an additional unique haplotype found in South Africa (Pardini *et al.* 2001; Andreotti *et al.* 2016b). White Shark in the Northwest Atlantic are most closely related to White Shark in South Africa; however, the populations have likely been separated for at least a half million years and are genetically distinct (mtDNA $\Phi ST = 0.10$, $p < 0.00001$; microsatellite $FST = 0.1057$, $p < 0.021$) (O'Leary *et al.* 2015; Andreotti *et al.* 2016b). White Shark in the Mediterranean have separate haplotypes from those in the Northwest Atlantic but the sample sizes in the analysis are too small for definitive conclusions about gene flow between these populations (Gubili *et al.* 2011). Satellite tracking information from other jurisdictions suggests that although this species is highly migratory, it rarely disperses across ocean basins, having high philopatry to particular pelagic and coastal aggregation sites (Pardini *et al.* 2001; Boustany *et al.* 2002; Jorgensen *et al.* 2010 – see **Dispersal and Migration**). For instance, both mtDNA and biparentally inherited DNA suggest Australian White Shark display high reproductive philopatry to coastal aggregation sites and have limited gene flow across ocean basins, even to New Zealand (Blower *et al.* 2012). Reproductive philopatry was also found from mtDNA in White Shark at Guadalupe Island, confirming low dispersal (Diaz-Jaimes *et al.* 2016). While mtDNA evidence indicates there may be no gene flow between females from the Northwest Atlantic and those from other populations, the possibility of genetic dispersal by males cannot be excluded despite the apparent philopatry in all populations studied..

Genetic structuring within the Northwest Atlantic population has not been studied and is required. However, a low M-ratio (0.71, $p < 0.004$) and a high inbreeding coefficient ($F_{IS} = 0.222$, $p=0.001$) indicate low genetic diversity, a potential for inbreeding, and a recent genetic bottleneck in this population (O'Leary *et al.* 2015). Additionally, Northwest Atlantic White Shark likely have a low effective population size, at least smaller than that of the South African White Shark population based on a comparative genetic study (O'Leary *et al.* 2015; Andreotti *et al.* 2016a). Populations in each of the Northeast Pacific and South Africa form single populations, based on genetic studies, and since these have a similar geographic range size to the Northwest Atlantic population, it is unlikely that genetic structuring exists for it either (Jorgensen *et al.* 2010; Onate-Gonzalez *et al.* 2015; Andreotti *et al.* 2016b; Diaz-Jaimes *et al.* 2016). These genetic studies, along with active tracking of seasonal migration between the U.S. and Canada (Skomal *et al*. 2017 – see **Dispersal and Migration**), suggest that White Shark of the entire Northwest Atlantic are a single population. However, genetic structuring between eastern and southwestern coasts of Australia suggests that philopatry in White Shark can be strong enough to create genetic structure over small scales (Blower *et al.* 2012).

Thermal fronts and the reproductive philopatry and high site fidelity of both males and females form the largest barriers to dispersal (Jorgensen *et al.* 2010; Gubili *et al.* 2011; Blower *et al.* 2012). The 15°C isotherm may be the main northern limit to its distribution in the Northwest Atlantic (Casey and Pratt 1985). Although possibly rare, ocean-wide dispersals do occur, even across warm tropical waters usually avoided by White Shark (e.g., Bonfil *et al.* 2005). It is unknown how much gene flow these rare long dispersal events create.

Designatable Units

The designatable unit (DU) identified in the 2006 COSEWIC report is "Canada's Atlantic population". However, under new COSEWIC guidance, the population is best described as the Northwest Atlantic DU, as subpopulation structure within the Northwest Atlantic is unlikely (Curtis *et al.* 2014).

In the Atlantic Ocean, the most closely related White Shark populations (Northwest Atlantic and South Africa) have FST values of ~0.1 (microsatellite DNA), indicating some level of discreteness, although clustering analysis identified some individuals from the Northwest Atlantic having genotypes very consistent with those from S. Africa and vice versa (suggesting dispersal in both directions). Analyses with mtDNA are inconclusive in terms of significance because sharks are known to have high female philopatry, which may produce high levels of population differentiation for maternally inherited mtDNA markers. Such markers do not reflect population differentiation across the genome if males mediate dispersal. However, satellite tracking indicates White Shark rarely cross ocean basins and have high site philopatry in all populations studied. Therefore, until a broad examination of population structure using nuclear heritable markers is conducted, the Northwest Atlantic White Shark is considered as a separate DU. Although tracking and genetic information indicate the Atlantic population of White Shark in Canada is distinct from those in other ocean basins, it is not distinct from the population in U.S. waters.

Special Significance

White Shark is the largest predatory fish and one of the few sharks that regularly preys upon marine mammals (Compagno 2001). The species has been known to the Mi'kmaq people of Atlantic Canada for thousands of years: a tooth has been found in an oyster midden dated 1,000 to 2,000 years B.P. at Pig Island, Northumberland Strait, Nova Scotia (Gilhen 1999). There is no species-specific ATK in the report. However, White Shark, like all species, is important to Indigenous peoples who recognize all interrelationships within an ecosystem.

White Shark is notorious for its attacks on humans and boats (Miller and Collier 1981; Burgess and Callahan 1996). Four attacks by White Shark on boats are known from Atlantic Canada (Table 1): 1) in 1873 or 1874 a 4 m White Shark attacked a dory off the St. Pierre Bank, Newfoundland; it was identified by tooth fragments embedded in the hull (Putnam 1874); 2) in June 1920, a 4.6 m White Shark attacked a boat off Hubbard Cove, St. Margaret's Bay, Nova Scotia; it was identified from scars on the boat and description of a tooth embedded in it (Piers 1934); 3) in July 1932, a 4.6 m White Shark attacked a boat 16 km NW of Digby Gut, Nova Scotia; it was identified from a tooth embedded in the hull (Piers 1934); 4) on 9 July 1953, a 3.7 m White Shark attacked and sank a dory off Fourchu, Cape Breton Island, Nova Scotia; neither of the fishermen on board was attacked but one of them drowned. The shark was identified from teeth embedded in the hull (Day and Fisher 1954).

Table 1. Chronological list of White Shark records from Atlantic Canada from opportunistic and fisheries sightings (excluding observations from directed White Shark tagging expeditions). * = not authenticated. Source: DFO 2020 White Shark sightings and strandings database.

Location	Date	Length FL (m)	Sex	Fishing gear	Remarks	Source
Pig Island, Northumberland Strait, NS	1000-2000 years bp				Tooth in oyster stratum	Gilhen (1999)
St. Pierre Bank, NS	1873 or 1874	3.9			Teeth in attacked dory	Putnam (1874)
Off Hubbard Cove, St. Margaret's Bay, NS	June 27, 1920	4.6			Tooth scrapes on attacked dory.	Piers (1934)
Georgetown PEI	September 17, 1921	2.1		Mackerel net	Caught by Capt Sam Hemphill	The Guardian (1921)
Georgetown PEI	September 17, 1921	2.7		Mackerel net	Caught by Capt Sam Hemphill	The Guardian (1921)
White Head Island, near Grand Manan, NB	June (mid), 1930	11.3		herring weir	Size suspect, though teeth reported taken.	Vladykov & McKenzie (1935)
16 km NW of Digby Gut, NS	July 2, 1932	4.6			Tooth in attacked motorboat	Piers (1934)
Harbour de Loutre, Campobello Island, NB	November 22, 1932	7.9		herring weir	Trapped in herring weir	Piers (1934)
French Village, NS	August 11, 1934	4.57	M	Mackerel seine	Reported in news article by fish harvester.	Joyce pers. comm. (2016)
Wedgeport, NS	August, 1938	2.6	M	rod & line	Caught on rod & line by Ms. Michael Lerner	Anon (1940) in Templeman (1963)
Whale Head, N shore, St. Lawrence River	August, 1938			Unknown		Vladykov & McAllister (1961)
Isle Caribou, N shore, St. Lawrence River	August, 1942	2.7		Unknown		Vladykov & McAllister (1961)
Isle Caribou, N shore, St. Lawrence River	August, 1943	3		Unknown		Vladykov & McAllister (1961)
Deer Island, NB	August 24, 1949	3.87	F	herring weir	Trapped in herring weir; immature.	Scattergood *et al.* (1951)

Location	Date	Length FL (m)	Sex	Fishing gear	Remarks	Source
Portneuf River estuary, N shore, St. Lawrence River	August 27, 1949	4.6			Shot by W.B. Scott.	Templeman (1963)
French Village, NS	1950s		F	Mackerel purse seine	Juvenile. Reported by fish harvester. Caught in trap.	Joyce pers. comm. (2016)
Between Passamaquoddy Bay & Grand Manan, NB	August 20, 1952	4.3			Observed attack on porpoise.	Day & Fisher (1954)
Off Fourchu, Cape Breton Island, NS	July 9, 1953	3.7			Teeth in attacked dory; dory attacked and sunk.	Day & Fisher (1954)
Wedgeport, NS	July 9-10, 1953	2.4	M	rod and line	Caught by tuna fisherman.	Day & Fisher (1954)
La Have Islands, NS	August 12, 1953	4.7		herring trap	Caught in herring trap.	Day & Fisher (1954)
St. Croix River, near Dochet Island between ME & NB	August 25, 1953				Observed attack on seal.	Day & Fisher (1954)
Mace's Bay, Bay of Fundy, NB	August 3, 1954	2.6		herring weir	Trapped in herring weir.	Leim & Day (1959)
Maces Bay, NB	September 10, 1954	4.87	F	herring weir	Caught in herring weir.	Hogans & Dadswell (1985)
Ireland Bight, Hare Bay; depth 26 m	August 10, 1956	3.7		cod trap	Teeth in codtrap leader.	Templeman (1963)
SE Grand Bank (44º30'N, 50º12'W)	August, 1956	3.7-4.6		otter trawl	Spanish otter trawl.	Templeman (1963)
Northumberland Strait, 13 km off Wallace, NS	July 30, 1962	3		hake gillnet	Tooth examined by L.R. Day.	Templeman (1963)
Northumberland Strait, 13 km off Wallace, NS	August, 1962	2.7		hake gillnet	ID by W.G. Smith, fishery officer.	Templeman (1963)
Wallace, NS	August, 1962^{+}	6		hake gillnet	Escaped from gillnet.	Templeman (1963)
Wallace, NS	September, 1962^{+}	6		hake gillnet	Escaped from gillnet	Templeman (1963)
Noel, Minas Basin, NS	Sept. 2, 1965			net or handline	Reported by fish harvester.	DFO
Passamaquoddy Bay, between ME & NB	1969				Observed attack on porpoise.	Arnold (1972)
Passamaquoddy Bay off Leonardville, Deer Island, NB	August 13-14, 1971	4.3	F	otter trawl	Caught in otter trawl.	Scott and Scott (1988)
Letete Passage, NB	August 8, 1977^{+}	5.05	F	herring weir	Caught in herring weir.	Hogans & Dadswell (1985)
Passamaquoddy Bay off Mascarene Shore, NB	August 8-9, 1977^{+}	5.2		herring weir	Trapped in herring weir.	Scott and Scott (1988)
Gulf of St. Lawrence, off Alberton, PEI	August 4, 1983	5.2	M	cod gillnet	Caught in cod gillnet	Scott and Scott (1988)
Off Tiverton	July, 1988	4.5		gillnet	Caught in gillnet	Connors Bros. Ltd. In Mollomo (1998)
Southern Scotian Shelf	November, 1989			pelagic longline (tuna)	Japanese longliner (bigeye tuna), discarded.	Scotia-Fundy Observer database

Location	Date	Length FL (m)	Sex	Fishing gear	Remarks	Source
Sable Island	Late 1980s				Tooth recovered from seal carcass.	DFO
65 km west of Sable Island	Oct. 1992			cod trawl	Juvenile. Canadian vessel trawling cod, discarded.	Scotia-Fundy Observer database
Bay of Fundy	Early 1990s	4.2		gillnet	Caught in gillnet.	Campana, pers. comm. (2004)
48.10.60, 64.09.00 (4Tn), Quebec Region	August 15, 1998			gillnet (cod)		Quebec region observer database
49.08333 -50.8833 (Newfoundland)	July 24, 2009			gillnet	Caught at depth of 313 m.	NL Observer Database.
10 miles from Trout River, Newfoundland	August 17, 2010	2.00		gillnet		DFO
Economy, NS	2010	3.05	M	herring weir	Juvenile caught in a weir.	DFO
Economy, NS	August 11, 2011	3.00	F	herring weir	Juvenile caught in a weir	DFO
Grand Manan, NB 44°52′93″N, 66°44′32″W	August 17, 2012	>3.0			Observed preying on a harbour porpoise	Turnbull and Dion (2012)
Passamoquoddy Bay, NB, Sawpit off Swallowtail Lighthouse, Grand Manan	August 6, 2013				Eating a seal	Wong pers. comm. (2016)
Magdalen Islands	Sept. 25, 2013				White Shark bites on marine mammal carcass	DFO
St. Andrews, NB	July 21, 2014				Whale watching with Quoddy Link Marine.	DFO
White Sands, PEI	September 3, 2014				Dead pilot whale scavenged by White Shark	The Eastern Graphic (2014)
Parsborro (Minas Passage - West Bay), NS	July 30, 2015	3.66	M		Reported by NS DNR. Carcass washed out to sea	DFO
Port Mouton, NS	2015				Possibly up to 5 sighted while tuna fishing	DFO
Seal Island, NS	August 2015				Possibly a white attacking a seal	DFO
Alice Head Cove, Saint Margaret's Bay, NS	Late Aug. / early Sept. 2015	5.49		mackerel / tuna trap	18 foot shark reported by fish harvester.	DFO
New Brunswick	September 15, 2015				Porpoise carcass attacked by a white	DFO
Alma, NB	June 2016				Tooth recovered from lobster buoy	DFO
Cape Chignecto Point 45.324444, -64.950386	July 7, 2016				Teeth marks in lobster buoy	Chisholm pers. comm. (2016)

Location	Date	Length FL (m)	Sex	Fishing gear	Remarks	Source
Cross Island, Lunenburg, NS	July 31, 2016				Shark trying to feed on harbour porpoise	CTV News 2016
St. Andrews, NB	August 1, 2016	5.2			St. Andrews Sport Fishing Co. captured video	CBC News 2016
Mosher's Island, NS 44.259194, -64.315125.	August 7, 2016	3.05 - 3.66			Sighted by mackerel harvester	DFO
St. Margarets Bay, NS	August 19, 2016	4.6		mackerel / tuna trap	Caught in mackerel trap and released	DFO
White Point Shoal, NS 43 56.25' N, 64 43.02' W	September 26, 2016	3.66 - 3.96			Tuna fisherman (rod and reel) reported sighting	DFO
Approx 43 55.65' N, 64 44.103' W	September 30, 2016	3.05 - 3.66			Tuna fisherman (rod and reel) reported sighting	DFO
Wedgeport, NS	Fall 2017			tuna rod and reel	White Shark bit tuna	DFO
Grand Desert Beach, NS	September 21, 2017				Seal carcass showing bite mark.	DFO
Cape Sable Island	December 19, 2017				Shark bite on lobster buoy	DFO
Letete Passage, NB	June 20, 2018	4.6			Kayakers spotted fin near Hospital Island	DFO
Economy, NS	July 22, 2018				Shark grabbed a bass that was on the line and breached out of the water.	DFO
Bothwell, PEI 46° 24' 2.25", -62° 3' 59.76"	25-Jul-18	3.66-4.57			Reported by a PEI bluefin charter captain.	DFO
Big Tusket Island, NS 43 deg 38.852' N 065 deg 59.697' W	17-Aug-18 11:20 am	3.96-4.27			Video taken by recreational boaters	CBC News 2018
St Mary's Bay, Newfoundland N 46 55.888, W 53 43.950	September 5, 2018	4.57			Report by DFO Science in Newfoundland	DFO
Southwest Port Mouton, NS	September 28, 2018				Seal carcass showing bite mark	DFO
Freeport, NS 44 23.260N 66 21.750W	September 8, 2018	3.96			White Shark eating humpback whale carcass	Corke, pers. comm. (2018)
White Point Shoal, NS 43 54 N, 64 33 W	September 28, 2018	3.35-3.66		tuna rod and reel	Hooked by tuna rod and reel	DFO
Tail of the Grand Banks 43° 22' N, 50° 06' W	Nov. 28, 2018	2.13 – 2.44		otter trawl	Bycatch in yellowtail flounder fishery	DFO
Near Walton, NS	July 23, 2019	2.44-3.05			Bass fishing	Halifax Today, 2019
Gull Island, NS	July 27, 2019	5.48			Circled surfer	DFO

Location	Date	Length FL (m)	Sex	Fishing gear	Remarks	Source
Passamoquoddy Bay, NB	August 12, 2019				Whale watching observation	CBC News 2019
Canso, 45 deg 18.621 min N, 060 deg 55.930 min W	August 15, 2019	3.05-3.66			Observation while mackerel fishing	DFO
Black Beach, NB	August 18 2019				Feeding on humpback whale	DFO
Passamoquoddy Bay, NB	August 24, 2019				Whale watching observation	CBC News 2019
Passamoquoddy Bay, NB	September 9, 2019				Whale watching observation	Jolly Breeze Whale Watching
Passamoquoddy Bay, NB	September 10, 2019				Whale watching observation	Jolly Breeze Whale Watching
Back Bay, NB	September 15, 2019			Weir	Caught in weir	CBC News 2019
Canso, NS	October 26, 2019				Bit body of tuna on rod and reel	DFO
Point Lepreau, NB	October 29, 2019				Shark washed up dead on beach	DFO

Due to its large size, striking appearance, predatory prowess, and potential danger, White Shark has been both revered and demonized in popular culture (Ellis 1994). The celebrated cultural status of White Shark makes its jaws and teeth particularly sought-after as curios; and its fins are used as a food additive for markets catering to Asian delicacies and traditional medicines. Even in the face of protective legislation, the high prices paid for White Shark parts remains a powerful incentive to stimulate and maintain black market trading in such goods, but the origin and species of shark parts on the black market are uncertain.

DISTRIBUTION

Global Range

White Shark is widely distributed in sub-polar to tropical seas in both hemispheres, from 60°N to 60°S, but aggregates in temperate continental shelf waters of the western North Atlantic, Mediterranean Sea, southern Africa, southern Australia, New Zealand, and the eastern and western North Pacific (Figure 2; Compagno 2001; Fergusson *et al.* 2009). In the western North Atlantic, the White Shark ranges from Hare Bay, Newfoundland, to northern Brazil (Templeman 1963; Gadig and Rosa 1996). In the eastern North Pacific, it ranges from the central Bering Sea to Mazatlan, Mexico (Kato 1965; Cook pers. comm. 1987).

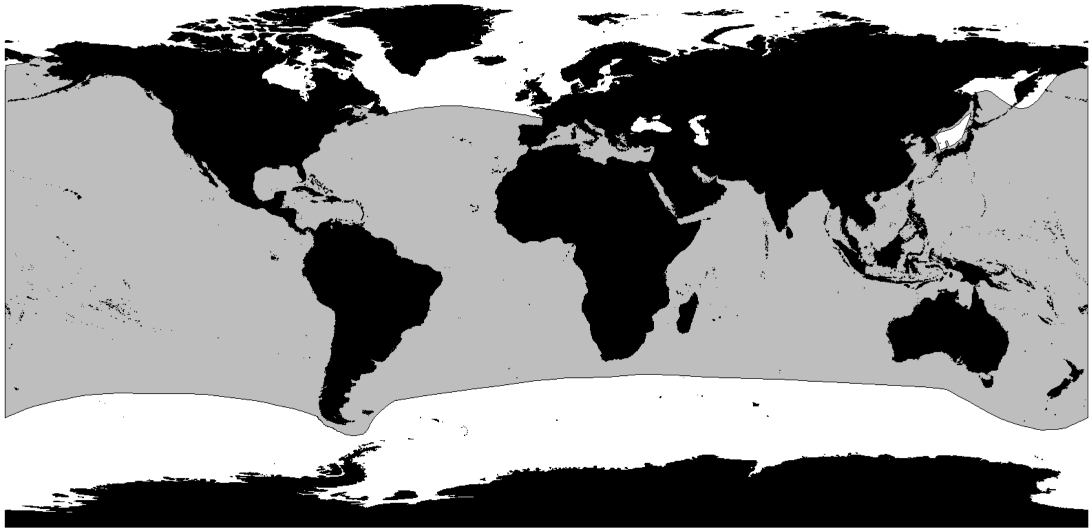

Figure 2. Global distribution of White Shark. Source: IUCN 2019.

Canadian Range in the Atlantic

This species occurs regularly and seasonally in Canadian Atlantic waters, known from 85 confirmed or probable records since 1874 in addition to tracking of tagged White Shark into Canada and 21 sharks observed (19 tagged) during tagging efforts in 2018 and 2019 off Nova Scotia (Tables 1–3, Figure 3). Observations throughout Atlantic Canada include, but are not limited to, the northeast Newfoundland Shelf, the northern coast of Newfoundland, the Grand Banks, the St. Pierre Bank, Sable Island Bank, St. Margaret's Bay, Passamaquoddy Bay, the Bay of Fundy, off Grand Manan, the Northumberland Strait, Chaleur Bay, and in the Laurentian Channel as far inland as the Portneuf River Estuary (on the north shore of the St. Lawrence Estuary) (Putnam 1874; Piers 1934; Vladykov and McKenzie 1935; Day and Fisher 1954; Leim and Day 1959; Vladykov and McAllister 1961; Templeman 1963; Arnold 1972; Mollomo 1998, Skomal *et al.* 2017). White Shark records from Atlantic Canada (Figure 3, Table 1) consist primarily of incidental captures and observations plus four cases of attacks on boats (Templeman 1963; Mollomo 1998). Tracking shows White Shark using most of the shallow continental shelf off Nova Scotia and Newfoundland out to the limits of Canada's Exclusive Economic Zone (EEZ), with few movements north of Newfoundland (Figure 3, Skomal *et al.* 2017). The occurrence of White Shark in Atlantic Canada is seasonal and inter-annual and is likely the result of sharks with distribution further south migrating north during the late summer and early fall months (Figure 4b, Curtis *et al.* 2014; Skomal *et al.* 2017); these movements are potentially correlated with the seasonal shift of the warm Gulf Stream toward the coast (Hogg 1992). Of the 76 Atlantic Canada sighting records for which the month is known, all occur from June to December; the most (33) occurred during August, while the remainder occurred mainly in June, July, or September (Figure 4a). Sharks tagged by the private organization Ocearch in 2020 migrated into Canadian waters mostly from June to November with only a few sharks tracked in Canada briefly during December, January, and February (Table 2,3, Ocearch 2020).

Collectively, the foregoing suggests that the Canadian component of this species' distribution represents the northern edge of their distribution in the Northwest Atlantic.

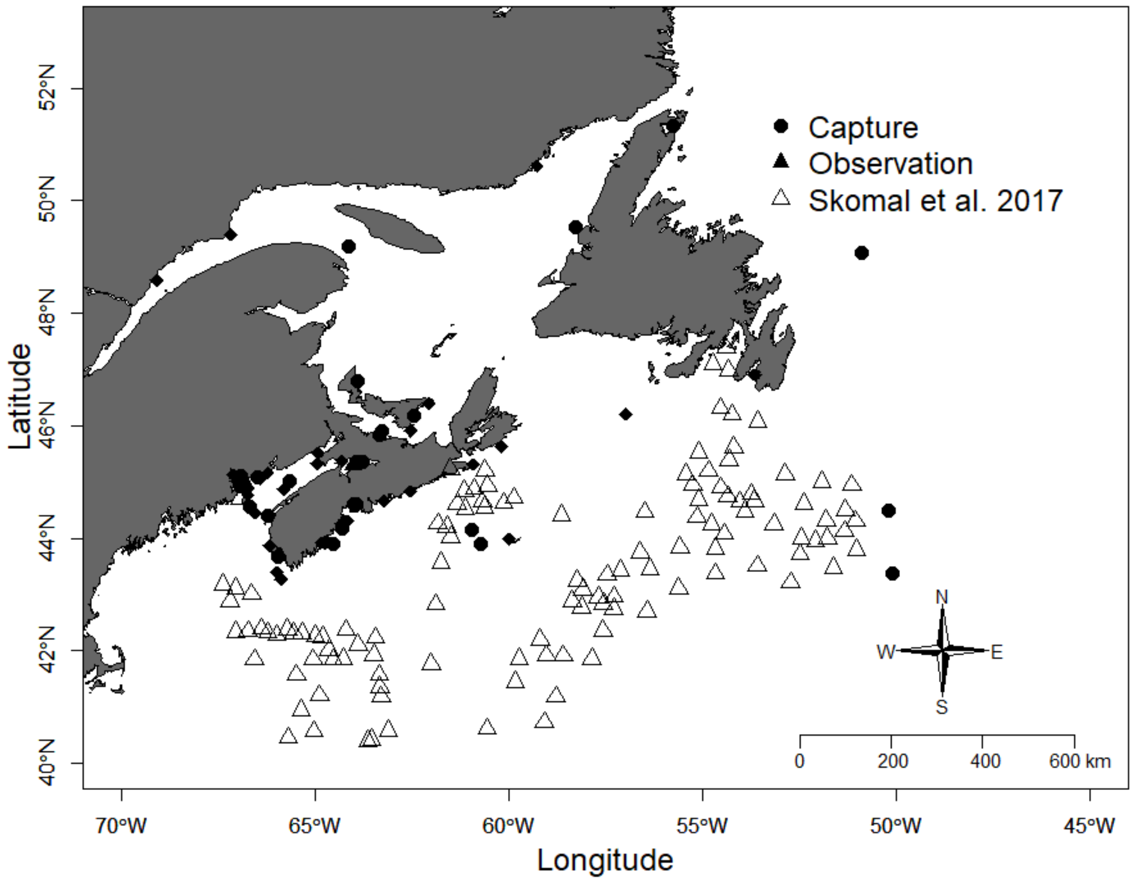

Figure 3. Canadian range of White Shark in the Atlantic Ocean based on sightings and incidental capture of White Shark and tracking of White Shark in Atlantic Canada from PSAT (n=27) and SPOT (n=5) tags modified from Skomal *et al.* 2017. Source: DFO (2020) White Shark sightings and strandings database, and digitized position data from maps in Skomal *et al.* (2017).

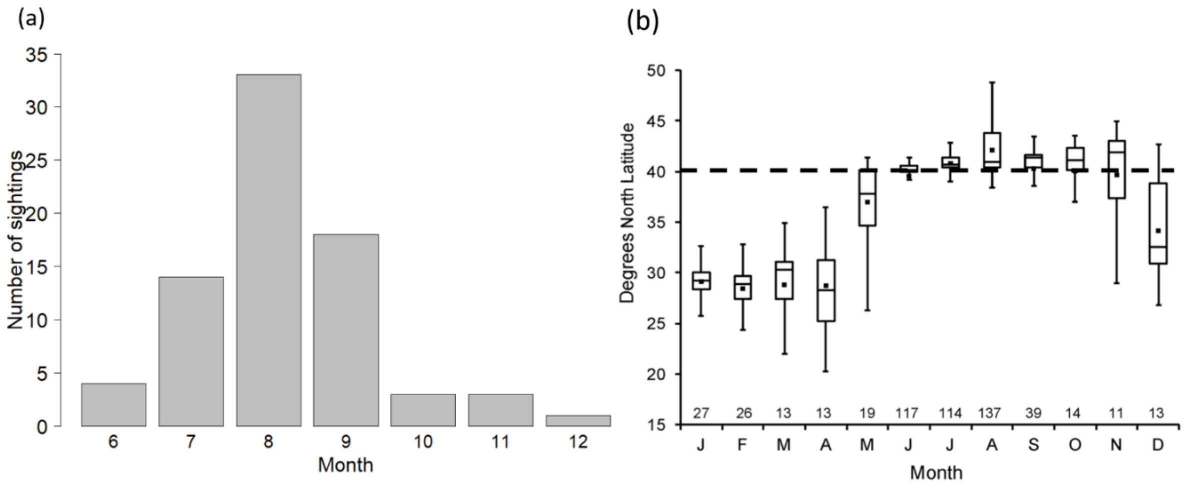

Figure 4. (a) The frequency of sightings by month of White Shark in Atlantic Canada. Source: DFO 2020 White Shark sightings and strandings database. (b) The seasonal distribution of sightings and catches of the White Shark in the Northwest Atlantic, from Curtis *et al*. (2014). Dashed line is the minimum latitude of Canada's EEZ in the Atlantic.

Table 2. List of White Shark tagged and observations on White Shark made while on tagging expeditions in Canadian Atlantic waters between September 2018 and October 2019. Source: DFO, 2020, Ocearch pers. comm. 2020.

Location tagged	Date	Total length (m)	Sex	Locations tracked in Canada	Tagged by
Port Mouton, NS	Sept 2018	3.0	M	Scotian Shelf (Sept– Oct 2018)	DFO
Lunenberg, NS	Sept 2018	3.9	M	Lunenberg (Sept-Oct 2018, Aug-Nov 2019), Cape Sable Island (Jul 2019), Walter Island (Nov 2019)	Ocearch
Lunenberg, NS	Sept 2018	3.9	M	Lunenberg (Sept 2018, Aug-Sept 2019)	Ocearch
Lunenberg, NS	Sept 2018	3.4	M	Lunenberg (Sept – Oct 2018, Oct 2019)	Ocearch
Lunenberg, NS	Sept 2018			Not tagged	Ocearch
Lunenberg, NS	Oct 2018	4.3	F	Lunenberg (Oct 2018), South NS off Seal Island (Oct-Nov 2018, Jul 2019), Scotian Shelf (Nov 2018), Bay of Fundy (Jul-Oct 2019)	Ocearch
Lunenberg, NS	Oct 2018	2.9	F	Lunenberg (Oct 2018), Southeast NS off Halifax and Cape Sable Island (Jul 2019)	Ocearch
Lunenberg, NS	Oct 2018	2.7	M	Lunenberg (Oct 2018), Off Wedgeport (Jul 2019), Cape Sable Island (Oct 2018, Aug 2019), Off Westport (Oct 2019)	Ocearch
Port Mouton Island, NS	Sept 2019	4.8	F	No data yet	DFO
Port Medway, NS	Sept 2019	3.7	F	Not tagged	DFO
Green Bay, NS	Sept 2019	3.0		Not tagged	DFO
Scaterie Island, NS	Sept 2019	3.7	M	Cape Breton (Sept 2019)	Ocearch
Scaterie Island, NS	Sept 2019	3.9	M	Scaterie Island and off Port Morien (Sept 2019)	Ocearch

Location tagged	Date	Total length (m)	Sex	Locations tracked in Canada	Tagged by
Scaterie Island, NS	Sept 2019	4.3	F	Scaterie Island, Sable Island, Southeast Scotian Shelf (Sept 2019)	Ocearch
Scaterie Island, NS	Sept 2019	2.5	F	Scaterie Island (Sept 2019), Northeast Scotian Shelf (Sept 2019), Southeast Scotian Shelf (Oct 2019)	Ocearch
Lunenberg, NS	Sept 2019	3.6	F	Lunenberg (Sept 2019)	Ocearch
Lunenberg, NS	Sept 2019	3.3	M	Lunenberg (Sept 2019)	Ocearch
Lunenberg, NS	Oct 2019	2.9	M	Lunenberg (Oct 2019), Eastern and Southwest Scotian Shelf (Oct 2019)	Ocearch
Lunenberg, NS	Oct 2019	3.1	F	Lunenberg, Eastern Scotian Shelf, South NS off Seal Island and Lockeport (Oct 2019)	Ocearch
Lunenberg, NS	Oct 2019	3.5	M	Lunenberg (Oct 2019)	Ocearch
Lunenberg, NS	Oct 2019	3.1	M	Lunenberg, Southwest Scotian Shelf (Oct 2019)	Ocearch
Lunenberg, NS	Oct 2019	3.6	M	Lunenberg, Off Lockeport, Southwest Scotian Shelf (Oct 2019)	Ocearch

Table 3. List of White Shark tagged by Ocearch in US waters that have been tracked in Canadian Atlantic waters up to November 2019. Source: Ocearch 2020, pers. comm. 2020.

Location tagged	Date tagged	Total length (m)	Sex	Locations tracked in Canada
Jacksonville, FL	Mar 2013	4.4	F	Grand Banks (Oct-Dec 2013, Nov-Dec 2014), Scotian Shelf (Nov 2016-Jan 2017)
Cape Cod, MA	Aug 2013	3.8	F	Halifax (Oct 2015), Deer Island NB (Oct 2016), New Harbour and Northeast NS (Nov 2016)
Cape Cod, MA	Aug 2013	4.3	F	Grand Banks (Dec 2015-Feb 2016)
Nantucket, MA	Oct 2016	3.0	M	Bay of Fundy (Aug 2017), Grand Banks (Aug 2018)
Hilton Head, SC	Mar 2017	2.6	F	Scotian Shelf (Aug-Nov 2017)
Hilton Head, SC	Mar 2017	3.8	M	NS East coast (Sept-Nov 2017, Jul-Sept 2018), Cape Breton Island (Sept 2018), South NL and Avalon Peninsula (Oct-Nov 2018), Grand Banks (Oct-Nov 2018)
Hilton Head, SC	Feb 2019	2.7	M	North and east Scotian Shelf (Jun 2019), Cape Breton (Jun-Jul 2019), Southeast Scotian Shelf (Nov 2019), Lunenberg (Nov 2019), Magdalen Islands (Jul-Sept 2019), PEI (Sept 2019), Chaleur Bay (Sept 2019)
Hilton Head, SC	Feb 2019	3.8	F	Grand Banks (Jun-Jul 2019)
Hilton Head, SC	Feb 2019	3.9	F	Off Seal Island (Oct 2019)

Extent of Occurrence and Area of Occupancy

Augmenting the limited sightings database with tracking work by Skomal *et al.* (2017), the extent of occurrence (EOO) of the White Shark in Atlantic Canada is approximately 1,029,903 km² (1,346,138 km² including land area). However, recent tagging work by Ocearch in 2018 and 2019 that has tracked White Shark near the EEZ on the northeastern Grand Banks suggests the EOO could be at least 1,062,590 km² (1,380,744 km² including land area) (Ocearch pers. comm. 2020; 2020). There are insufficient data to calculate a reliable index of area of occupancy (IAO), but the same data used to calculate EOO suggest an IAO much higher than 2000 km², given White Shark's wide-ranging movements throughout the most of Canada's Atlantic EEZ south of Newfoundland. There were insufficient data in the previous report (COSEWIC 2006) to judge if the EOO has increased, but it is unlikely to have changed.

Search Effort

The first recorded observation of a White Shark in Atlantic Canada was in 1874 from an attack on a dory on St. Pierre Bank, Newfoundland (Table 1). There have been active commercial fisheries in Atlantic Canada that could catch White Shark for over half a century, including groundfish and herring fisheries and pelagic longline fisheries. These are historically the primary sources of White Shark bycatch in the U.S. and Canada (Skomal *et al.* 2012, Table 1). There has been no survey effort in Atlantic Canada other than two tagging programs conducted over a few weeks in Fall 2018 and 2019 by the NGO Ocearch and DFO in Canada. Ocearch has spent 412.5 hours over 35 days total, with an average of 5-6 hooks per day deployed, across September to October 2018 and 2019 (Ocearch pers. comm. 2020).The reporting of opportunistic sightings and incidental catch has increased in recent years since the White Shark was listed as Endangered under the *Species at Risk Act* (SARA) in 2011. The DFO efforts to educate the public and harvesters on reporting and the implementation of mandatory reporting of interactions with White Shark in commercial (2018) and recreational (2019) fisheries have also increased the number of White Shark sighting records.

HABITAT

Habitat Requirements

White Shark occurs in coastal inshore waters, offshore on the continental shelf, and off the shelf into open ocean pelagic habitat, from the intertidal to the upper continental slope and mesopelagic zone. Known bathymetric range is from just below the surface to just above the bottom down to a depth of at least 1,128 m in the Northwest Atlantic (Skomal *et al.* 2017). It occurs in the breakers off sandy beaches, off rocky shores, and readily enters enclosed bays, lagoons, harbours, and estuaries, but does not penetrate brackish or fresh waters to any known extent (Compagno 2001). Sand habitat is particularly important for White Shark foraging in South Africa (Kock *et al.* 2018).

White Shark have a wide thermal tolerance, having been recorded in temperatures between 1.6 and 30.4°C (Figure 5d, Skomal *et al.* 2017). Despite this wide thermal range, there is evidence that temperature plays a role in habitat choice. In South Africa, White Shark abundance is higher during the winter when there is no upwelling, conditions are more stable, and water temperature is warmer (Towner *et al*. 2013). Catches of White Shark in eastern Australia's shark control programs peak at temperatures 19°C or below (Payne *et al.* 2018). Tracking studies show White Shark spend most of their time in temperatures between 14 to 25°C with the highest occurrence between 18–20°C when not moving offshore (Weng *et al.* 2007b; Bruce and Bradford 2012, 2015; Lee *et al.* 2018; Wintner and Kerwath 2018), including in the Northwest Atlantic (Figure 5b,d, Curtis *et al.* 2014; Skomal *et al.* 2017). Here, median temperature of incidental captures of White Shark was 19.5°C for young-of-the-year sharks, but was 16°C for adult sharks, reflecting a possible ontogenetic change in thermal habitat use (Curtis *et al.* 2014).

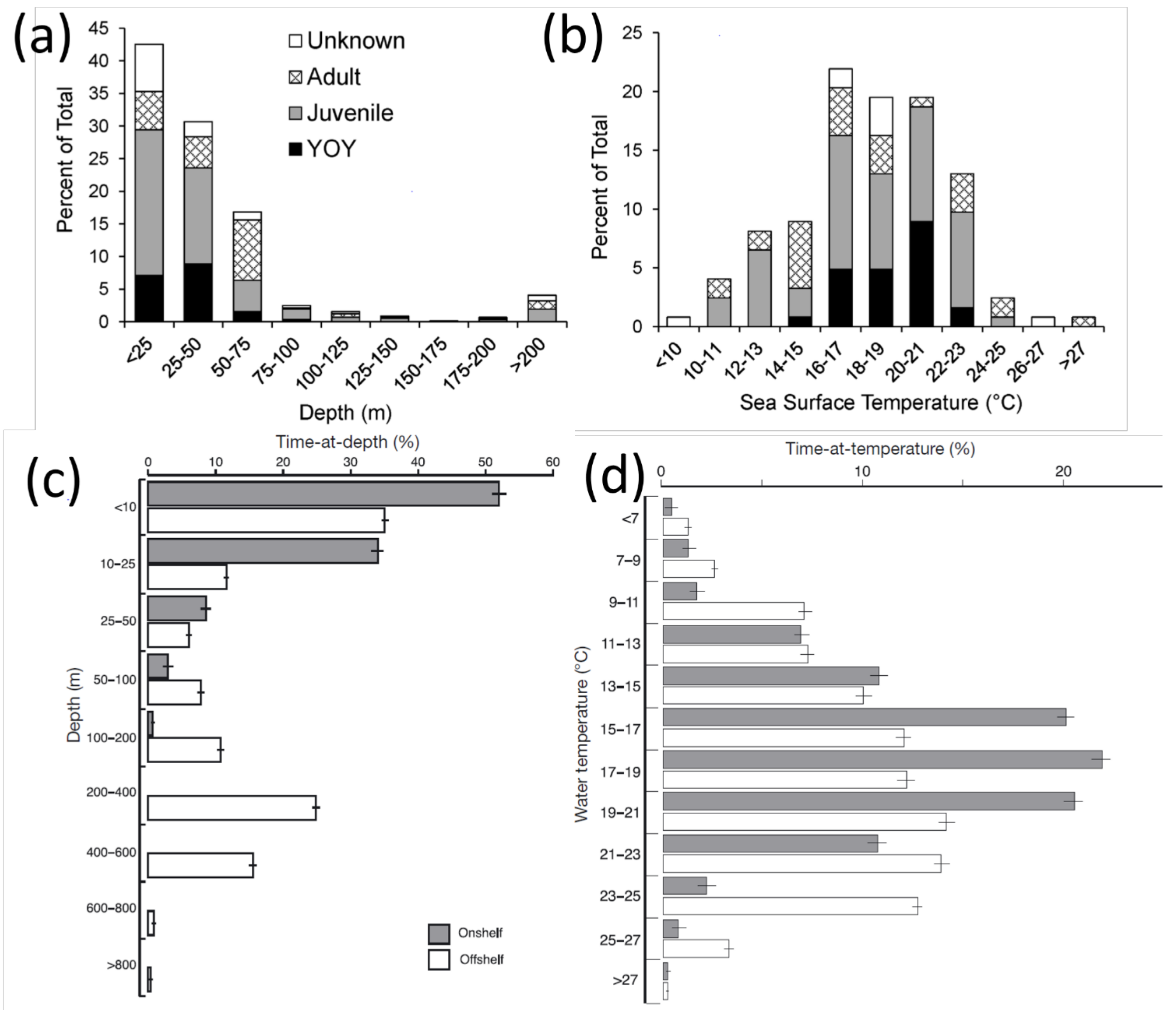

Figure 5. (a) Distribution of bottom depths and (b) sea surface temperatures of White Shark sightings and captures in the Northwest Atlantic, reproduced from Curtis *et al.* 2014. (c) Percentage of time (mean ± SE) spent at depth and (d) sea surface temperature for 21 PSAT tagged sharks, reproduced from Skomal *et al*. (2017).

White Shark is a wide-ranging, migratory species capable of crossing ocean basins, including the Atlantic and Pacific (see Dispersal and Migration). However, White Shark primarily occupy coastal waters <100 m deep, seasonally migrating to deeper, oceanic habitat to mate or feed (Boustany *et al.* 2002; Carlisle *et al.* 2012; Curtis *et al.* 2014, 2018). Their rate of foraging is higher in coastal habitat (Carlisle *et al.* 2012), which is particularly important for the growth of young-of-the-year and juveniles that use it throughout the year in the Northwest Atlantic (Skomal *et al.* 2017; Curtis *et al.* 2018). Juveniles predominate in this habitat (Curtis *et al.* 2014). The high abundance of young-of-the-year White Shark in the New York Bight suggests it may serve as important nursery habitat (Casey and Pratt 1985, Curtis *et al.* 2014, 2018). Larger sharks use coastal habitat primarily in summer (Weng *et al.* 2007a,b; Jorgensen *et al.* 2010; Bonfil *et al.* 2010; Francis *et al.* 2012). In the Northwest Atlantic, adults move off the continental shelf to mesopelagic depths between fall and spring (Skomal *et al.* 2017, Figure 6, see **Dispersal and Migration**).

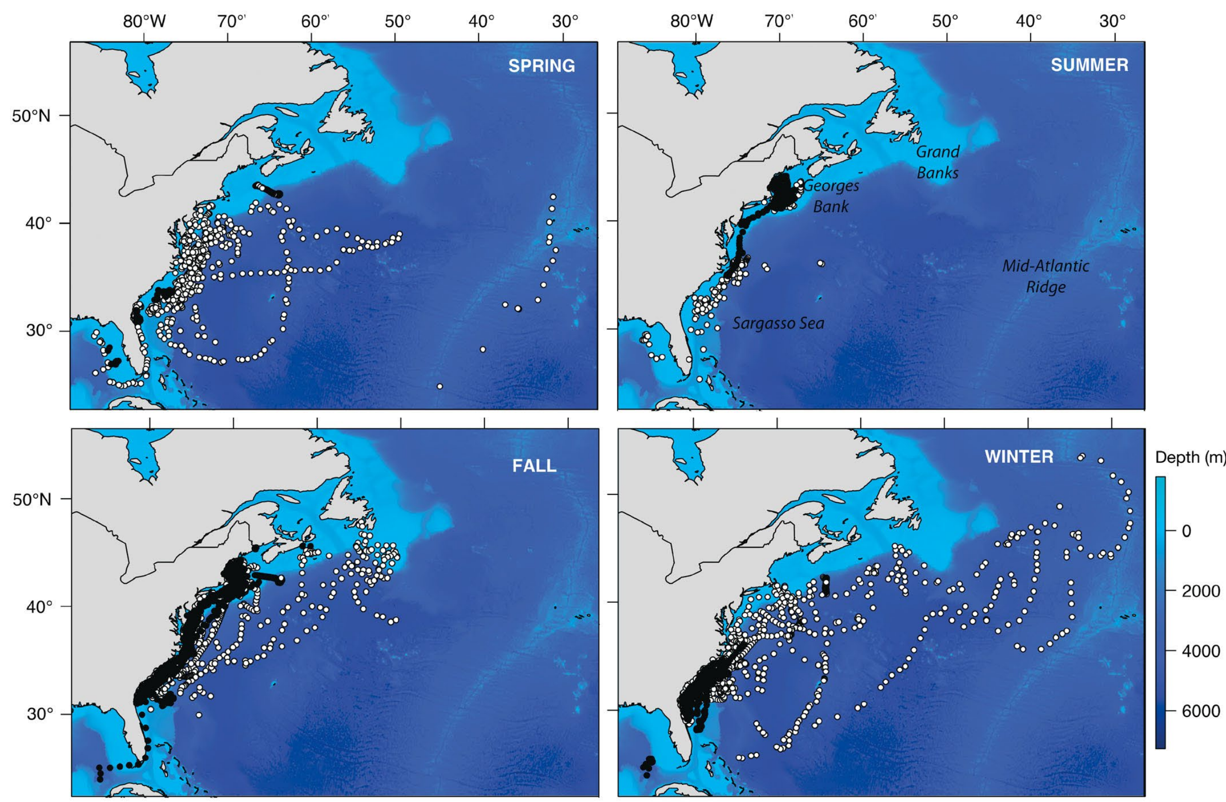

Figure 6. The positions (coastal=black, pelagic=white) of White Shark tagged with both SPOT (n=5) and PSAT (n=24) tags in the Northwest Atlantic by season. Reproduced from Skomal *et al.* (2017).

White Shark may occupy the entire water column but have higher occurrences at particular depths. In coastal habitats, they occupy shallow depths (Bruce *et al.* 2006; Weng *et al.* 2007b; Bonfil *et al.* 2010) and in the Northwest Atlantic are reported to spend over half their time at <20 m depth (Skomal *et al.* 2017, Figure 5a,c). Over 92% of the 564 opportunistic sightings and incidental catch records in this coastal habitat since 1800 occurred at depths <100 m, with a median of 30 m (Figure 5a, Curtis *et al.* 2014). Beyond the continental shelf in oceanic habitat, White Shark punctuate their time at shallow depths (<100 m) with deeper dives to the mesopelagic zone 200-1000 m deep, likely to forage (Figure 5c, Boustany *et al.* 2002; Bonfil *et al.* 2005; Weng *et al.* 2007a,b; Skomal *et al.* 2017; Gaube *et al.* 2018).

White Shark can show homing and philopatric behaviour to specific aggregation sites or "hotspots" often associated with foraging, such as sea lion colonies (Johnson *et al.* 2009; Jorgensen *et al.* 2010; Kock *et al.* 2013). In the Northwest Atlantic, White Shark presence around coastal Nova Scotia, the Gulf of St. Lawrence, and Sable Island may indicate foraging on Atlantic grey seal (*Halichoerus grypus*) (Lucas and Natanson 2010; Hammill *et al.* 2017). However, in the eastern Pacific some individuals may forage for dispersed prey over wider areas (Domeier and Nasby-Lucas 2013).

Habitat Trends

It is unknown to what degree habitat deterioration has contributed to the apparent global decline of this species. In Atlantic Canada, there are no known activities altering the habitat and hence abundance or distribution of White Shark. Given its coastal association, effects on White Shark biology from U.S. coastal developments and offshore energy projects are possible (Curtis *et al.* 2018). Habitat in White Shark is determined partially by prey, and the increase in abundance of the Atlantic Grey Seal (*Halichoerus grypus*) in Canada and the U.S. has improved prey availability (NMFS 2009; Skomal *et al.* 2012; Hammill *et al.* 2015, 2017). The increasing frequency of warm anomalies in Atlantic Canada (Brickman *et al.* 2018) could expand White Shark thermal habitat northward while warmer waters could also retract distribution to the south (Payne *et al.* 2018).

BIOLOGY

The most recent and comprehensive biological information on White Shark comes from populations in California and Australia; there has been little research on White Shark in Canadian waters. However, recent tagging and genetics studies in the Northwest Atlantic demonstrate connectivity between sharks in the U.S. and Canada. Tagging and tracking work is ongoing in the North Atlantic by several organizations, including DFO, Ocearch, Massachusetts Division of Marine Fisheries, and the Atlantic White Shark Conservancy. There is also some updated life history information on White Shark in the Northwest Atlantic, mostly from incidental fisheries catch in the U.S. (Curtis *et al*. 2014).

Life Cycle and Reproduction

Lifespan in Northwest Atlantic White Shark was recently estimated to be 40 years for females and 73 for males, based on bomb radiocarbon dating (Hamady *et al.* 2014; Natanson and Skomal 2015). While the maximum age estimate for females is accurate for the samples examined, Natanson and Skomal (2015) noted that there were limited samples of large females. Studies on other pelagic sharks (Natanson *et al*. 2002) suggest similar lifespans for males and females and this is likely to be the case for this species. Additionally, Harry (2018) has suggested that maximum ages in many sharks, including White Shark, are underestimated even when using reliable methodologies such as bomb carbon validation. It is believed the much lower estimate of lifespan for female White Shark is an underestimate and the maximum age is more likely to be similar to that of males.

Intrinsic rate of population increase (r) is estimated at 0.035–0.056 depending on method and assumptions, an intermediate value among elasmobranchs (Smith *et al*. 1998; Dillingham *et al.* 2016; DFO 2017). Instantaneous natural mortality (M) is estimated to be between 0.063 and 0.125 (Smith *et al*. 1998; Mollet and Cailliet 2002; DFO 2017). Using the values for r and the number of female offspring produced over a lifetime (m) for this population estimated by DFO (2017) based on assumptions of a longer lifespan (70 years), the generation time (G) is:

$$G = ln(m)/r = ln(4.4)/0.035$$

This method gives a generation time estimate of 42 years. Assuming a shorter lifespan, m becomes 5.6 and r becomes 0.101 (DFO 2017) and gives a generation time of 17 years. However, the estimate of 42 years is assumed to be more accurate based on recent studies of Northwest Atlantic White Shark growth and lifespan. Estimated juvenile annual survival from mark-recapture research in the eastern Pacific is high (0.63, SE = 0.08), and increases steadily with age, reaching 0.95 (SE = 0.02) in adult sharks, likely due to greater experience in prey capture and reduced predation risk (Benson *et al.* 2018; Kanive *et al.* 2019).

The maximum size of White Shark is unknown, but growth studies estimate it at 5 to 6 m total length (TL) (Tanaka *et al.* 2011; Christiansen *et al.* 2016). Reports of White Shark reaching total lengths greater than 7 m have not been verified (Figure 7, Compagno 2001). The largest verified White Shark from Atlantic Canada was 5.6 m caught in a cod gillnet off Alberton PEI in 1983 (Scott and Scott 1988; Curtis *et al*. 2014).

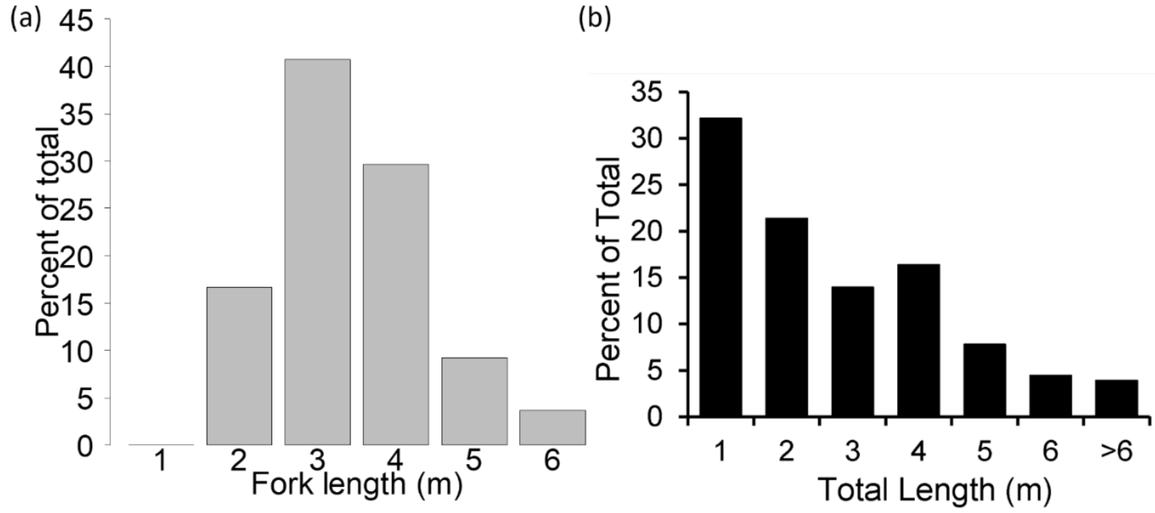

Figure 7. The distribution of estimated White Shark (a) fork length from the DFO 2020 White Shark sightings and strandings database in Atlantic Canada and (b) total length from the sightings database of the whole Northwest Atlantic reproduced from Curtis *et al.* (2014).

Estimates of age at sexual maturity range from four to 33 years depending on geographic location (Compagno 2001; Dudley and Simpfendorfer 2006; Tanaka *et al.* 2011; Natanson and Skomal 2015; Christiansen *et al.* 2016). Similarly, size at maturity ranges from 3.1 to 4.1 m TL for males and 4 to 5 m TL for females (Francis 1996; Pratt 1996; Tanaka *et al.* 2011). Females can be a metre longer than males at the same age, and a thirty-three-year difference in age has been estimated to exist between males and females of the same size (Hamady *et al.* 2014). There is only one estimate of size of maturity for male White Shark (~3.8 m TL) in the Northwest Atlantic, based on clasper morphology (Pratt 1996). Natanson and Skomal (2015) used bomb radiocarbon dating combined with the minimum estimates of size at maturity and estimated age at maturity at 33 and 26 years for females and males, respectively. However, these estimates are high given the minimum estimates of lifespan, indicating there is still uncertainty on White Shark growth in the Northwest Atlantic.

White Shark are ovoviviparous (aplacentally viviparous), with yolk sac reserves augmented by histotrophy of maternal lipids and late term oophagy (Gilmore 1993; Francis 1996; Uchida *et al*. 1996; Sato *et al.* 2016). Gestation period is still uncertain, potentially as high as 18-20 months (Francis 1996; Mollet *et al.* 2000; Bruce 2008) but is at least 10 months in the Northwest Pacific (Christiansen *et al.* 2014). Litter size varies from two to 10 and possibly to 17, with an average of seven, and fecundity increases with size of the female (Cliff et al. 2000; Compagno 2001; Christiansen *et al.* 2014). Litter size in the Northwest Atlantic is unknown. Maximum lifetime reproductive output of a female White Shark has been estimated to be 45 pups (Compagno 1991). Length at birth is assumed to be between 1.09–1.65 m (Compagno 2001). The length of the reproductive cycle is unknown but could be two years based on tracking and photo-identification (Dewar *et al*. 2013; Domeier and Nasby-Lucas 2013; Chapple *et al.* 2016). It may also be more than three years, or unpredictable, as post-partum females may require a year or more between pregnancies to rebuild energy stores (Compagno 1991).

Mating may occur anywhere throughout the northeastern coastal waters of the U.S., with Cape Cod being a possible aggregation spot based on the observation of possible mating scars (Pratt 1996; Skomal *et al.* 2017). Opportunistic data from strandings and bycatch have recorded reproductively mature White Shark of both sexes along the Atlantic Coast of Canada (Figure 7, Table 1). Parturition likely occurs in the spring and summer, but in an unknown area, from where young-of-the-year sharks then migrate to potential nursery habitat in the New York Bight and the Mid-Atlantic Bight (Casey and Pratt 1985; Curtis *et al.* 2014; Skomal *et al.* 2017).

Physiology and Adaptability

White Shark can tolerate a wide range of temperatures and environmental conditions (see **Habitat**, Payne *et al.* 2018). They are observed from sub-polar to tropical waters, including in the Northwest Atlantic from the coast to the Gulf Stream and the Mid-Atlantic Ridge (Skomal *et al.* 2017).The ability of White Shark to remain agile predators in colder water is in part due to countercurrent vascular heat exchangers that allow them to maintain a body temperature higher than the ambient water temperature (Carey *et al.* 1982; Goldman 1997; Compagno 2001). Tracking studies demonstrate White Shark regularly enter water as cool as 4°C in the Northwest Atlantic (Skomal *et al.* 2017). Their large size, and thus large thermal inertia, and their thermoregulatory abilities likely modulate potential metabolic effects caused by changes in water temperature (Goldman 1997; Skubel *et al.* 2018).

White Shark is a highly visual predator with a duplex retina, featuring a low rod-to-cone ratio (about 4:1) for acute, and possibly full-colour vision (Gruber and Cohen 1985). It visually investigates surface objects (Strong 1996; Collier pers. comm. 1986; Fallows pers. comm. 2000) and that often brings it into contact with humans (Miller and Collier 1981; Collier pers. comm. 1986; Burgess and Callahan 1996; Fallows pers. comm. 2000).

The life history of White Shark, especially its late age at maturity, suggests vulnerability to high fishing mortality (Francis 1996; Wintner and Cliff 1999; Hamady *et al.* 2014, Dapp *et al*. 2015). Its widespread distribution combined with an opportunistic feeding strategy may allow the species to readily disperse from localized threats and move to better feeding areas. However, its life history and ovoviviparous reproduction also increases its vulnerability to organic pollutants and the likelihood that pollutants will transfer from mother to offspring during gestation (Lyons *et al.* 2013a; Mull *et al.* 2013).

Dispersal and Migration

White Shark can swim long distances, e.g., from Hawaii to California (Compagno 2001; Boustany *et al.* 2002), from South Africa to Australia (Bonfil *et al.* 2005), and from Florida to an area 930 km south of Greenland (Skomal *et al.* 2017). This ability to cross ocean basins results in sporadic observations off oceanic islands such as Hawaii (Taylor

1985, Jorgensen *et al.* 2010; Block *et al.* 2011) and the Azores (Compagno *et al.* 1997; Skomal *et al.* 2017).

In the Northwest Atlantic, conventional and acoustic tagging information shows that White Shark range widely throughout U.S. and Canadian waters (Figure 6). Individuals showed movements all along the Atlantic coast of the U.S. and Canada, with regular seasonal migrations between Florida and as far north as Newfoundland (Figure 6, Skomal *et al.* 2017). Nine White Shark tagged by Ocearch in the U.S. (50% of all U.S. Ocearch-tagged White Shark) migrated into Canadian waters, as far north as the Magdalen Islands, Chaleur Bay, and the Grand Banks between summer and fall (Table 3, Figure 3b, Ocearch 2020; pers. comm. 2020). Conversely, 17 White Shark tagged by Ocearch in Canadian waters in fall moved south into US waters (Table 2, Ocearch 2020; pers. comm. 2020).

Telemetry studies focused on the Canadian population have only recently been started, with DFO implementing an acoustic tagging program and acoustic receivers along Nova Scotia's eastern coast in 2018 (Bowlby pers. comm. 2019). Acoustic tagging of White Shark in the U.S. showed ~60% of all sharks tagged acoustically, including immature and mature individuals of both sexes, have migrated into Canada from the U.S. since 2011 (Chisholm pers. comm. 2019). Overall, about 18% of all acoustically tagged sharks migrated into Canadian waters (Chisholm pers. comm. 2019). Satellite tagging of the Canadian population has also recently started off Nova Scotia by DFO (n = 2 shark) and Ocearch (n = 17 sharks, Table 2, Ocearch pers. comm. 2020). An additional six sharks were tagged off Cape Cod from a collaboration of DFO, MDMF, and the Atlantic White Shark Conservancy, and this collaboration will continue tagging sharks in Canada and the U.S. into the future. The sharks tagged so far by DFO have mostly either migrated to or remained in the U.S., with only two (including one U.S. tagged shark) spending significant time in Canadian waters (from June to October 2017 for the U.S. tagged shark) before migrating southward (Bowlby pers. comm. 2019). Preliminary evaluation of dispersal and movement in Canada is consistent with foraging behaviour. The sharks tagged by Ocearch in Fall 2018 spent limited time moving along the Nova Scotian coast or offshore in Canada's EEZ and beyond before moving south to the Carolinas or Florida; by July 2019, all six of the sharks tagged in 2018 had returned to Nova Scotia by summer or fall 2019 (Table 2, Hueter pers. comm. 2018; Ocearch 2020).

The frequency of long-range movements along coastlines and across ocean basins changes ontogenetically and seasonally. Tagging data to date show this population moves widely throughout the Northwest Atlantic, spending significant time in both coastal and oceanic habitat, with a few seasonal patterns (Skomal *et al.* 2017; Curtis *et al.* 2018). Smaller sharks (<3 m) seasonally migrate from summer habitat in the northeast shelf of the northeastern U.S. and Atlantic Canada, to winter in the southeastern U.S. and the Gulf of Mexico, following prey and thermal regimes (Figure 6, Casey and Pratt 1985; Curtis *et al.* 2014; Skomal *et al.* 2017). As White Shark grow larger, their coastal migrations increase in distance and depth (Skomal *et al.* 2017; Curtis *et al.* 2018). Sub-adults and adults are also shelf-oriented during summer, but often move offshore for the rest of the year, lacking the clear seasonal migratory patterns displayed by juveniles (Figure 6). These offshore movements, likely related to foraging, extend over a 30° latitudinal range, with some White

Shark moving near the Azores (Skomal *et al.* 2017). In fall and winter, larger sub-adult and adult sharks move as far south as the Bahamas and in summer as far north as Newfoundland and southeast of Greenland (Skomal *et al.* 2017). It is also mostly the larger juveniles and adults of this population that make the longer migration into Canadian waters each summer based on the size distribution of sharks here (Figure 7, Curtis *et al.* 2014). White Shark of all sizes have been recorded in sightings and fisheries databases on the continental shelf in each season, but sightings increase in New England and Canadian waters and reach their most northerly distribution in late summer and early fall (Figure 4, Curtis *et al.* 2014). Both the acoustically tagged sharks and the sharks tagged by Ocearch migrated into Atlantic Canada from June to November, although some acoustic detections have occurred in February and March (Table 2,3, Chisholm pers. comm. 2019; Ocearch 2020). In winter, White Shark observations were concentrated below Cape Hatteras (~35°N), closer inshore, where they are rarely observed in summer (Curtis *et al.* 2014).

Similar patterns exist for other White Shark populations (Bruce *et al.* 2006; Bonfil *et al.* 2010; Domeier *et al.* 2012; Andreotti *et al.* 2016b) but fewer individuals may migrate over the open ocean (Bonfil *et al.* 2005; Bruce and Bradford 2012). Long-range, offshore, and seasonal movements of adult White Shark are also more common elsewhere (Domeier and Nasby-Lucas 2008; Jorgensen *et al.* 2010; Duffy *et al.* 2012). Dispersal in White Shark is limited by high philopatry and site-fidelity (Jorgensen *et al.* 2010; Blower *et al.* 2012; Bruce and Bradford 2012). However, it is still unclear whether such site-fidelity and philopatry for foraging and reproduction, exists for the Canadian Atlantic population. Increasing seal populations off Cape Cod in the Northeastern U.S. may be causing aggregation at these sites (Skomal *et al.* 2012).

Interspecific Interactions

White Shark are born between 1.09 and 1.65 m TL, and such a large size at birth minimizes predation risk. Humans have been identified as the single largest cause of mortality to White Shark (Compagno 2001). However, there is one reported attack of an Orca (*Orcinus orca*) on a White Shark off California (Pyle *et al.* 1999). At least two Orcas killed White Shark at hotspots in South Africa, resulting in the disappearance of sharks from these areas for a time (Engelbrecht *et al.* 2019).

White Shark is an apex predator with high energetic requirements, metabolic rates, and a feeding periodicity less than two weeks (Semmens *et al.* 2013). As such, it exploits a broad prey spectrum covering multiple trophic levels. The broadening of its dentition with growth suggests that at a length of about 300-340 cm this species undergoes a dietary shift from bottom-dwelling fishes to marine mammals (Tricas and McCosker 1984; Estrada *et al.* 2006; Hussey *et al.* 2012).

Smaller White Shark (<2.5 m TL) tend to consume relatively small demersal prey, including teleosts, small elasmobranchs, and invertebrates, while larger individuals tend to take larger nektonic prey, including pinnipeds, odontocetes, and large elasmobranchs (Klimley 1985, 1994; Cliff *et al*. 1989; Bruce 1992; Fallows and le Sueur 2001; Amorim *et al.* 2018). Trophic level, ranging from 4.2 to 5.0 or higher (Hussey *et al.* 2015), generally increases with age (Estrada *et al.* 2006; Hussey *et al.* 2012). White Shark will also switch from hunting sea lions to fish when sea lion pupping season ends (Kock *et al.* 2013). They are generalists but there is intraspecific variation, sometimes spanning more than one trophic level, that suggests a degree of individual specialization on prey (Kim *et al.* 2012). However, at every growth stage White Shark is highly opportunistic and can kill a wide variety of prey (LeMier 1951).

Scavenging on floating cetacean carcasses represents a significant, and previously underestimated, component of White Shark ecology (Pratt *et al*. 1982; Dudley *et al*. 2000; Curtis *et al.* 2006), with a recent study showing up to 40 White Shark scavenging for up to 13 hours at a time on a single carcass in False Bay, South Africa (Fallows *et al.* 2013). White Shark also hunt dolphins (Wcisel *et al.* 2010, Sprogis *et al.* 2018), and have attacked and consumed Harbour Porpoises (*Phocoena phocoena*) in the Bay of Fundy (Day and Fisher 1954; Templeman 1963; Arnold 1972; Turnbull and Dion 2012). In Atlantic Canada, it is probable White Shark regularly scavenge on, and potentially hunt, cetaceans (Table 1, Pratt *et al.* 1982; Casey and Pratt 1985; Taylor *et al.* 2013); with the historical decline of pinnipeds in the Northwest Atlantic, cetaceans probably formed an important component of White Shark diets in the region (Carey *et al.* 1982). However, White Shark in the U.S. Atlantic are incorporating more seals into their diets as seal populations rebound (Skomal *et al.* 2012). White Shark have been implicated in attacks on Grey Seal off eastern Canada (Brodie and Beck 1983).

POPULATION SIZE AND TRENDS

For the Northwest Atlantic, in over 210 years (1800-2010) of sighting records and fishery observer reports, there were 649 confirmed records of White Shark (Curtis *et al.* 2014). Only a fraction (43) came from Canadian waters. There are no surveys for White Shark in Canadian waters other than the recent tagging programs (see **Distribution** and **Dispersal and Migration** sections). Until these tagging programs, most records came from opportunistic stranding and sightings, published historical observations, and occasional reported incidental catch. There is substantial fishing effort in the form of pelagic longline, small pelagic weir and purse seines, and groundfish trawls and gillnets that could potentially catch White Shark in Canada. Fishing effort is monitored in part by at-sea observers, dockside monitoring, and Fishery Officers, but observer coverage is incomplete and variable in many fisheries and thus inadequate to fully characterize White Shark occurrence. For instance, the majority of Atlantic groundfish fisheries have annual observer coverage varying from <1-5%, with Div. 3NO Yellowtail at 25% and Northern Shrimp at 100%, while swordfish and tuna longline fisheries have targeted observer coverage below 10%. International longline fishing effort for pelagic species occurring outside of Canada has increased exponentially in the Northwest Atlantic over much of the last fifty years (Figure 8). Reporting also increased in Canada after the species was listed as Endangered under the SARA in 2011.

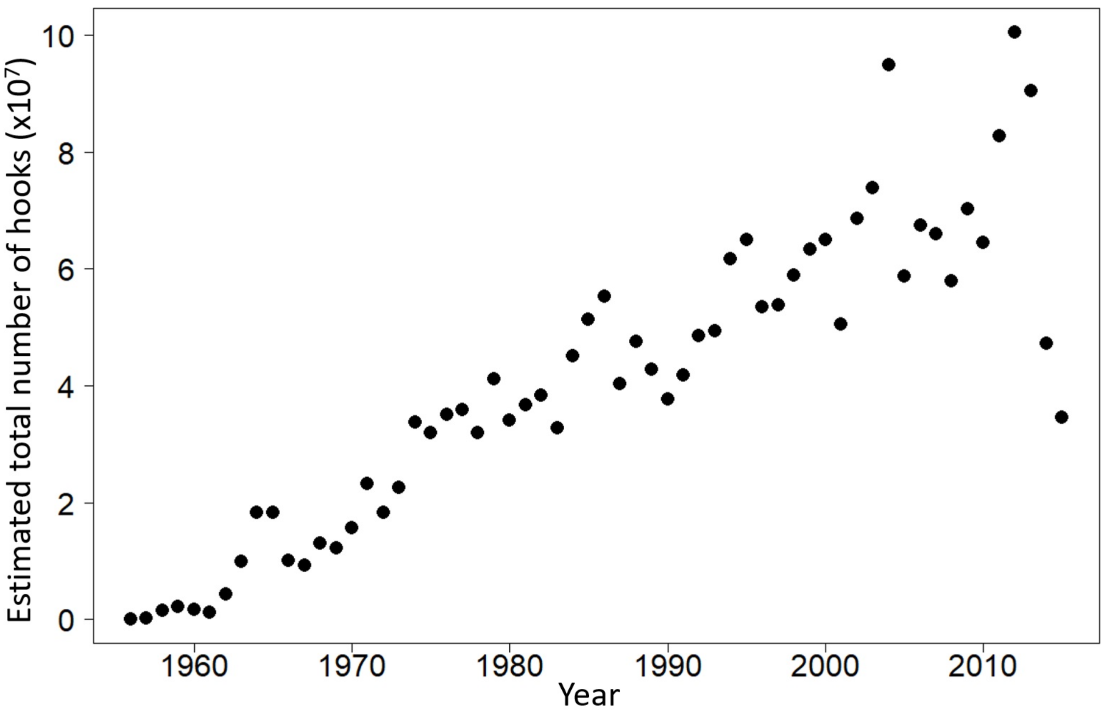

Figure 8. Estimates of the total longline fishing effort, represented by total number of hooks, in the Northwest Atlantic. Source: ICCAT (2019).

Abundance and Trends

Information on the global population size of White Shark is sparse, but most sources agree population numbers are low compared to other wide-ranging shark species (Fergusson *et al.* 2009; Chapple *et al.* 2011; Towner *et al.* 2013; Andreotti *et al.* 2016a; Hillary *et al.* 2018), with a low natural rate of increase (Smith *et al.* 1998; DFO 2017). Partially from this rarity, information on abundance of White Shark globally is data-limited, especially with respect to different life-history stages (Huveneers *et al.* 2018). As it is an apex predator, population size is understandably low (Cortés 1999; Estrada *et al.* 2006).

There are no estimates of White Shark abundance in the waters of Atlantic Canada; however, between 1874 and September 2018, 85 White Shark observations were recorded, with 45 of those records (33 authenticated) since 2009 (Table 1). In addition, 19 sharks were tagged in Canada in 2018 and 2019 with an additional three observed during these expeditions (Table 2). While less than half of the sightings records come from fisheries catch (see **Threats – Biological Resource Use**), the low level of observer coverage does not permit conclusions about the regularity of occurrence of White Shark in these fisheries. There are 6,087 records of White Shark, albeit unconfirmed, in the U.S. pelagic longline database from 1986-2000 extracted from over 200,000 sets but most of these (80%) were from areas south of Florida (Baum *et al.* 2003). Those are disputed as having been accurately identified as White Shark (Burgess *et al.* 2005). The International Commission for the Conservation of Atlantic Tunas (ICCAT) reports only six mt, representing 10–16 individual sharks, caught in the Northwest Atlantic between 1987 and 2018, primarily by U.S. fleets (ICCAT 2019).

The number of mature White Shark in the Northwest Atlantic is unknown. The South African population has relatively low abundance based on both photo mark-recapture (n=438 95% CI = 353−522) and genetic effective population size analysis (Ne=333; 95% CI = 247−487) (Andreotti *et al*. 2016a). A separate genetic study compared the effective population size of South African White Shark (Ne = 365, 95% CI=188–1998) to that of Northwest Atlantic White Shark (Ne=44, 95 CI=31–66), but only the relative difference in effective population size can be interpreted and the absolute numbers are unreliable. Nonetheless, analysis suggests the Northwest Atlantic population is, or recently was, less abundant than the South African population (O'Leary *et al.* 2015).

Only three published studies have examined trends in White Shark abundance in the Northwest Atlantic (Baum *et al.* 2003; McPherson and Myers 2009; Curtis *et al.* 2014). Additionally, one genetics study has suggested this population suffered a recent genetic bottleneck (O'Leary *et al.* 2015). Baum *et al*. (2003) calculated trend information based on catch per unit of effort (CPUE) logbook data from the U.S. pelagic longline swordfish and tuna fleets in the Northwest Atlantic from 1986 to 2000, estimating a decline of 79% in CPUE over this period (95% CI: 59 to 89%). This decline was based on 6,087 trip records primarily from the southeastern seaboard of the U.S. and Caribbean, although the species in many of these records are unverified. McPherson and Myers (2009) also estimated a decline in historical White Shark sightings in Atlantic Canada up to 2005, but due to the opportunistic nature of the data, the magnitude of this decrease was highly uncertain. Additionally, the decrease they inferred is now contradicted by the increase in sightings since 2005 (Table 1).

Curtis *et al.* (2014) estimated relative abundance trends for White Shark based on three data sources (Figure 9): the U.S. Northeast Fisheries Science Center's (NEFSC) fishery-independent longline survey (1961-1989, 2009), catches in five recreational fishing tournaments (1965-1996), and U.S. observer data from commercial bottom longlining (1994-2010). These trends are based on a Bayesian hierarchical analysis combining the three indices, although one of the indices (observer data) is not temporally coincident with the other indices (excepting the single 2009 overlap of the NEFSC survey series with observer data). Their analysis showed approximately the same decline from the 1960s to the 1990s (-73%) as the logbook data (-79%) used by Baum *et al*. (2003). However, the analysis suggested that since the 1990s, and continuing into the 2000s, the White Shark population in the coastal Northwest Atlantic has been increasing (Figure 10). The estimated increase is exclusively dependent on the observer dataset from the bottom longline fishery, which started only in 1994, and showed a highly variable but increasing trend until its final year (2010) (Figure 9). Considering only the point estimates, the data suggest the population approximately doubled since the 1990s.

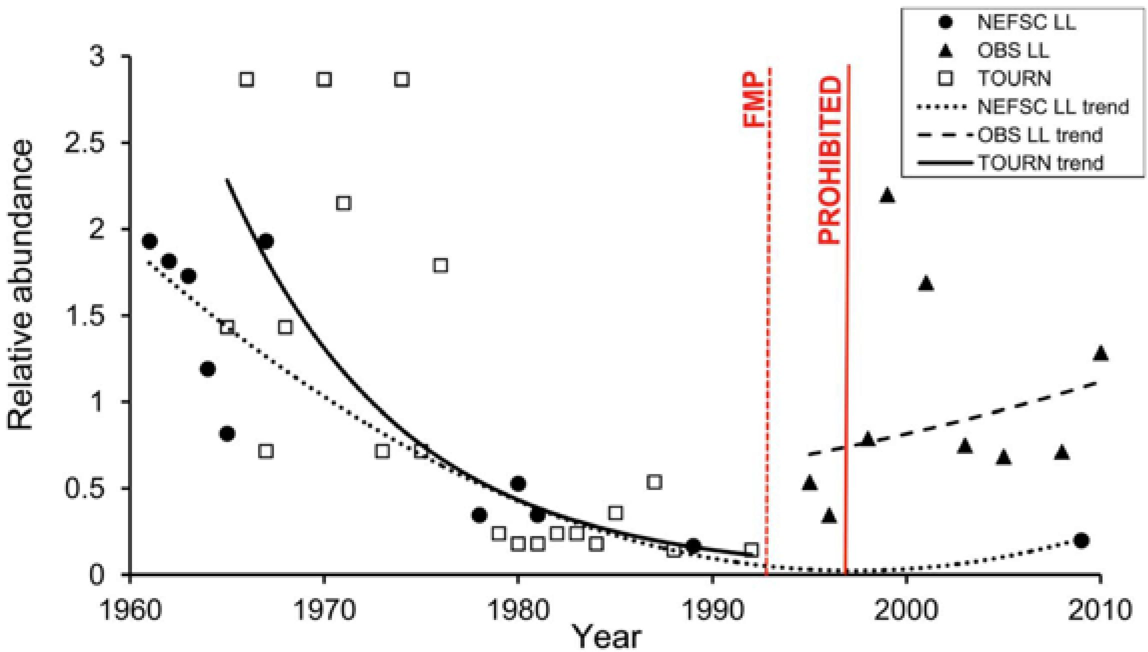

Figure 9. The separate trend in relative abundance of White Shark for each of the three indices in U.S. waters (Northeast Fisheries Science Center fishery-independent longline surveys, tournament database, and observer program of directed longline fishery) used in the analysis of Curtis *et al.* (2014). The dotted red line is when the Fisheries Management Plan for the White Shark was introduced and the solid red line is when the White Shark was prohibited from commercial and recreational capture. Reproduced from Curtis *et al.* (2014).

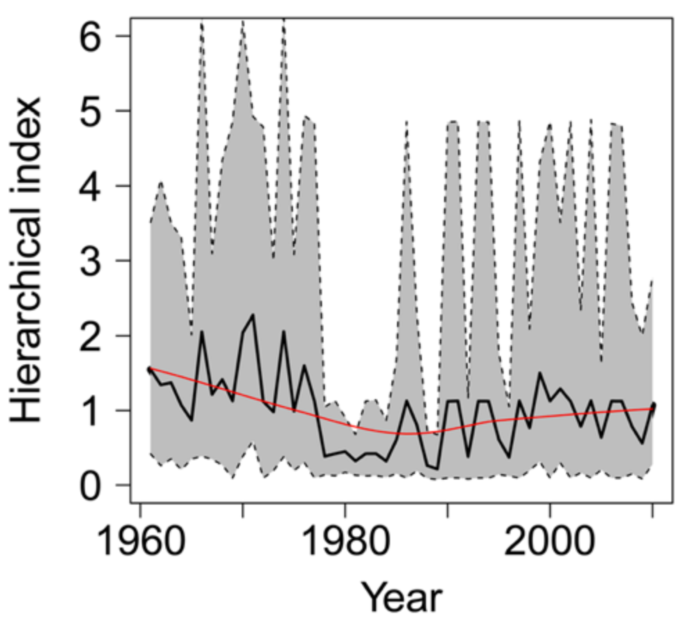

Figure 10. The trend (red line) in relative abundance of White Shark based on hierarchical Bayesian analysis of three indices from U.S. waters (Northeast Fisheries Science Center fishery-independent longline surveys, tournament database, and observer program of directed longline fishery). Black line is the posterior mean and the grey area represents the 95% credible interval around the trend. Reproduced from Curtis *et al.* (2014).

Curtis *et al*. (2014) acknowledged that the understanding of trends based on their analysis of this White Shark population is highly uncertain. Indeed, they state that their analysis had the largest amount of uncertainty associated with the trend in relative abundance, with confidence intervals being 4-5 times greater than the magnitude of the point estimates (Figure 10). They did attempt to validate the estimated increase through examination of sightings records (Figure 11) and found some corroboration of an increase. The increase in Grey Seal population off the northeast coast of North America (Wood *et al*. 2020), a major prey item for White Shark, would also lend support to some increase in the shark population.

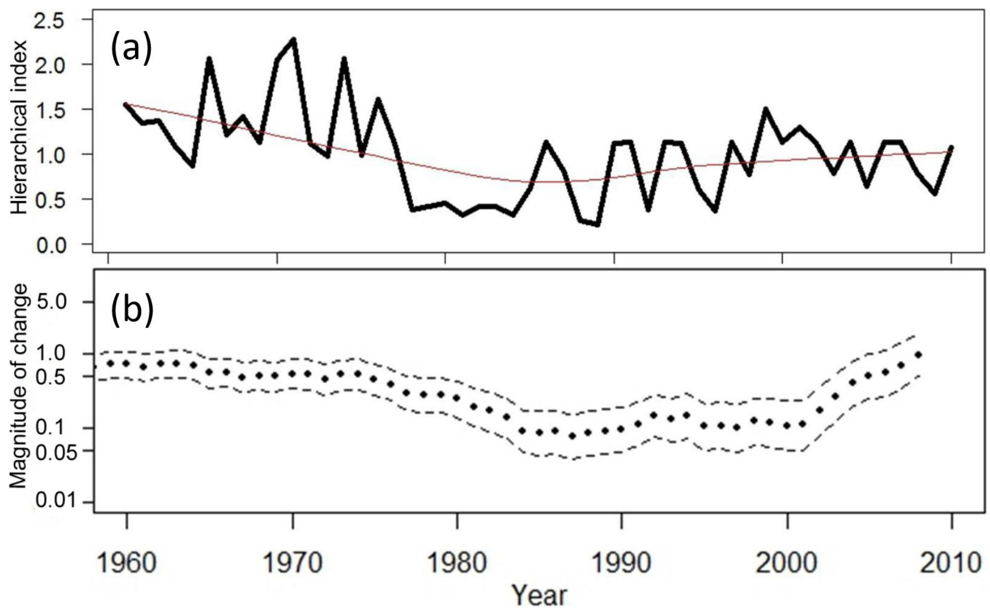

Figure 11. Comparison of the trend in relative abundance of White Shark observations between (a) the hierarchical Bayesian analysis of three indices from U.S. waters (Northeast Fisheries Science Center fishery-independent longline surveys, tournament database, and observer program of directed longline fishery); and (b) the database of sightings and capture records subset from 1959-2009. Reproduced from Curtis *et al.* (2014).

However, there are several reasons to question the magnitude of the estimated increase derived from the Curtis *et al*. (2014) Bayesian analysis. First, the analysis suggests an increase from the late 1990s to the late 2000s of approximately 155%. This implies a population growth rate of approximately 11%/yr, an unrealistically high rate for this species. Second, the estimated increase associated with sightings is highly sensitive to the assumption of fixed observation effort. It is likely that both sighting effort and the verification of White Shark sightings has increased since management plans, observer programs, and tagging programs have been implemented in Canada and the U.S., leading to some overestimate of White Shark increase. Lastly, the sole data set spanning the entire time period analysed (NEFSC fishery-independent survey) shows very little change in White Shark relative abundance from the late 1990s to the late 2000s, although there is only a single data point for the survey after 1990.

Bowlby and Gibson (2020) conducted simulation analyses to evaluate how many animals must have been removed from the population to have caused the historical decline rate, and then accounted for these removals when projecting the population forward, to evaluate its capacity for subsequent increase. If White Shark in the Northwest Atlantic are as long-lived as research shows, then their analysis suggests that the population is unlikely to have doubled in abundance over the past 30 years. Mitigation measures implemented in fisheries would have had to be 100% effective at eliminating all sources of incidental mortality for the population to have doubled. Concerning whether the CPUE indices used in Curtis *et al*. (2014) to construct trends analyses are likely to index abundance, Bowlby and Gibson (2020, p. 4999) state:

> "That the abundance index [referring to the Curtis *et al*. trends analysis] increased so rapidly from the 1990s suggests that climatic or environmental variation has affected the distribution of White Shark in the Northwest Atlantic and thus encounter probabilities in the fishery-independent data (e.g., Hobday and Evans 2013), or that there have been changes in fleet behavior that increase susceptibility to capture (e.g., Tidd, Brouwer, & Pilling 2017). The recent trend is very unlikely to be solely due to changes in abundance over time."

Bowlby and Gibson (2020) further suggest that the life history of White Shark confers high vulnerability to extremely low levels of incidental mortality and that their widespread distribution and potential for interaction with multiple international fleets (Queiroz *et al*. 2019) is cause for concern.

While all analyses agree on the decline of the White Shark population from the 1960s to the 1990s, there is substantial uncertainty about the magnitude of any subsequent increase. Based on the only consistent data set throughout the entire time period (the NEFSC fishery-independent survey), the population has at the least been stable since the 1990s. Assuming that the population has remained stable since the estimated declines between the 1960s and 1990s, the population would currently be depleted by 73-79% compared to 1960 abundance level. This time period represents approximately 1.5 generations.

Some of the apparent recent increases in White Shark sightings in Atlantic Canada may also be associated with rebounding Atlantic Grey Seal population. It is also possible that the sightings increase could represent range shifts and extended migrations further into Canada from the U.S., caused by changes in thermal habitat. Changes in the interaction of the Labrador Current with a northerly shifting warm Gulf Stream could be causing increased frequency of warm anomalies off the Scotian Shelf (Peterson *et al.* 2017; Saba *et al.* 2017; Brickman *et al.* 2018), bringing Canadian Atlantic waters further within the thermal preferences of the White Shark. Finally, increased reporting of sightings to DFO is likely responsible, at least in part, for the rapid increase in records in Atlantic Canada since the 2006 report (Bowlby pers. comm. 2019). Anecdotally, this recent increase in sightings throughout the Northwest Atlantic is still ongoing, even excluding the increases observed at

Cape Cod (Curtis pers. comm. 2019). There is then an indication of an increasing trend throughout the Northwest Atlantic, even if its magnitude is uncertain, but there is also strong indication of depletion relative to historical abundance.

White Shark populations outside of the Northwest Atlantic have shown evidence of declines. Targeted shark control programs can quickly reduce White Shark populations, with marked reductions (~80–90%) from historical abundance in Australia (Reid and Krogh 1992; Roff *et al.* 2018) and irregular declines off Natal, South Africa (Cliff *et al.*1989). The decline of White Shark sightings and fisheries interactions in the Northwest Pacific (Christiansen *et al.* 2014), the decline of sightings at a hotspot in False Bay, South Africa (Hewitt *et al.* 2018), and their apparent extirpation in South America (Amorim *et al.* 2018) suggest that even the removal of only a few individuals can have a noticeable effect. However, increased protection in New South Wales has stabilized, and possibly increased, White Shark interactions with a shark meshing program (Reid *et al.* 2011; Lee *et al.* 2018). A gillnet ban and reduction in fishing effort may be responsible for increased incidental catch of White Shark in the Southern California Bight (Lowe *et al.* 2012). Ultimately, White Shark population growth rates are slow (Smith *et al.* 1998; Braccini *et al.* 2017); population modelling of the West Australia population suggests only a 2–6% increase can be expected per year when there is no fishing (Braccini *et al*. 2017).

Rescue Effect

Tagging information and genetic studies indicate regular movement of White Shark between Canada and adjacent U.S. waters. However, rescue of the Canadian segment of the population could not be based on migration of fish from U.S. waters because those fish are from the same Endangered DU.

Based on analysis of both the mitochondrial control region and multiple nuclear-encoded microsatellite loci, and tagging data, the White Shark population in the Northwest Atlantic is considered demographically isolated, even from a geographically close population in the Mediterranean, and is therefore dependent primarily on intrinsic growth (Gubili *et al*. 2011; O’Leary *et al.* 2015). There is evidence of restricted gene flow among females with South Africa population, the closest population genetically to White Shark in the Northwest Atlantic (Gubili *et al*. 2011; O’Leary *et al.* 2015). This makes an extra-regional rescue effect unlikely, and this population may even be experiencing a genetic bottleneck and inbreeding (O’Leary *et al.* 2015).

THREATS AND LIMITING FACTORS

Threats

The IUCN Threats Calculator was used to assess the scope and severity of risk to the population from current and imminent threats (Master *et al.* 2012). Scope of a threat is defined as the percentage of the population expected to be impacted by the threat within 10 years if current circumstances and trends continue. Severity is the level of damage (percent population loss) to the population within the scope identified for the threat that can reasonably be expected if current circumstances and trends continue over the next 10 years or three generations, whichever is longer. Timing is defined as whether the threat is occurring now or only expected in the future. An IUCN Threat Calculator is provided for the White Shark DU (Appendix 1).

<u>IUCN 5. Biological Resource Use – Low Impact</u>

Human activity is the most significant source of White Shark mortality worldwide, most often as bycatch in commercial longlines or as sport fish targeted for their lucrative jaws, teeth, and fins (Compagno *et al*. 1997; Fergusson *et al*. 2009). Generally, White Shark were not historically targeted by commercial fisheries, rather they are captured as bycatch in the eastern Pacific (Lowe *et al*. 2012; Santana-Morales *et al*. 2012; Lyons *et al*. 2013b), Australia (Bruce and Bradford 2012), and the Northwest Atlantic (Baum *et al*. 2003; Skomal *et al*. 2012; Curtis *et al.* 2014). Additionally, they are targeted by beach meshing programs meant to control their numbers or exclude their presence near beaches in South Africa and Australia, and these have indicated declining populations in those areas (Cliff *et al*. 1989; Reid *et al*. 2011; Roff *et al*. 2018). Because of their coastal habitat use, young-of-the-year and juvenile sharks are susceptible to capture in near-shore entangling nets, such as gillnets and seine nets, and to longlining and recreational angling (Figure 12, Lowe *et al*. 2012; Santana-Morales *et al*. 2012; Lyons *et al*. 2013b; Ramirez-Amaro *et al*. 2013; Curtis *et al.* 2014).

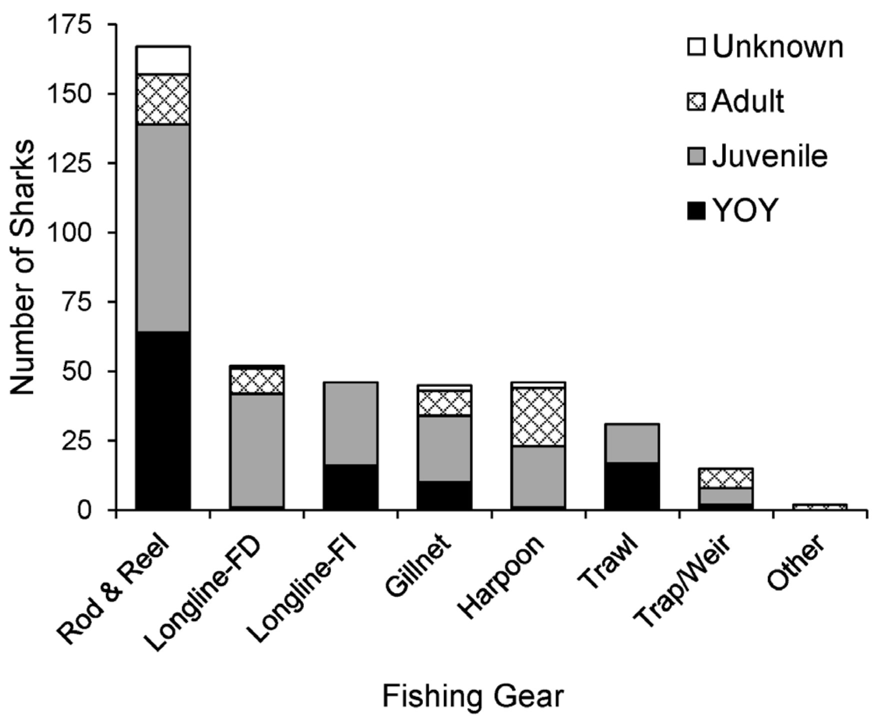

Figure 12. White Shark caught by fishing gear type and life history stage in the Northwest Atlantic sightings and incidental capture data base of Curtis *et al.* (2014). FD: fishery-dependent; FI: fishery-independent. Reproduced from Curtis *et al.* (2014).

The degree to which fishing mortality affects the Northwest Atlantic population is highly uncertain due to low levels of observer coverage in almost all fisheries. In the U.S., fishing effort in the fisheries (groundfish and bluefin tuna longline) historically responsible for the most bycatch has been decreasing over the last 20-30 years (Skomal *et al*. 2012; Curtis pers. comm. 2019) but the effect of this effort reduction on the White Shark population is unknown.

The late age of maturity of White Shark results in slower recovery from overexploitation, even with low levels of fishing mortality (Hamady *et al.* 2014; Braccini *et al.* 2017). From active tracking in California, natural mortality (0.08) was estimated to be six times less than the rate of interactions with gillnets (0.48), indicating incidental fishing interactions would impact population growth (Benson *et al.* 2018). In fact, incidental fishing mortality likely caused the extirpation of the South American White Shark population in the Atlantic (Cione and Barla 2008; Amorim *et al.* 2018).

Mortality from incidental capture is poorly estimated in Atlantic Canada, because interactions with fisheries are underestimated due to low observer coverage and species misidentification (DFO 2017). Based on a sparse data set of observations, 38 of 85 (45%) of White Shark records from Atlantic Canada since 1874 were incidental capture (including two records from the Scotia Fundy Observer Program, one from the Quebec Region Observer Database, and one from the Newfoundland Observer Database), with ten records of incidental capture since 2009 (Table 1). Thirty-two of these fisheries interactions resulted in mortality (DFO 2017, Table 1), and the last time two were killed in one year was 1977 (although potentially a double record of the same shark). There are undoubtedly more unreported mortalities and it is unknown how such mortality contributes to changes in population size. However, the White Shark population likely remains susceptible to very low levels of fishing mortality. Using a life history simulation model, theoretical removals of 20 animals per year caused 72% of population trajectories to decline when projected into the future (DFO 2017).

Management measures have recently been put in place to understand and reduce the chance of mortality from incidental capture. Under the SARA, reporting of interactions with White Shark in logbooks was made mandatory in all relevant fisheries by 2019. However, enforcement of recording in SARA Logbooks or other reporting tools is critical to the effectiveness of this measure; otherwise, shark bycatch continues to go unrecorded unless an observer is aboard. Additionally, in 2019, hook size and line strength were limited in the DFO Maritimes Region shark recreational and charter licences to reduce the risk of harm to White Shark. Hook size and line strength restrictions were also introduced for Newfoundland shark recreational licences in 2020 (Dunne pers. comm. 2020).

IUCN 9. Pollution – Unknown Impact

As long-lived, apex predators consuming fat-laden prey, White Shark are expected to bioaccumulate pollutants in their tissues, as has been found for other elasmobranchs (Cagnazzi *et al*. 2019). Zitko *et al*. (1972) found that muscle and liver tissue from White Shark taken in the Bay of Fundy-Gulf of Maine area had higher levels of PCBs and chlorinated hydrocarbon pesticides than other fishes. While the health impacts of these pollutants on White Shark have not been investigated, they may negatively impact reproductive fitness of males, possibly via compromised gametogenesis or impaired sperm motility (Cadbury 1997). Studies in carcharhinids suggest toxicity can result from exposure to organic pollutants and can affect stress responses in stingrays (Cullen *et al*. 2019, Lyons *et al*. 2019). Juvenile White Shark in the Southern California Bight had mean mercury levels six times higher than the established wildlife screening value of concern (0.5 µg/g) and had significant levels of organic contaminants in their livers, with DDT concentrations (72.37 µg/g) the highest reported for any elasmobranch (Mull *et al.* 2012). In South Africa, White Shark had plasma concentrations of mercury and arsenic so high they would be toxic in other animals, but these sharks showed no evidence of adverse health effects, suggesting protective mechanisms may exist (Merly *et al*. 2019). The potential for maternal offloading in White Shark is also likely increased due to their high trophic position (Lyons *et al*. 2013b). As such, organochlorines and heavy metals may be a concern, but the extent and biological effects of such toxicity are unknown.

Limiting Factors

The degree to which the Northwest Atlantic White Shark population has recovered to baseline levels since its protection in the U.S. in the 1990s is uncertain, although abundance is thought to be increasing (Curtis *et al.* 2014). The status of White Shark in Canada is largely determined by events outside of Canadian waters. The main factor limiting the recovery of these White Shark is the species' late age of maturity and low fecundity, which limit its population growth rate, as is typical of the majority of shark species (Smith *et al.* 1998; Hamady *et al.* 2014; Natanson and Skomal 2015). Furthermore, although adults can readily migrate to adapt to climate change, changes in prey type, increasing water temperatures and ocean acidification, the latter two factors may negatively affect White Shark pups and nursery grounds, because pups cannot move long distances to find waters conducive to their survival and growth.

Number of Locations

White Shark is highly mobile and migratory, meaning an individual may span across its Northwest Atlantic range throughout its lifetime. All individuals within Canada likely form a single population and the primary threat is incidental bycatch, which applies throughout the range in Canadian waters. However, White Shark in the DU are wide-roaming and the threat of mortality is random and ephemeral, therefore the Locations concept does not apply.

PROTECTION, STATUS AND RANKS

Legal Protection and Status

Due to their high profile and low numbers, White Shark are one of the most highly protected shark species internationally. At the beginning of 2005, CITES listed White Shark in Appendix II. White Shark is also listed in Appendices I and II of the Convention on Migratory Species, a United Nations Treaty Organization. The species has been protected from both commercial and recreational fisheries along U.S. Atlantic and Gulf Coasts under the federal Fisheries Management Plan since 1997 (NMFS 1997). In Canada, finning (keeping only the fins) of all shark species was made illegal in 1993 (DFO 2006), and White Shark was officially listed under Schedule 1 ('Endangered') of the SARA in 2011. Under the provisions of section 32 (1) of the Act it is illegal to kill, harm, harass, capture, or take White Shark, and under section 32(2) it is illegal to possess, collect, buy, sell, or trade White Shark. As such, within U.S. and Canadian EEZ waters, White Shark is relatively well-protected from fisheries; however, White Shark does move frequently into unprotected, international waters (Skomal *et al.* 2017; Huveneers *et al.* 2018). Canadian and U.S. prohibitions do not reduce shark interactions with fishing gear, some of which result in 100% mortality in gillnets and deeper-water trawls.

Non-Legal Status and Ranks

White Shark was designated as Vulnerable by the IUCN in 2019 based upon criteria A2bd due to past and ongoing global declines in mature individuals (Rigby *et al.* 2019). White Shark is not yet ranked on the national scale by NatureServe (2019), but has a rank ranging from not ranked to imperilled on the global scale. White Shark's General Status rank is also unrankable at the national level, but the Northwest Atlantic population is imperilled, indicating risk of extirpation due to few occurrences for both the migratory (S2M) and non-breeding populations (S2N).

Habitat Protection/Ownership

Generally, there has been little effort to protect White Shark habitat. White Shark receive some protection from various time-area closures and closed areas along the U.S. east coast as well as a few marine protected areas (MPAs) in Canada, such as the Gully and St. Anns Bank MPA; however, these protected areas are small compared to the home range size of White Shark and the use of these MPAs by White Shark is unknown.

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BIOGRAPHICAL SUMMARY OF REPORT WRITER(S)

Geoffrey Osgood, BSc, completed his Bachelor of Science, Honours in Ecology and Zoology at the University of Calgary in 2014 and since then has been working on his PhD in Biology at the University of Victoria studying the use of marine protected areas for shark conservation.

Julia K. Baum is Associate Professor of Biology at the University of Victoria in British Columbia, Canada, and a 2017 Pew Fellow in Marine Conservation. She earned her BSc from McGill University (1999; Montréal), and her MSc (2002) and PhD (2007) from Dalhousie University (Halifax), all in Biology. Julia subsequently held a David H. Smith Conservation Research Fellowship at Scripps Institution of Oceanography, UC San Diego, followed by a Schmidt Ocean Institute Postdoctoral Fellowship at the National Center for Ecological Analysis and Synthesis (NCEAS), UC Santa Barbara. Amongst other foci, Julia's research has documented precipitous declines in shark populations and the cascading effects of the loss of apex predators.

Appendix 1 Threats Calculator.

THREATS ASSESSMENT WORKSHEET				
Species or Ecosystem Scientific Name	White Shark (*Carcharodon carcharias*) Atlantic population			
Element ID			**Elcode**	899
Date:	July 9, 2020			
Assessor(s):	D. Lepitzki (facilitator), B. Leaman (Co-Chair), G. Osgood (report writer), J. Baum (report writer), R. Claytor (Co-Chair), B. McBride, D.Keith, J. Shaw, M. Trudel, M. Trebel, S. Lenhert, A. MacNeil, D. Sam			
References:	Post-provisional status report			
Overall Threat Impact Calculation Help:			**Level 1 Threat Impact Counts**	
	Threat Impact		**high range**	**low range**
	A	Very High	0	0
	B	High	0	0
	C	Medium	0	0
	D	Low	1	1
Calculated Overall Threat Impact:			Low	Low
Assigned Overall Threat Impact:			**D = Low**	
Impact Adjustment Reasons:			The overall calculated threat impact of Low was retained as the assigned overall threat impact; however, the threats assessment group concluded that the lower end of the range of the predicted population decline in the next 100 years caused by the threats acting in the next 10 years could be zero, instead of the 1-10% range projected due to the combined scope of pervasive and severity of slight for threat 5.4.	
Overall Threat Comments			The species is globally distributed in sub-tropical and temperate waters, but absent from cold polar waters; hence Atlantic and Pacific populations in Canada are isolated from each other and are separate designatable units. This very large apex predator is rare in most parts of its range, but particularly so in Canadian waters, which represent the northern fringe of its distribution and occurrences are primarily seasonal. However, there are increasing records of its occurrence in Atlantic Canada associated with warming ocean waters, although still fewer than 100 since 1874. No abundance trend information is available for Atlantic Canada. Numbers have been estimated to have declined by about 73-79% over 1-2 generations in areas of the Northwest Atlantic Ocean outside of Canadian waters. The species is highly mobile, and individuals in Atlantic Canada are likely seasonal migrants belonging to a widespread Northwest Atlantic population; hence the status of the Atlantic Canadian population is considered to be the same as that of the broader population. Additional considerations include the long generation time (~42 years) and low reproductive rates (estimated gestation is 10-20 months and average fecundity is 7 live-born young) of this species, which limit its ability to withstand losses from increase in mortality rates. Bycatch in commercial fisheries, particularly the pelagic long line fishery, is considered to be the primary cause of mortality, along with recreational fishing. Time frame for scoring severity and timing is 100 yrs (maximum allowable). Threats assessed to Canadian population, including threats outside Canadian waters. Population trend in NW Atlantic waters is highly uncertain but appears to be increasing and thought to be due to increased measures to mitigate mortality from incidental capture in commercial fisheries.	

Threat		**Impact (calculated)**		**Scope (next 10 Yrs)**	**Severity (10 Yrs or 3 Gen.)**	**Timing**	**Comments**
1	Residential & commercial development						
1.1	Housing & urban areas						Not relevant for this DU
1.2	Commercial & industrial areas						Not relevant for this DU
1.3	Tourism & recreation areas						Not relevant for this DU

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
2	Agriculture & aquaculture						
2.1	Annual & perennial non-timber crops						Not relevant for this DU
2.2	Wood & pulp plantations						Not relevant for this DU
2.3	Livestock farming & ranching						Not relevant for this DU
2.4	Marine & freshwater aquaculture						Current evidence (observation and tagging) shows interaction of White Shark and salmon aquaculture sites with possibility of entanglement, although nets modified recently to minimize entanglement. Likely to be rare occurrence but increasing aquaculture may increase entanglement probability.
3	Energy production & mining						
3.1	Oil & gas drilling						White Sharks have been observed around oil platforms and could potentially suffer displacement if there were increased numbers of platforms. However, this is considered a low probability in the near future.
3.2	Mining & quarrying						Not relevant for this DU
3.3	Renewable energy						Not likely relevant to this DU. Windfarm siting could impact this DU via EMF associated with underwater transmission cables, or physical disturbance when laying the cables. Evidence from North Sea windfarms suggests potential impacts but no evidence concerning White Shark at present.
4	Transportation & service corridors						
4.1	Roads & railroads						Not relevant for this DU
4.2	Utility & service lines						Transmission lines from windfarms would have potential impacts via electromagnetic field effects around cables. Research in other areas shows effects varying by species but no current evidence concerning this DU.
4.3	Shipping lanes						White shark are found normally at depths <100 m and sighting records average ~30 m depth in coastal habitats. Its relative mobility renders it less likely to be subject to collisions with marine traffic.
4.4	Flight paths						Not relevant to this DU
5	Biological resource use	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	
5.1	Hunting & collecting terrestrial animals						Not relevant to this DU
5.2	Gathering terrestrial plants						Not relevant to this DU
5.3	Logging & wood harvesting						Not relevant to this DU

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
5.4	Fishing & harvesting aquatic resources	D	Low	Pervasive (71-100%)	Slight (1-10%)	High (Continuing)	Fishing effort in the pelagic longline fisheries in the Northwest Atlantic, a traditional source of bycatch mortality of White Sharks, has increased steadily since the 1960s, although declining in the most recent years. Limited observer coverage in these fisheries (<10%) yields similarly limited information on the magnitude of bycatch mortality. However, even limited bycatch mortality is projected to generate declines in White Shark populations. Entanglement with herring weirs has been recorded and represents potential mortality source. Exposure to potential bycatch by both commercial and recreational fisheries is likely high but the probability of capture and mortality is much lower. Generally, scope is thought to be pervasive (at low end) and severity is slight to negligible because available evidence shows (with significant uncertainty) that the population is increasing. Current bycatch mitigation measures in fisheries are thought to be effective and continuing.
6	Human intrusions & disturbance		Negligible	Small (1-10%)	Negligible (<1%)	High (Continuing)	
6.1	Recreational activities						Not relevant to this DU
6.2	War, civil unrest & military exercises						Not relevant to this DU
6.3	Work & other activities		Negligible	Small (1-10%)	Negligible (<1%)	High (Continuing)	Research tagging (non-lethal) of about 10-15/yr currently.
7	Natural system modifications						
7.1	Fire & fire suppression						Not relevant to this DU
7.2	Dams & water management/use						Not relevant to this DU
7.3	Other ecosystem modifications						Unknown. Adults can readily migrate to adapt to climate change which could affect prey availability; changes in prey type either positive or negative are possible through climate change.
8	Invasive & other problematic species & genes						
8.1	Invasive non-native/alien species/diseases						Not relevant to this DU
8.2	Problematic native species/diseases						Not relevant to this DU
8.3	Introduced genetic material						Not relevant to this DU
8.4	Problematic species/diseases of unknown origin						Unknown
8.5	Viral/prion-induced diseases						Unknown
8.6	Diseases of unknown cause						Unknown

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9	Pollution		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	Various sources of pollution (9.1, 9.2, 9.3, and 9.5) considered together.
9.1	Domestic & urban waste water						Microplastics from urban wastewater (cosmetics) in prey.
9.2	Industrial & military effluents						As long-lived, apex predators consuming fat-laden prey, White Shark are expected to bioaccumulate pollutants in their tissues, particularly organochlorines and heavy metals. While the health impacts of these pollutants on White Shark have not been investigated, they may negatively impact reproductive fitness of males.
9.3	Agricultural & forestry effluents						Not relevant for this DU
9.4	Garbage & solid waste						Not relevant for this DU
9.5	Air-borne pollutants						Not relevant for this DU
9.6	Excess energy						Not relevant for this DU.
10	Geological events						
10.1	Volcanoes						Not relevant for this DU
10.2	Earthquakes/tsunamis						Not relevant for this DU
10.3	Avalanches/landslides						Not relevant for this DU
11	Climate change & severe weather		Not a Threat	Pervasive (71-100%)	Neutral or Potential Benefit	High (Continuing)	
11.1	Habitat shifting & alteration		Not a Threat	Pervasive (71-100%)	Neutral or Potential Benefit	High (Continuing)	Long-term warming may shift the centre of distribution for this species to the north, potentially changing the impact of incidental capture fisheries in Atlantic Canada but decreasing in southern waters. Increasing water temperatures and ocean acidification may negatively affect White Shark pups and nursery grounds, because pups cannot move long distances to find waters conducive to their survival and growth.
11.2	Droughts						Not relevant for this DU
11.3	Temperature extremes						Not relevant for this DU
11.4	Storms & flooding						Not relevant for this DU
11.5	Other impacts						Unknown
Classification of Threats adopted from IUCN-CMP, Salafsky *et al*. (2008).							