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**Maritimes Region**

# Guidance for Setting Reference Points for the Sea Cucumber (*Cucumaria frondosa*) Fishery in the Maritimes Region, and Status of the Southwest New Brunswick Sea Cucumber Fishery in 2019

Ryan Martin, Michelle Greenlaw, Melanie Barrett

St. Andrews Biological Station
Fisheries and Oceans Canada
125 Marine Science Drive
St. Andrews, N.B., E5B 0E4

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**Foreword**

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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## ABSTRACT

Commercial harvesting of Sea Cucumbers in the Maritimes Region, specifically *Cucumaria frondosa*, has occurred since 1999. Current stock status indicators are based on fishery dependent information including catch rates and port sampled split weight, as fishery independent information is lacking. Indicators are presented for all fishing zones and areas that are regularly fished, including Southwest New Brunswick (SWNB) Zone 1, 4W Offshore Zones 1 and 2, 4W Mid-shore Zone F, and 4Vs offshore Area of Access 2 (AOA 2). Catch rates for all areas are presented in kg/m$^2$, and an additional catch rate indicator, kg/hr*m, is also presented for SWNB Zone 1. Limit Reference Points (LRPs) were established for all areas based on their highest mean catch rates (kg/m$^2$), a proxy for virgin biomass ($B_0$). The LRPs were set as 20% of the $B_0$ proxy for all areas, with the exception of SWNB Zone 1 which was set as 30% of the $B_0$ proxy for the kg/hr*m catch rate indicator. The LRP for SWNB Zone 1 is more precautionary due to the risk associated with fishing all known available habitat and consistently declining catch rates since the beginning of the fishery.

An assessment of the SWNB Sea Cucumber population was conducted based on current stock status indicators (catch rates and split weights). Both catch rate (kg/m$^2$ and kg/hr*m) and size-based indicators have been declining since the beginning of the fishery. The fishery does not currently provide the necessary data for a detailed assessment that would evaluate the impacts of the fishery on the SWNB Sea Cucumber stock. Broad guidance for establishing spatial reserves was also discussed and it was recommended, that for a data-limited fishery like this one, at least 30% of expected Sea Cucumber habitat be set aside from fishing.

## CONTEXT

Science advice was requested by Fisheries and Oceans Canada Resource Management on guidance for setting reference points for the Sea Cucumber (*Cucumaria frondosa*) fisheries in the Maritimes Region, and for the status of the SouthWest New Brunswick (SWNB) Sea Cucumber (*Cucumaria frondosa*) fishery. This is the first assessment of the SWNB Sea Cucumber fishery since licences were converted from Stage II Exploratory to limited-entry in 2011. No stock assessment framework has previously been adopted for this stock, and no formal science advice has been provided for this fishery since 2009 following an assessment of the Stage II Exploratory status (DFO 2009, Rowe et al. 2009). Science advice was also provided on this fishery in 2006 before it moved from Stage I Experimental to Stage II Exploratory status (DFO 2009).

Science advice was also requested to provide guidance on establishing spatial fishing reserves for the 4W offshore fishing areas, which can be used for establishing reserves for other Sea Cucumber fishing areas in the future.

## BIOLOGY OVERVIEW

*Cucumaria frondosa* is the most common Sea Cucumber in the North Atlantic (Hamel and Mercier 2008, Bruckner 2006b, Levin and Gudimova 2000). They aggregate in high densities (Hamel and Mercier 1995, Singh et al. 2001) although their distribution is patchy. They have a football shape, with leathery skin ranging in colour from yellowish white to dark brownish-black and are covered with five rows of retractile tube feet used to attach to the bottom (Figure 1; Gosner 1978, Jordan 1972). Compared to other sea cucumber species commercially harvested elsewhere, they are small, thin-walled, and filter feed plankton from the water column. They use tentacles distributed around their mouth to capture particles in suspension in the water column, including phytoplankton and the tiny animalcules of the zooplankton (Jordan 1972, Hamel and Mercier 1998). As suspension feeders (Hamel and Mercier 1998, Singh et al. 1998), and prey to several other species (Hamel and Mercier 2008), *C. frondosa* form a key component of many cold-temperate ecosystems. Information about the life history characteristics of *C. frondosa* in the Maritimes Region, including growth rates, age and size at maturity, mortality, recruitment, and stock structure is limited. Much of our understanding of this species comes from research in other areas, particularly the Gulf of St. Lawrence (Hamel and Mercier 1995, 1996a, 1996b, 1996c, 1997, 1998). While some of this information will be applicable to Sea Cucumber populations in the Maritimes Region, site-specific differences are expected.

*Figure 1. Cucumaria frondosa images from benthic footage in Offshore 4W (Photo: Ocean Pride Fisheries Ltd.).*

## GROWTH RATES

Growth rates for *C. frondosa* in the Maritimes Region have not been determined. Studies from the Gulf of St. Lawrence show that individuals grow to 12 cm in 4.5–5.5 years, reaching commercial size (25–30 cm) in approximately 10 years (Hamel and Mercier 1996b). A similar growth rate is reported for *C. frondosa* in the Barents Sea where they require a minimum of 10 years to reach commercial size (Gudimova et al. 2004). Gudimova et al. 2004 also suggest that growth rates become very slow after approximately 10 years and that the estimated life span for *C. frondosa* is 20–22 years. In Newfoundland, growth rates were shown to be even slower for both juveniles and adults, taking a minimum of 25 years to reach market size of 15 cm (Hamel and Mercier 1996b, So et al. 2010). Growth rates are expected to be influenced by environmental conditions, such as temperature and phytoplankton concentrations (Hamel and Mercier 1998, Singh et al. 1999). The Bay of Fundy likely has phytoplankton concentrations with similar magnitudes, and thus similar growth rates to the Gulf of St. Lawrence. Market size is estimated to be 10 years, with size at maturity reached at 3–4 years. However, Mid-shore and Offshore regions of the Scotian Shelf likely have substantially lower chlorophyll concentrations than the Bay of Fundy and Gulf of St. Lawrence, and thus potentially slower growth rates and a much longer timespan to reach commercial size (Appendix II).

## AGE AND SIZE AT MATURITY

There is no direct method of ageing *C. frondosa*, however, it is expected that they take at least several years to reach commercial size. The age at maturity for *C. frondosa* in the Maritimes Region has not been determined, however, in the St. Lawrence Estuary, sexual maturity was reached after 3–4 years at 8–10 cm and appeared more rapid in deeper water (20 m) (Hamel and Mercier 1996b). Individuals observed at shallower depths (< 15 m) did not reach maturity within a 5-year time frame (Hamel and Mercier 1996b). This is a similar age of maturity to other sea cucumber species (*Parastichopus californicus, Holothuria fuscogilva, Isostichopus fuscus*), but is also longer than others (*Holothuria scabra, Stichopus japonicus*), which mature within 1–2 years (Therkildsen and Petersen 2006).

## MORTALITY

Natural mortality is unknown for adult Sea Cucumbers in the Maritimes Region, but assumed to be low as they have few natural predators. The Purple Sea Star (*Solaster endeca*), the main predator, preys upon *C. frondosa* throughout its life cycle (So et al. 2010). Compared to adults, newly settled larvae and small juveniles are much more susceptible to predatory species including Green Sea Urchins (*Strongylocentrotus droebachiensis*; Hamel and Mercier 1996b), sea stars, crabs, fishes and large nereid worms (Medeiros-Bergen and Miles 1997).

## RECRUITMENT

Information about the recruitment of holothurians in temperate waters is limited. Recruitment of sea cucumbers in the Maritimes Region is unknown, although significant recruitment events are assumed to be episodic. Along the eastern Atlantic coast, Buchanan (1967) documented episodic recruitment in *Cucumaria elongata* in which low to non-recruitment intervals exceeded 5 years. In SWNB, recruits are increasingly seen in the fishery, and have been reported in the catch over the last two years. However, the avoidance of smaller unmarketable individuals by the industry, and the permitted discarding of small sea cucumbers in the Maritimes Region since 2018, limits the biological information on recruitment that is attainable from the fishery. An index of recruitment may be achieved through camera drop or fishery-independent surveys.

The *C. frondosa* sex ratio is reported as close to 1:1 from a variety of sources (Coady 1973, Hamel and Mercier 1995, 1996b). Its reproductive cycle is characterized by annual spawning and highly synchronized gamete release (Hamel and Mercier 1996b, 1996c). The spawning season varies among populations from different locations, however, Lacalli (1981) and Singh et al. (2001) described an April to June spawning season in the Bay of Fundy. In Passamaquoddy Bay, spawning occurs every spring in May or June. In Nova Scotia, *C. frondosa* spawns earlier, at the end of March (Sherrylynn Rowe, MUN, pers. comm.). Gametogenesis is initiated by an increase in day length around January, while spawning is triggered by a mix of factors, including tide, high phytoplankton concentrations in the water column, and diet components (Hamel and Mercier 1995, 1996b, 1996d). Males spawn first and females release their oocytes when the water column is already filled with spermatozoa (Hamel and Mercier 1996c). Oocytes remain in the planktonic stage for about 35–50 days, and then settle on rocks or pebbles, usually in crevices located in the shaded area under hard substrata (Hamel and Mercier 1996b). In Maine, juveniles have also been found in high concentrations on mussel beds, or on coralline algae and kelp holdfasts (Medeiros-Bergen and Miles 1997).

## STOCK STRUCTURE

The stock structure of *C. frondosa* in the Maritimes Region (i.e., the relationship of individuals in this area to adjacent areas) is unknown, including the source of recruits and the extent of movement among areas. Recruitment may connect the mid-shore and offshore Sea Cucumber fishing areas, given the duration of the larval sea cucumber water column phase and the oceanographic current patterns in the area (Shackell et al. 2013). Though the exact patterns of sea cucumber larval dispersal in the Maritimes is unknown (Shackell et al. 2013), larval dispersal of benthic species in general is broad and dependent on a variety of biological and physical conditions (Cowen and Sponaugle 2009).

Adults aggregate rather than being randomly distributed. Aggregations are targets for exploitation, with areas of high density heavily fished. Density and proximity of adults is important for reproductive success (Purcell et al. 2013, Shackell et al. 2013).

## MOVEMENT

Previously, the sea cucumber was considered mainly sessile, with dispersal presumed to occur over several weeks during the planktonic embryonic and larval phase (Hamel and Mercier 1996d). However, previous research on population structure and connectivity was primarily centred on pelagic phases or rafting of benthic juveniles or adults. Movement of juveniles and adults were thought to range from a few centimetres to a few metres, however, new research suggests that sea cucumber can actively modify their buoyancy, leading them to tumble or float at speeds much faster than crawling (Hamel et al. 2019). Active buoyancy modification happens in juveniles as early as 6 months post settlement and was recorded in wild adult populations. In experimental trials, it was triggered with decreasing salinity and increasing turbidity, and generated speeds of up to 90 km/day (Hamel et al. 2019).

*C. frondosa* are also reported to exhibit a size-dependent migration with depth. Jordan (1972) indicated that the population of *C. frondosa* at Lamoine Beach, Maine is composed of smaller individuals inshore year round, with larger individuals moving offshore in winter, leading to a decrease in the inshore abundance and biomass during the winter months. A similar size-dependent migration was observed in the St. Lawrence estuary where sexually mature individuals moved to deeper water once temperatures rapidly decreased in autumn (Hamel and Mercier 1996a). In the Mid-shore and Offshore fishing areas of the Scotian Shelf, lower average round and split weights are reported for the Mid-shore area compared to Offshore areas in

NAFO Divisions 4W and 4Vs. However, it is unknown whether this size segregation is due to migration or other factors.

## HABITAT

*C. frondosa* is typically distributed between 20 and 100 m depths, with some variation among sites (Jordan 1972, Coady 1973, Hamel and Mercier 1996b, Singh et al. 2001, Grant 2006). They can occur at depths of up to 300 m and can be found in tide pools of the lower intertidal zone (Brinkhurst et al. 1975). *C. frondosa* commonly settles on rocky or pebble substrates (Hamel and Mercier 1996b), although they have been occasionally observed on sand (So et al. 2010). Sea cucumbers found on sandy substrate off St. Pierre Bank, Newfoundland were smaller than those attached to rock, which may be explained by the limited food resources available on sand, resulting in low feeding rates and use of energetic reserves (So et al. 2010). In southwest New Brunswick (SWNB), the Zone 1 fishing area is comprised of large, steep vertical structures that provides a refuge from drag gear and support solid masses of sea cucumbers.

# FISHERY OVERVIEW

Sea cucumbers had been fished for subsistence by indigenous communities for centuries along the west coast of North America (Mathews et al. 1990) and in the Canadian Arctic (Wein et al. 1996). Commercial harvesting of holothurians in North America started in the 1970s on the west coast of the United States of America (USA) and in the 1980s on the west coast of Canada (Bruckner 2005, 2006a, 2006b, Conand and Sloan 1989, Hamel and Mercier 2008, Therkildsen and Petersen 2006). It expanded to the east coast of Maine and to the Atlantic provinces of Canada in the late 1990s.

Sea cucumber fisheries worldwide have expanded in response to a growing demand for sea cucumber products, and the depletion of traditionally fished stocks. New species, including *C. frondosa*, have become commercially important due to the declining availability of these traditional species. *C. frondosa* is now the most abundant commercial Sea Cucumber on the globe.

Interest in a Sea Cucumber fishery for the Maritimes Region began in the early 1990s, but was slow to develop due to lack of initial market potential, as the Sea Cucumbers obtained were thin-walled compared to the other sea cucumber species on international markets. In 1996, an experimental license was issued for both Georges Bank and the Scotian Shelf. Only three fishing trips were conducted, before fishing was discontinued (DFO 1996). By 1999, there was renewed interest in harvesting Sea Cucumber and two experimental licences were issued for the inshore portion of Northwest Atlantic Fisheries Organization (NAFO) Division 4X, known as Lobster Fishing Area (LFA) 36, in SWNB. One additional experimental licence was issued in NAFO Division 4X, the inshore waters of Southwest Nova Scotia, to test gear performance and develop markets. These three licences used modified scallop and urchin rakes to harvest Sea Cucumbers.

In 2004 and 2005, Ocean Leader Fisheries Ltd. and Louisbourg Seafoods Ltd. were approved for experimental licences in NAFO Divisions 4W and 4Vs, respectively, outside the 50 nautical mile (nm) limit. In 2006, WT Grover Fisheries Ltd. was granted access to NAFO Division 4W in the Mid-shore area from 12 to 50 nm. Favourable catch rates and market size Sea Cucumbers were present in the surveyed areas.

The Sea Cucumber fishery in the Maritimes Region has been divided into five management areas:

1. Southwest New Brunswick (SWNB)
2. 4W Mid-shore
3. 4W Offshore
4. 4Vs
5. 4X

## LICENCES

There are six limited entry commercial licences for Sea Cucumber on the Scotian Shelf and in the Bay of Fundy (Table 1). The licences are a combination of inshore and offshore vessel-based licences and enterprise allocations. There are no First Nations components such as Food, Social and Ceremonial (FSC) licences. Recreational harvesting of Sea Cucumber is not permitted.

*Table 1. Sea Cucumber licences and output controls for the Scotian Shelf.*

| Number of Licences* | Area | Type | 2018–2019 Controls |
|---|---|---|---|
| 2 | SWNB | Independent Fleet | Zones 1: 200 t, Zone 2: 180 t |
| 1 | 4Vs Offshore | Enterprise Allocation | Areas 1–8: 800 t, AOA 2 capped at 600 t. |
| 1 | 4W Midshore | Enterprise Allocation | Zones A-C & E-J: 800t |
| 1 | 4W Offshore | Enterprise Allocation | Zone 1: 400 t, Zone 2: 200 t |
| 1 | 4X Inshore | Vessel-based | Zones 1–5: 50 t |

*As of November 2019

## SEASON

In SWNB, the fishing season runs from the second Tuesday in January to March 31. In 4W and 4Vs, it runs from May 1 to March 31 the following year. The month of April is closed to fishing as spawning likely occurs then.

## GEAR

The authorized gear for all Sea Cucumber fishing areas is a modified scallop drag, with some differences between the gear used in SWNB and in 4VW. Since 2009, the authorized gear for SWNB has been 'Tinker' gear. Gear specifications are described in Rowe et al. 2009. In 4W and 4Vs, the authorized gear is 'Green' gear. The maximum width for both gear types is 10 feet. The 'Green' gear consists of a bag-like net of steel and twine mesh with a 3 metre wide steel frame having a mouth opening of 10 inches. The bottom of the drag consists of up to ½ inch hardened chain forming a chain sweep. The top of the drag consists of twine running back to the cod end.

## BYCATCH AND DISCARDS

Bycatch in the Maritimes Region Sea Cucumber fisheries is expected to be minimal, as Sea Cucumbers typically make up more than 90% of the catch (Rowe et al. 2009). In SWNB, sea urchins are the most frequent bycatch species contributing up to 3% of the catch (DFO 2009). Other reported bycatch includes: seastars, crabs, Sea Scallop (*Placopecten magellanicus*), Iceland Scallop (*Chlamys islandica*), Lobster (*Homarus americanus*), and octopus. At-sea observers record bycatch information, however, since 2016, licence holders have reported bycatch in commercial logbooks. No bycatch is permitted to be kept, and must be returned to the water immediately as discards.

There is no minimum landed size for Sea Cucumber, as it is difficult to determine Sea Cucumber length. Before 2018, licence holders were not authorized to discard Sea Cucumbers, rather, they were expected to not fish in areas where catches of small Sea Cucumbers were high. At an October 2017 meeting of the Maritimes Region Sea Cucumber Advisory Committee, the industry presented evidence that discarded Sea Cucumbers have high survivability after being harvested by trawl and then exposed to harsh conditions, such as being out of the water and starved. Based on the evidence provided, licence conditions were amended in 2018–2019 to allow small Sea Cucumbers to be released. At the October 2018 meeting of the Maritimes Region Sea Cucumber Advisory Committee, the industry was encouraged to measure Sea Cucumbers that were being discarded. Information from the SWNB Sea Cucumber fishery, which occurs from January to March suggests that some Sea Cucumbers waiting to be discarded may freeze on deck while the retained catch is processed. Licence holders are encouraged to return small Sea Cucumbers to the ocean as quickly as possible to increase the Sea Cucumbers' chances of survival. Discarding non-marketable sized Sea Cucumbers will be beneficial to the population in the long term, as juveniles are expected to survive being discarded.

## CATCH MONITORING

Industry has accumulated a variety of data throughout the various stages of the fishery, but data collection protocols have changed over time, making it difficult to compare the entire time series (DFO 2009, Lundy 2015). Logbooks, dockside monitoring, at-sea observers, industry-led port sampling, Fisheries and Oceans Canada (DFO) Vessel Monitoring Systems (VMS), and scientific logging have been required at different periods. Measurements of round and split weights for a sample of the catch for each fishing day provide some record of the stock over time.

Currently, the Sea Cucumber fisheries in SWNB and on the Scotian Shelf are subject to 100% dockside monitoring of landings. Vessels are required to provide positional data via VMS which can be used to monitor or verify the location of vessels. Fishers are responsible for completing the Sea Cucumber Monitoring Document (i.e., commercial logbook) while at sea for every fishing event in a given trip, and upon landing the catch must provide completed logbooks to the dockside observer for catch verification. Detailed set information is also recorded in commercial logbooks including date, time, position, duration, distance, depth of each tow, and estimated catch weights for retained (directed) and discarded (bycatch) species. In SWNB, licence holders record the number of totes instead of estimated catch weight and did not provide set-level fishing information until recently. Inconsistencies in data recording over the span of the fishery has resulted in poor quality fishery data. Consequently, the industry has provided edited logbook data which has been used to calculate catch rates.

Collection of biological information is a requirement of the industry via port sampling. Round weights and split weights have been sampled at intervals in each fishing area and can be analysed to indicate changes in size structure or signs of recruitment. In 2019, a standardized split weight sampling protocol was included in the annual Conservation Harvesting Plan to ensure all licence holders are sampling consistently.

Licence holders are required to carry an at-sea observer for one trip per season. Though at-sea observers might provide additional biological information including round and split weights, they experience difficulties measuring and weighing Sea Cucumbers at sea. This, in addition to the infrequency of observed trips, means that biological data collected by the at–sea observer program is both temporally and spatially lacking.

In the absence of a stock assessment framework, fishery-dependent information has been considered provisional indicators of stock status and used to inform management decisions. For Sea Cucumber fisheries in the Maritimes Region, these include catch rates and size-based indicators (e.g., round and split weights). At the end of each fishing season, licence holders have been required to provide a report on the trends of these indicators for each Sea Cucumber fishing Zone or Area of Access.

## FISHING AREAS

Fishing is restricted to designated Sea Cucumber fishing areas in NAFO Divisions 4Vs, 4W and 4X (Figure 2, Figure 3). The designated Sea Cucumber fishing areas in 4W and 4X are referred to as Zones, while in 4Vs they are referred to as Areas of Access (AOAs). In 2017–2018, DFO Science conducted a review of indicator reports produced by industry. This review identified potential concerns related to fishing activities in one small concentrated area. Following the review, DFO Resource Management worked with licence holders to formalize management measures to support the addition of reserve areas. This work began in NAFO Division 4Vs during the 2018–2019 fishing season. Guidance on establishing reserves is discussed in a subsequent section of this document.

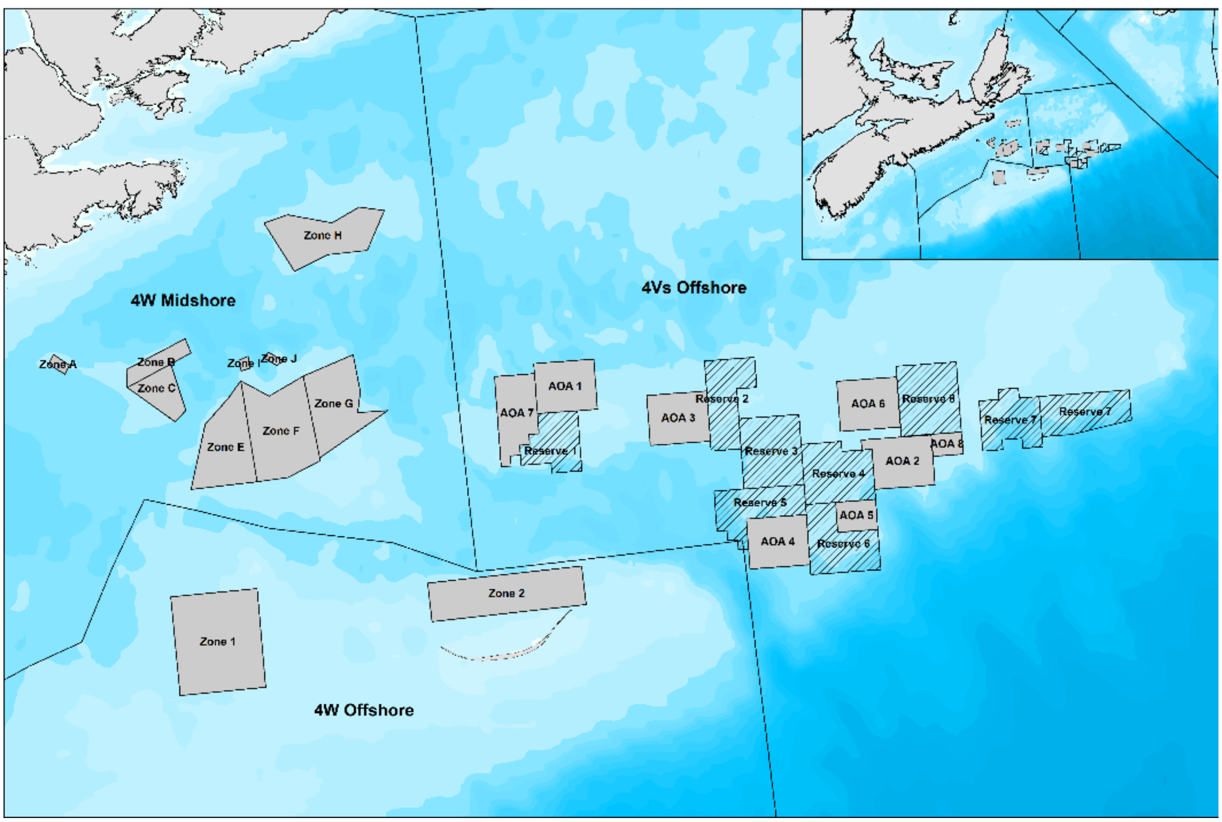


*Figure 2. Current Mid-shore and Offshore Sea Cucumber fishing areas and reserves in NAFO Divisions 4VsW.*

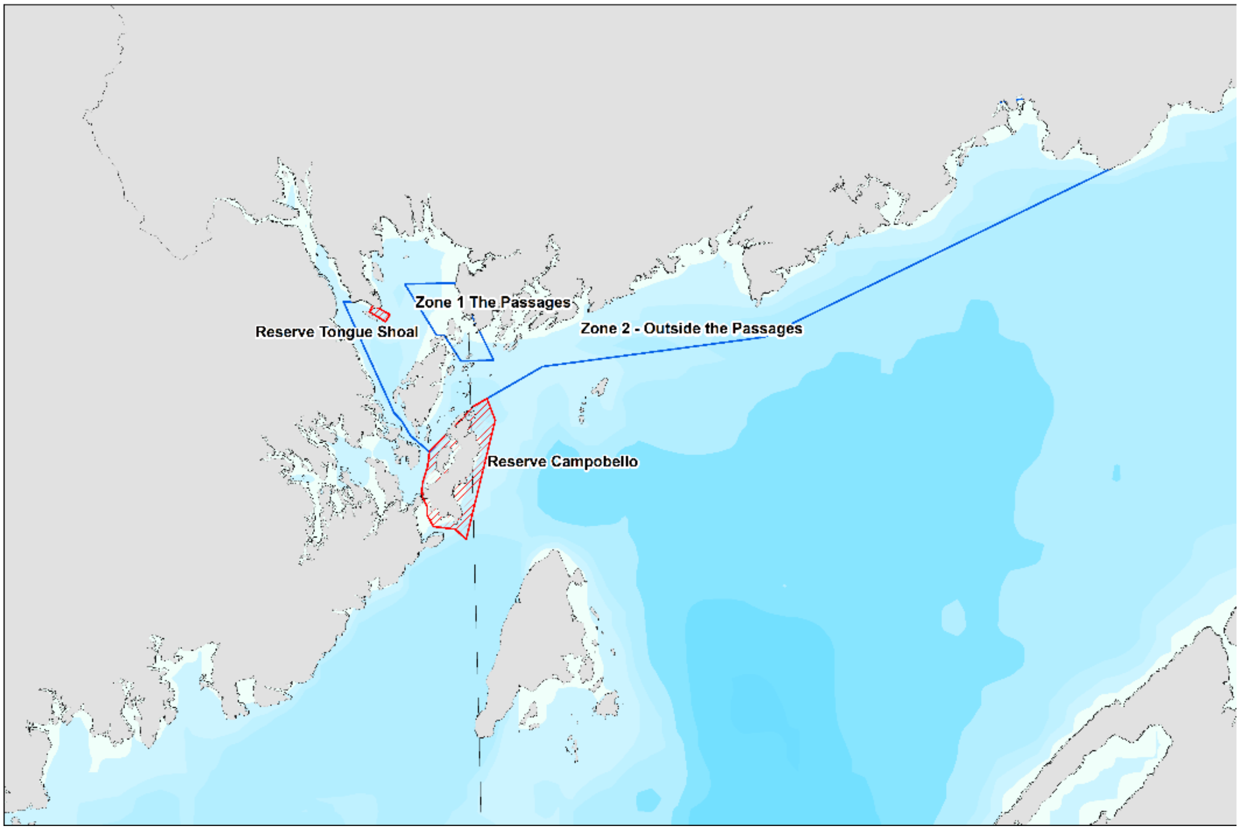


*Figure 3. Current Maritimes Region Sea Cucumber fishing Zones 1 and 2 of Southwest New Brunswick (SWNB) in NAFO Division 4X.*

## FISHING HISTORY

The Sea Cucumber landings in the Maritimes Region have slowly increased since the fishery began in 1999. Due to the privacy of confidential information, landings are only reported from 2009–2018 when there were more than five active licences in the Maritimes Region (Table 2). Landings have averaged 3,145 t since 2009, with a peak of 3,506 t in 2012. Total landings from all Sea Cucumber fisheries in the Maritimes Region are expected to reduce slightly in 2019 due to a TAC reduction in SWNB.

All landings for SWNB are dockside monitored. During dockside monitoring, landings are calculated as the number of full tote boxes (70 L) multiplied by 68.4 kg (150 lb), which is the valid average weight. Totes that are not full are weighed on an accurate scale by Dockside Monitors. To ensure the volumetric weigh-out method is accurate, full weigh-outs, at dockside on an accurate scale, are required at a rate of 20% of trips per vessel on a random basis. In 4W and 4Vs fishing areas, all landings are determined by dockside monitors based on one of two methods: by weighing all Sea Cucumbers or by the volumetric method of 953 kg per standard wharf box.

*Table 2. Total annual calendar year landings (t) for all Sea Cucumber fishing areas (SWNB, 4W Offshore, 4W Mid-shore, and 4Vs Offshore) in the Maritimes Region combined.*

| Zone | Year | Landings (t) |
|---|---|---|
| **All** | 2009 | 2,970.9 |
| **All** | 2010 | 2,794.6 |
| **All** | 2011 | 3,454.2 |
| **All** | 2012 | 3,506.7 |
| **All** | 2013 | 3,016.6 |
| **All** | 2014 | 2,863.0 |
| **All** | 2015 | 3,024.2 |
| **All** | 2016 | 3,467.1 |
| **All** | 2017 | 3,403.1 |
| **All** | 2018 | 2,954.0 |
| **All** | **Average** | **2,407.9** |

## Southwest New Brunswick

The SWNB Sea Cucumber fishery has been active since 1999 (Figure 4). From 1999 to 2006, two inshore (< 65 feet) experimental Sea Cucumber licences were authorized to harvest in the portion of NAFO Division 4X, known as Lobster Fishing Area (LFA) 36, using variations of modified scallop and urchin gear. The purpose of this Stage I experimental Sea Cucumber fishery was to test gear performance and market potential (Rowe et al. 2009). During this period, there was no cap on landings. The two licence holders were limited to an operating season from January to March 31 (extended once in 2002 until July to test harvest methods by divers). This season was chosen to minimize gear conflict with other fisheries in this area, including scallop. Since commencement of the experimental fishery in 1999, the licence holders have been required to submit a dockside monitoring document and a DFO science log.

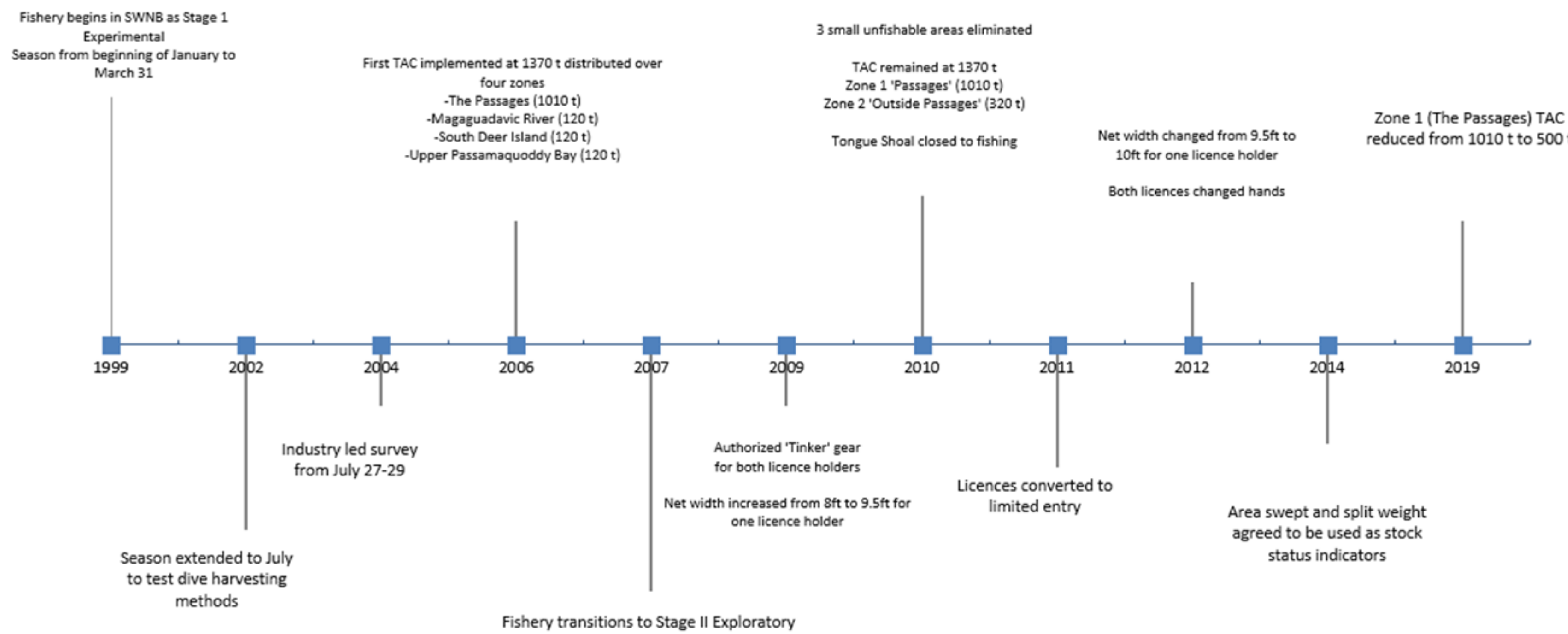


*Figure 4. Timeline of changes to the southwest New Brunswick Sea Cucumber (*C. frondosa*) fishery.*

In 2006, an overall Total Allowable Catch (TAC) of 1,370 t was implemented and distributed within four fishing zones. The zones and associated TACs were created based on previous fishing effort, the average annual landings during the previous five years, and a short survey conducted from July 27–29, 2004 (Rowe et al. 2009). The zones (Figure 5) and TACs implemented in 2006 included: The Passages at 1,010 t, Magaguadavic River at 120 t, South Deer Island at 120 t, and Upper Passamaquoddy Bay at 120 t. The TACs were divided equally between licence holders. An additional zone, St. Andrews Harbour, was closed to the fishery as a possible research area.

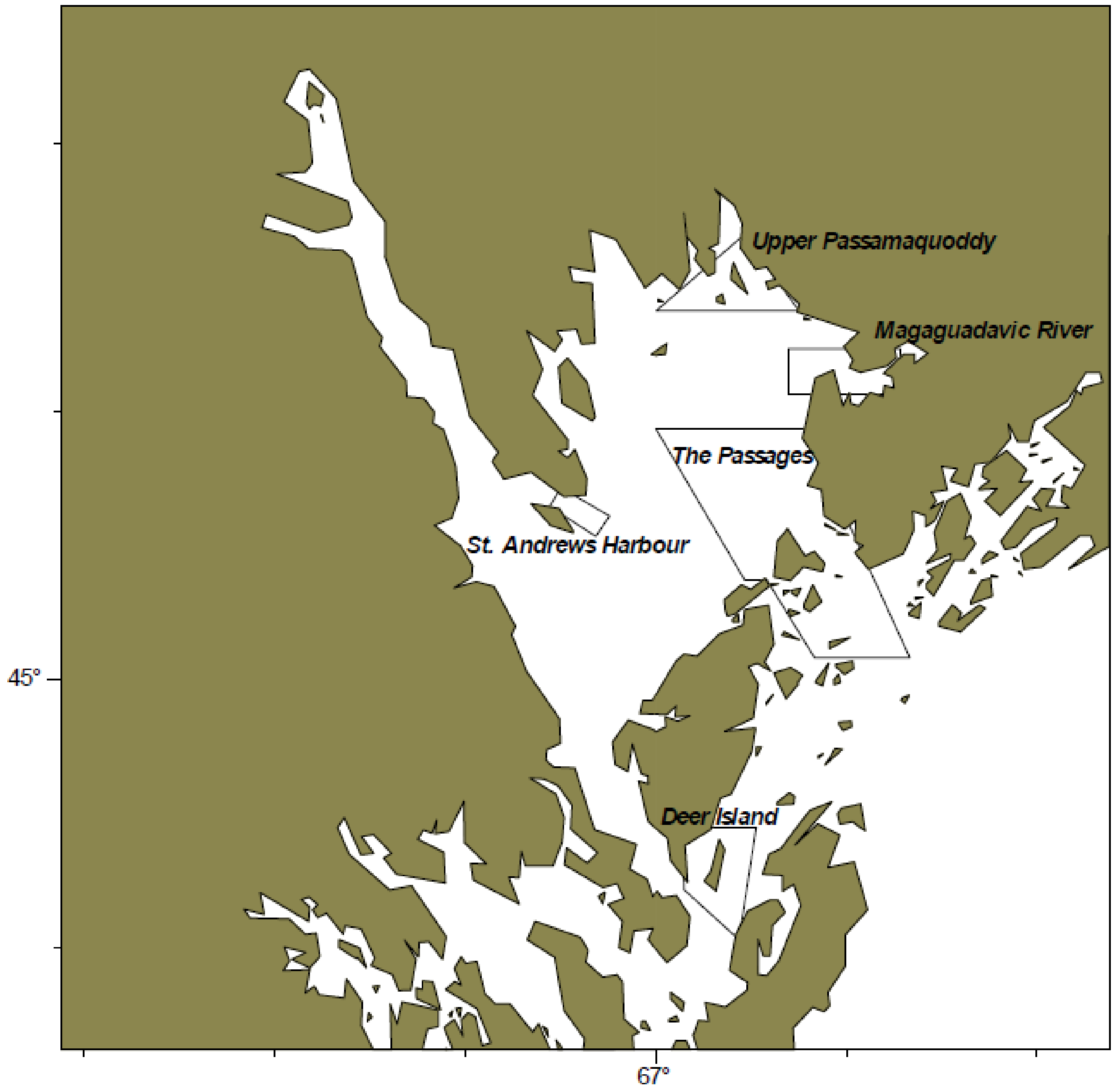


*Figure 5. Inshore Sea Cucumber fishing zones implemented in 2006 in the Lobster Fishing Area (LFA) 36 portion of SWNB.*

In 2007, following an Expert Opinion (DFO 2006), Stage II exploratory status was granted from the Stage I experimental status. Monitoring and log submission requirements remained in place during the exploratory status.

From 2007 to 2009, licence holders were unable to fish in some zones due to poor weather and ice conditions. They requested authorization to fish the quota that they missed from other areas of LFA 36, that were previously fished during the experimental phase. In 2010, after consultations through the advisory process, three zones (Magaguadavic River, South Deer Island, and Upper Passamaquoddy Bay) were eliminated while the same overall TAC of 1,370 t was maintained. The Passages Zone (Zone 1) remained with a TAC at 1,010 t and the remaining 360 t allocation was made available to harvesters inside the Scallop Conservation Zone (SCZ) area, a segment of LFA 36, now referred to as Outside The Passages Zone (Zone 2). Fishers were required to harvest throughout the SCZ and limit removals to a maximum of 60 t each in any one specific area, or 10 fishing days each, whichever was reached first. An independent industry-funded at-sea observer was required for at least one fishing day by each licence holder whilst fishing any portion of this 360 t.

In 2010, the “Tongue Shoal” area located in St. Andrews Harbour was closed to commercial Sea Cucumber fishing (Figure 5). This area was identified as having high concentrations of Sea Cucumbers and was considered to have a high level of benthic species diversity (Rowe et al. 2009). The closure reduces benthic contact and protects the high concentration of Sea Cucumbers in this area. The site was previously closed to Sea Cucumber harvesting for a proposed 2006 scientific depletion study, but the study was not completed.

In 2011, all licences were converted from exploratory to limited entry. The 2019 fishing season was set as the second Tuesday of January to March 31st. In 2012, both licences changed ownership. One of the new licence holders had been fishing Sea Cucumber in SWNB since the beginning of the fishery, before becoming the primary licence holder in 2012. The other licence holder was new to the fishery and had difficulty fishing in an unfamiliar area with strong tides and currents.

In 2019, “The Passages” or Zone 1 TAC was reduced from 1,010 t to 500 t based on concerns of declining trends in catch rates. The Zone 2 TAC remained at 360 t. Since the SWNB Sea Cucumber fishery began in 1999, approximately 90% of landings and effort on average, came from Zone 1, even though catch rates declined in the traditionally fished areas.

### 4W Offshore Fishery

In 2004 with an experimental licence, Ocean Leader Fisheries Ltd. began to harvest Sea Cucumber beyond the 50 nautical mile (nm) limit in NAFO Division 4W, excluding the haddock closed area west of Sable Island (Figure 6). This area is herein referred to as 4W Offshore. Industry surveys were conducted from June to July in an area designated Zone 1. In the fall, DFO Science conducted morphometric analyses, commercial fishing took place in December. In the summer of 2005, five additional Zones (2, 3, 4, 5 and 6) were included in the experimental survey area. These zones were surveyed in the fall, and DFO Resource Management and Science reviewed the data. During this period, a small quantity of Sea Cucumber were harvested.

In 2006, two new zones (7 and 8) were designated experimental and were surveyed. In April 2006, DFO issued license conditions for Zone 1 under a Stage II exploratory fishery with a TAC of 800 t.

In 2007, pre-season surveys were conducted in Zones 1 and 2. An additional area accompanying Zone 2, designated the Zone 2 extension, was also surveyed. Upon completion of the surveys, Ocean Leader Fisheries Ltd. was allocated a TAC of 800 t for Zone 1 and 200 t for Zone 2. A maximum of 40 fishing days in Zone 1 and 10 days in Zone 2 could occur, with an end of season date of October 31st, 2007. In 2011, DFO issued Ocean Leader Fisheries Ltd. an enterprise allocation licence for Zones 1 and 2 only in NAFO Division 4W.

From 2013 to 2015, the TAC was changed to a combined 880 t for Zones 1 and 2, with a maximum of 50 fishing days. In 2016, Zones 1 and 2 changed configuration at the request of the industry (Figure 7). In 2017, the total combined TAC was reduced as recommended by the licence holder to 600 t.

In 2018, zonal TAC caps were implemented with the intention of stabilizing landings from both zones. The caps were 400 t for Zone 1 and 200 t for Zone 2. Zone 2 removals were capped at less than Zone 1, to keep removals similar to historical levels until the impact of these removals on the population is determined. The licence holder also agreed to voluntarily distribute fishing effort within the zone. This is expected to continue for the 2019–20 season.

The spatial distribution of landings and effort in 4W Offshore has shifted slightly over the years as a result of exploration by licence holders and reconfiguration of Zones 1 and 2 in 2016 (Figure 7). Exploration has occurred throughout Zone 1 over the years, while exploration on the western portion of Zone 2 has been limited.

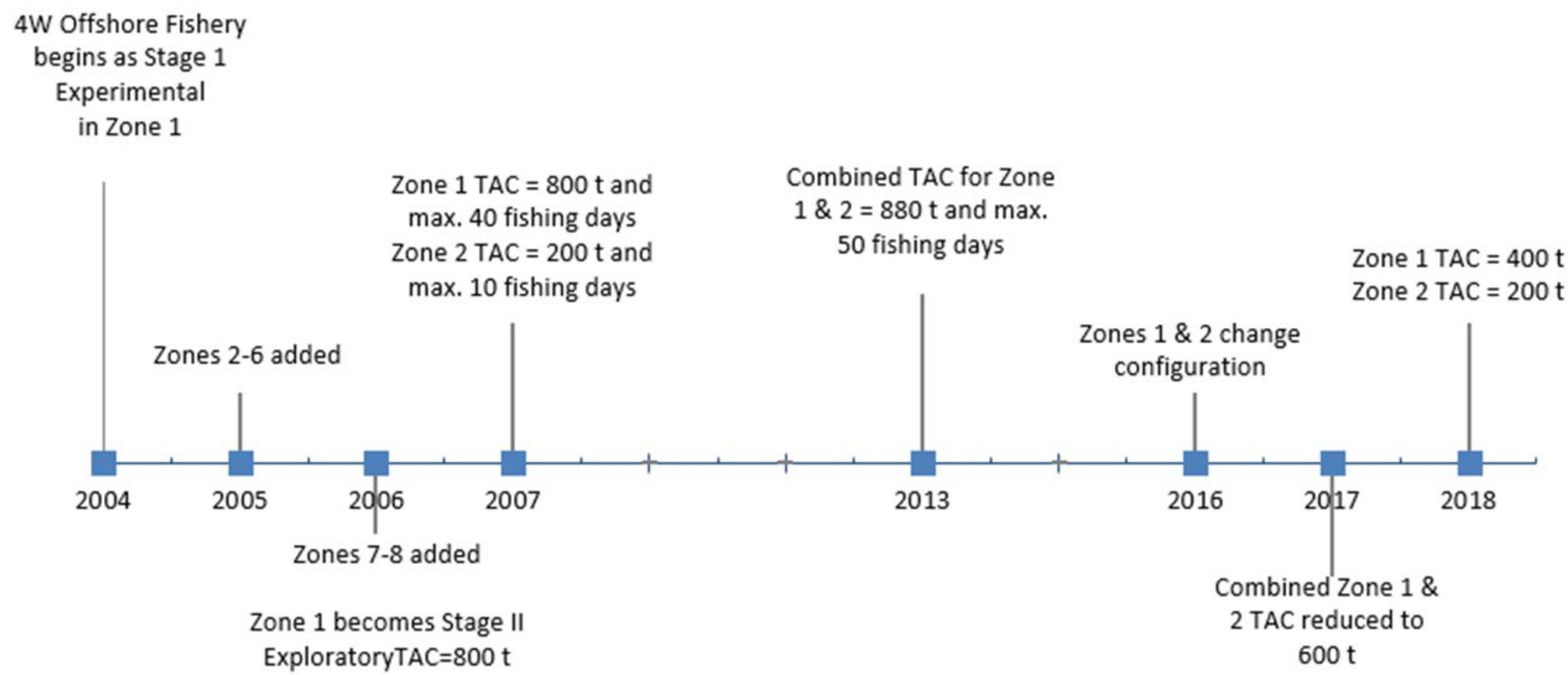


*Figure 6. Timeline of changes to the 4W Offshore Sea Cucumber (*C. frondosa*) fishery.*

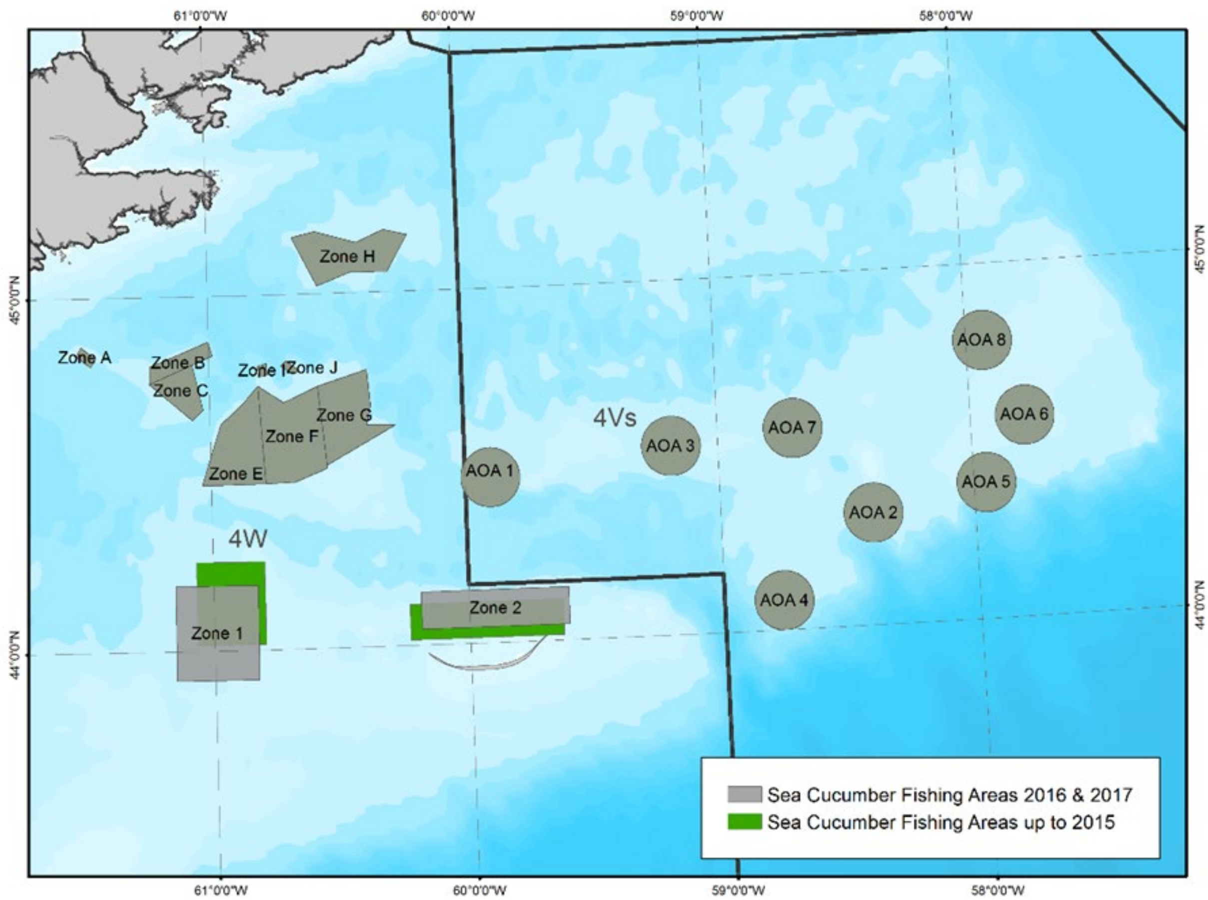


*Figure 7. Historical Offshore and Mid-shore Sea Cucumber fishing areas in NAFO Divisions 4VsW, prior to 2018. The green areas represent the 4W Offshore fishing areas Zones 1 and 2, up to 2015. Zones 1 and 2 were re-delineated in 2016 and are shown in grey.*

## 4W Mid-shore Fishery

In 2004, WT Grover Fisheries began conducting surveys and fishing commercially for Ocean Leader Fisheries Ltd. through a Joint Project Agreement. In 2006, WT Grover Fisheries applied for, and was granted, a Stage 1 experimental licence (Figure 8) in the Mid-shore (12–50 nm) of NAFO Division 4W in Zones A–J (Figure 7). In 2007, all zones but Zone D were surveyed. Large Sea Cucumbers beds were found in Zones E, F, and G. Sea Cucumbers were located in Zones B, C and H, but those areas required a more extensive survey to determine abundance.

In 2008, a TAC of 800 t with a maximum of 45 fishing days was approved for the 4W Mid-shore. Since TAC was implemented, almost all fishing in 4W Mid-shore has been focused in one small area of Zone F (Figure 7). Zone D is closed to fishing as it is located near sensitive sponge grounds. If fishing were authorized, the potential impacts to the sponge grounds should be considered.

For the 2018–19 season, effort moved to different areas in Zone F, and the catch rates remained among the highest levels within all Sea Cucumber fishing areas in the Maritimes Region. For the 2019–20 season, fishers have indicated that they will voluntarily move their effort away from the small patch in Zone F that they have fished since 2008. The expectation is that they will determine if other areas within Mid-shore Zone F or other Mid-shore zones have Sea Cucumber densities that support the 800 t removal.

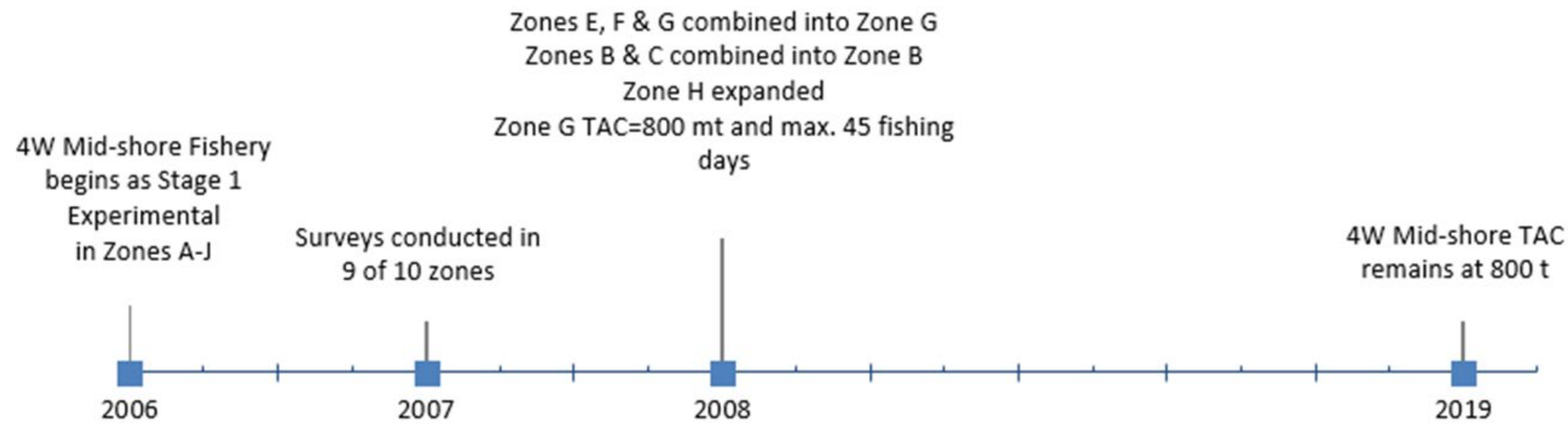


*Figure 8. Timeline of changes to the 4W Mid-shore Sea Cucumber* (C. frondosa*) fishery.*

## 4Vs Offshore Fishery

In 2005, Louisbourg Seafoods Ltd. applied for, and was granted, a Stage I experimental licence in the offshore (outside 50 nm) of NAFO Division 4Vs (Figure 9). Due to a combination of factors including markets, economics, and opportunity costs, Louisbourg Seafoods Ltd. postponed the commencement until 2008. In 2009, a Stage II exploratory licence with access to eight AOAs was approved for Louisbourg Seafoods Ltd. (Figure 7). Eight fishing areas were authorized to promote rotational harvesting. In an effort to achieve rotational harvest, up to 25% of the fishing effort (i.e., days and/or quota) could be committed to each area. A TAC of 800 t was approved for the offshore 4Vs area, further limited by maximum of 45 fishing days.

Removals from AOA 2 were capped at 600 t for the 2018–19 season, based on a DFO Science review of the previous fishing seasons, that identified a decline in indicator values and concentrated fishing effort in AOA 2 since 2011. The licence holder, in consultation with DFO Science, instituted Sea Cucumber reserves for the 2018–19 season (Figure 2). These were in response to the licence holder's request to change their fishing area locations and the concentrated fishing effort in AOA 2. The reserves were adopted on a provisional basis, and DFO continues to work with industry to confirm their suitability. The license holder agreed to complete a camera survey for one reserve area each season, but the camera survey did not occur in 2018–19. The theory of Sea Cucumber reserves and guidance on establishing new reserves is discussed in a subsequent section of this document.

In 4Vs, the 800 t TAC has been consistently caught since 2011, with a buildup phase of two years in 2009 and 2010. The majority of landings are from AOA 2, although there is continual exploration of areas outside that zone. In 2018, high concentrations of Sea Cucumber were found in the newly configured AOA 6. This area had not been explored previously, and was not part of the initial eight fishing areas designated in 2009. In 2018, landings were almost equal between AOA 2 and AOA 6, reducing pressure on AOA 2.

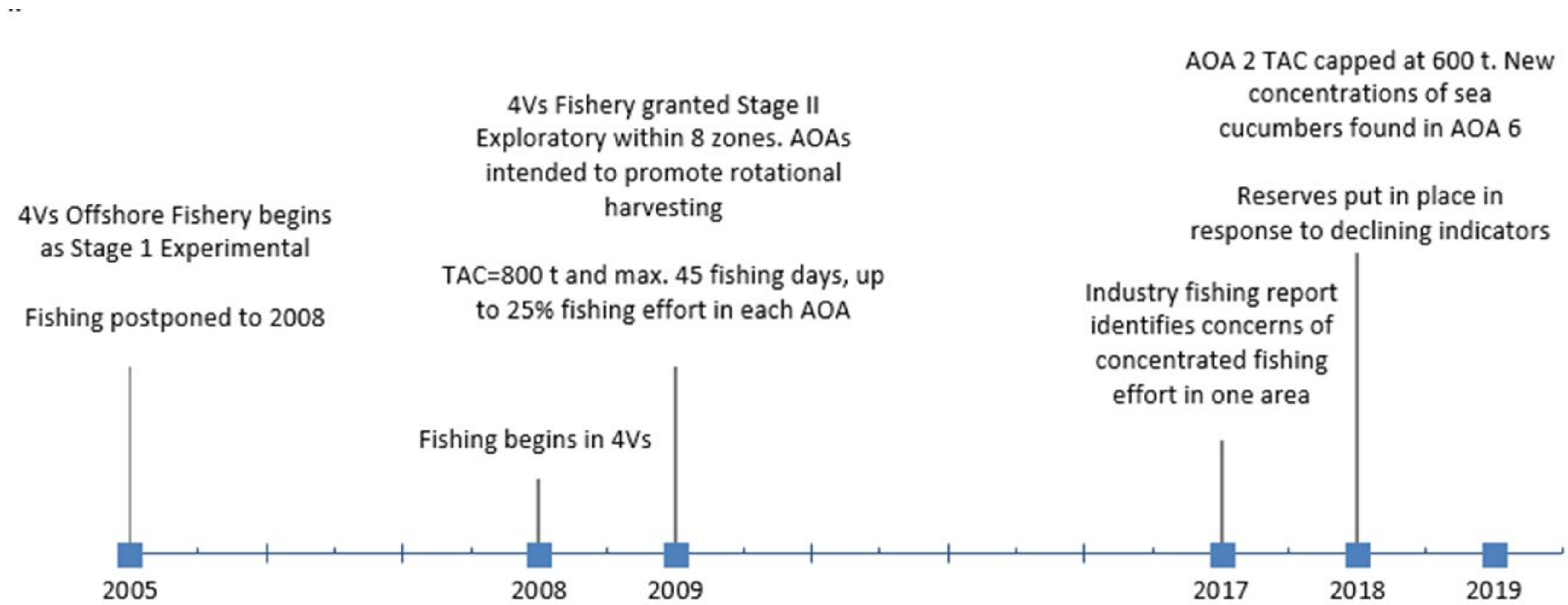


*Figure 9. Timeline of changes to the 4Vs Offshore Sea Cucumber (*C. frondosa*) fishery.*

# ASSESSMENT

## STOCK INDICATORS

Currently there are no surveys in the Maritimes Region that provide sufficient fishery-independent information on the abundance of Sea Cucumber, thus an assessment of Sea Cucumbers must be based on fishery-dependent data. It was agreed that kg/m$^2$, calculated as:

$$\frac{\text{catch (kg)}}{\text{distance towed (m)} * \text{drag width (m)}}$$

and split weight would be used as stock status indicators. One additional indicator was included for SWNB, kg/hr*m, which is calculated as:

$$\frac{\text{catch (kg)}}{\text{tow duration (hour)} * \text{drag width (m)}}$$

This indicator may be more representative of effort patterns in SWNB. In that fishery, drift from extreme tidal currents prevent fishers from recording the precise location of their tows while they haul their gear. Catch and tow durations recorded on commercial log sheets are used to calculate the catch rate indicator, kg/hr*m. Both catch rate-based indicators (kg/m$^2$ and kg/hr*m) are calculated as a mean catch rate per year (bootstrapped mean with replacement, with 5,000 iterations) with 95% confidence intervals (Bias Corrected and Accelerated (BCa), to correct for bias and skewness in the distribution of bootstrap estimates).

Indicators are presented for all fishing zones and areas that are regularly fished, including 4W Offshore Zones 1 and 2, 4W Mid-shore Zone F, 4Vs AOA 2, and SWNB Zone 1 (Figure 10, Figure 11). Catch and fishing locations recorded on commercial log sheets are used to calculate the area-based catch rate (kg/m$^2$). Tow distances are calculated between the start and end of set locations using R programming (function 'distHaversine', package 'geosphere'), which considers the shortest distance between two points, and does not take into account the possibility of a non-linear tow. Non-linear tows are noted in fishery logbooks, however, time did not permit distance of curved tows to be calculated for this analysis. Non-linear tows should be considered in the future when calculating catch rates, as this could artificially increase the area-based indicator if tows are longer than calculated. Using data from 2012–2018, curved tows accounted for 59%, 27%, 36%, and 34% of the total tows for 4W Offshore Zone 1, 4W Offshore Zone 2, 4W Mid-shore Zone J, and 4Vs Offshore, respectively. In 4W, tow lengths are now recorded from OLEX navigational software on board vessels, which provides an accurate tow length and could be used in the future to remove uncertainty. Vessel Monitoring Systems (VMS) data could also provide a more comprehensive understanding of where and how fishers tow. In SWNB Zone 1, curved tows accounted for 14% of all tows since they were first recorded in 2012, however, reference points are based on the kg/hr*m catch rate indicator, which removes the uncertainty in calculated distances due to curved tows.

The additional indicator presented for SWNB Zone 1, kg/hr*m, uses tow duration (hours) as a metric of fishing effort instead of tow distance (m) (Figure 12). This indicator was deemed more appropriate for SWNB Zone 1 as it removes the uncertainty in calculated distances due to curved tows and imprecise tow locations recorded on commercial logbooks. Fishers have noted difficulties recording precise fishing locations for each tow due to the vessel drifting with strong tides and currents in the area. Therefore, the kg/hr*m indicator is considered more representative of the true fishing effort in SWNB Zone 1.

In SWNB, catches are recorded on log sheets as the total number of totes kept, rather than estimated catch weights per tow, as is done in other Sea Cucumber fishing areas. Consequently, only average catch per tow for a trip can be calculated using the total catch (i.e., number of totes kept) and the number of sets. One licence holder began to record catches and fishing locations for individual tows in 2016, but this cannot be incorporated into the time series because similar data is not available for all years. Both licence holders in SWNB must begin to record precise fishing information (i.e., catch, coordinates, tow duration, etc.) for every set so that reliable catch rates can be calculated.

Indicators for SWNB Zone 1 (kg/m$^2$ and kg/hr*m) do not include the first six years of fishing (1999–2004), as fishing was largely exploratory and fishing practices changed in 2005 when vessels were replaced. Gear modifications (i.e., widening of the mouth of the drag) that occurred in 2009 and 2012 were accounted for in both catch rate indicators by multiplying the gear width by either distance towed (kg/m$^2$), or tow duration (kg/hr*m). This assumes a linear relationship between net width changes and catch for the indicators, which is a common assumption for *C. frondosa*, as well as for other sedentary invertebrate species in the region (Jonsen et al. 2009). The calculation of indicators was also restricted to tows with a distance between 125 m and 2,000 m, tow times greater than 3 minutes, and tows with greater than 0 kg catch to remove failed or short tows. These limitations reduce the total records by only 5%.

SWNB data exploration revealed issues with the quality and consistency of the information recorded on commercial log sheets, as well as differences in the efficiency of the two licence holders' fishing practices. Both licences changed hands in 2012 and one fisher experienced a steep learning curve fishing in an unfamiliar area with strong tides and currents. Only one licence holder had a complete time series of fishing data, while the other is missing two years of data (2012 and 2014). The two licence holders had consistently different catch rates and precision in recording tow times and distances (Figure 13, Figure 14). This made it difficult to average the records for the two licence holders for missing years. As a result, catch rate indicators for SWNB Zone 1 were based on records from only one licence holder. The data from this license holder was deemed most suitable for the calculation of catch rates because their records showed a good relationship between distance recorded on log sheets and calculated distance from start and end positions (Figure 15).

In SWNB, one licence holder has been increasing tow times and distances since 2014 (Figure 14). Although distance is accounted for in the catch rate indicators, gear saturation (artificially decreasing catch rates as the gear fills and can no longer retain more catch on longer tows) or small aggregated beds exist in the area fished might be occurring. Gear saturation is difficult to test in this fishery, as log sheets do not include information at the individual tow level. A cursory investigation into gear saturation compared catch rates for tows from 3–20 minutes to tows between 3–10 minutes (i.e., removing tows > 10 min). When longer tows were excluded, both catch-rate-based indicators (kg/m$^2$ and kg/hr*m) increased, suggesting that longer tows are not necessarily catching more Sea Cucumbers and that gear saturation may be occurring (Figure 16). To investigate sources of uncertainty, such as gear saturation or depletion, more thoroughly, it is recommended that the SWNB Sea Cucumber industry start recording catch details by set and provide precise fishing locations.

Caution is warranted when using catch-rate-based indicators due to the possibility that catch rates may remain stable as the population declines (i.e., hyperstability, Orensanz et al. 1998). This phenomenon could arise for a variety of reasons associated with Sea Cucumber fishing. In SWNB, if there is a spatial contraction of the stock to its preferred habitat; due to a lack of data from other habitats, it is not possible to determine if the Sea Cucumbers' current habitat is preferred. New research or the application of more efficient technology, including further use of cameras and multi-beams to find aggregations of Sea Cucumbers, could artificially stabilize indicators. In NAFO Divisions 4W and 4Vs, hyperstability could occur if fishers move to ‘virgin’ or healthy patches, artificially stabilizing the indicators.

To examine whether rotating to new fishing zones or AOAs is causing the catch rates to artificially stabilize, indicators were calculated for sub-fishing areas in NAFO Divisions 4W and 4Vs. Annual mean catch rates were calculated for each sub-fishing area with at least five records. In most cases (4Vs AOA 2 and 4W Offshore Zones 1 and 2), moving to a new area did not significantly influence catch rates (Figure 17, Figure 18, Figure 19), and therefore catch rate indicators may be representative of stock status trends for the whole fishing area. However, after six years, moving to a new area in 4W Mid-shore Zone F, 5–6 miles from the original fishing location caused higher catch rates (Figure 20). This difference in catch rates may warrant future independent monitoring of sub-areas, to ensure indicators are representative of the area fished.

Round and split weights have been collected in all areas but starting in different years (Table 3, Table 4), and provide a size-based indicator of stock status. Split weight is the weight of individuals that are drained of water, with the viscera (guts) removed and the head/flower intact. Split weight is considered a more reliable size-based indicator than round weight, as it removes some variability associated with water retention in the body walls. The number of samples collected for weighing in each fishing area have differed over time, as have the sampling protocols. The sampling protocol was updated in January 2019 and standardized across all fishing areas (Appendix I). Processing facilities are now expected to sample 100 individuals for round and split weight from each trip in all areas. Fishers are encouraged to set aside samples from each area if more than one area (Zone, AOA, or area within these) is fished during a trip to allow the calculation of zone specific indicators. Size-sorting of harvested Sea Cucumbers may occur prior to sample selection in the totes during transport to processing facilities, creating a size-related bias. Increasing the sample size to 100 individuals per trip attempts to rectify this sampling bias. Seasonal trends in split weight may be present in the Mid-shore and Offshore areas, and should be investigated further.

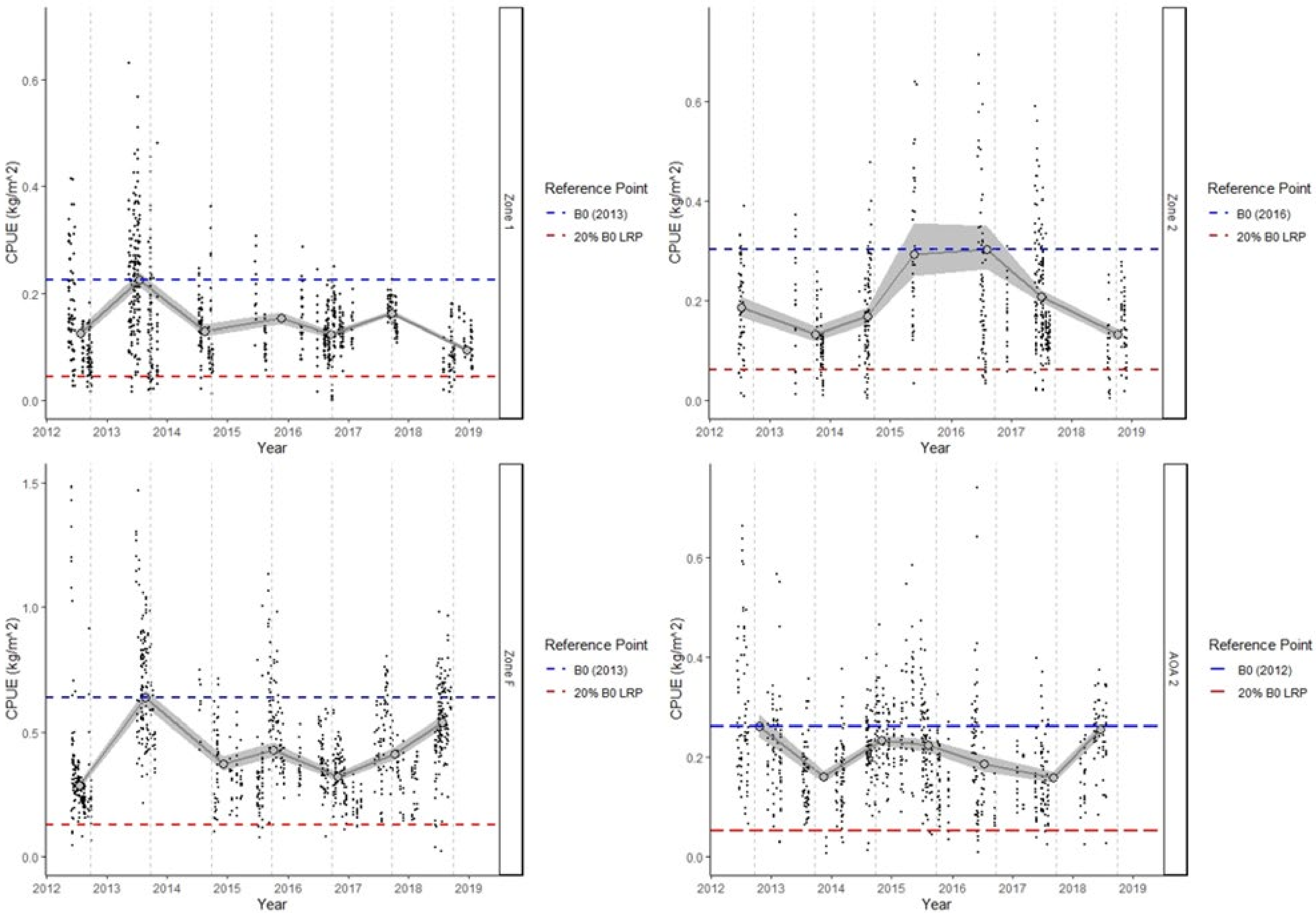


*Figure 10. Catch rates (kg/m$^2$) of Sea Cucumber in 4W Zone 1 (top left), 4W Zone 2 (top right), 4W Mid-shore Zone F (bottom left), and 4Vs AOA 2 (bottom right) from fisheries logbook data. Small black dots are daily catch rates, and the larger grey dots represent yearly mean catch rates. The shaded gray area represents the 95% confidence intervals. The blue lines represent $B_0$ (virgin biomass) based on the highest catch rate for the respective time series, while the red lines represent the Limit Reference Point of 20% of $B_0$. Please note that the CPUE scale for area Zone F is different.*

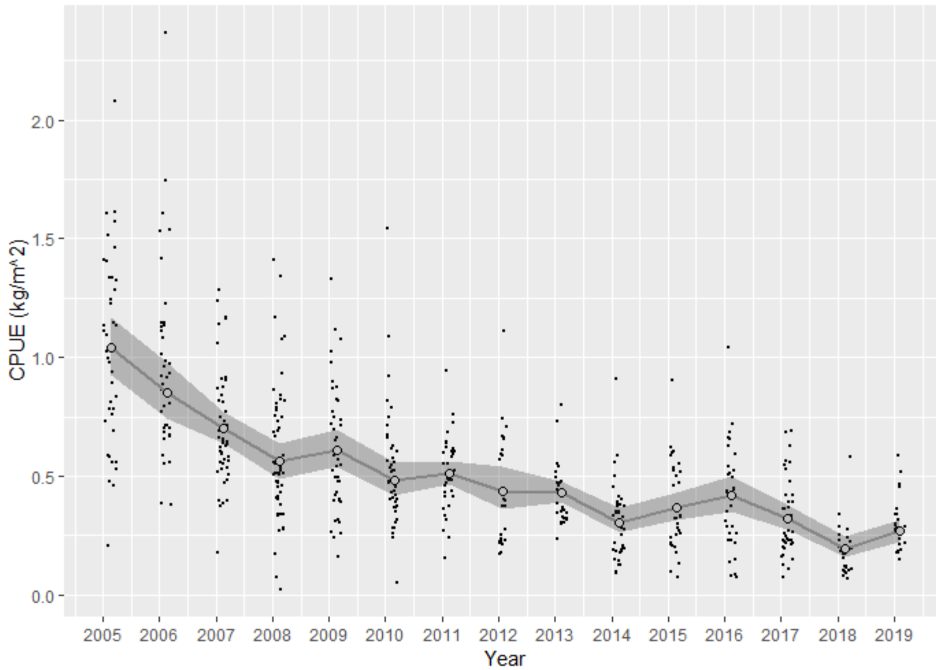


*Figure 11. Sea Cucumber catch rates (kg/m²) in Zone 1 of Southwest New Brunswick from fisheries logbook data. Small black dots are daily catch rates, and the larger grey dots represent annual mean catch rates. The shaded gray area represents the 95% confidence interval.*

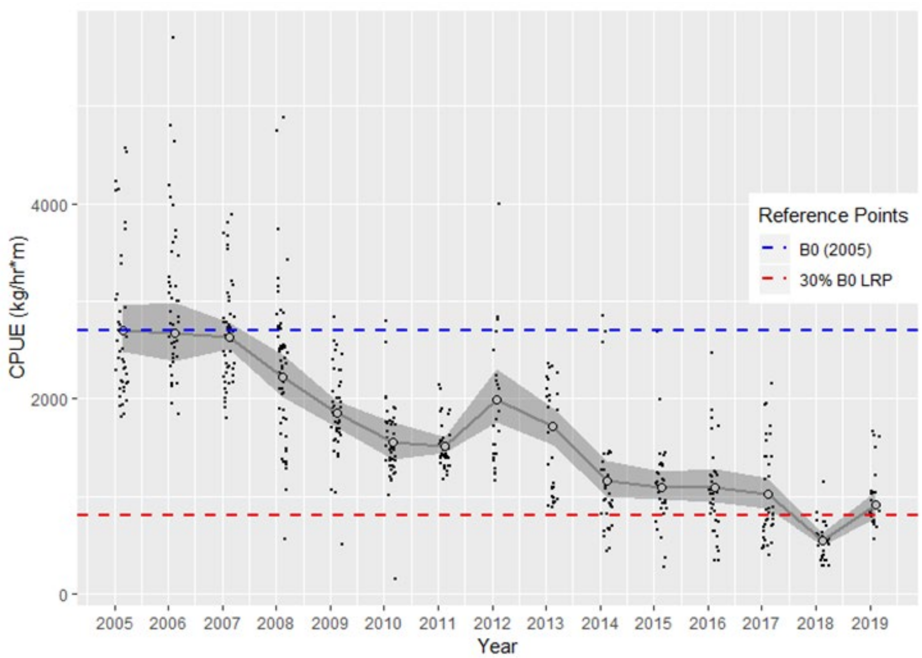


*Figure 12. Sea Cucumber catch rates (kg/hr*m) for Southwest New Brunswick Zone 1 from fisheries logbook data. Small black dots are daily catch rates, and the larger grey dots represent yearly mean catch rates. The shaded gray area represents the 95% confidence intervals. The blue line represents $B_0$ proxy (virgin biomass) based on the 2005 catch rate value. The red line represents the Limit Reference Point of 30% of the $B_0$ proxy. The 2018 mean catch rate value is marked with an asterisk as a reminder to interpret the value with caution as unusual environmental conditions and mechanical problems with vessels affected the reliability of the 2018 mean catch rate.*

*Table 3. Average round and split weights for 4W Mid-shore, 4W Offshore Zone 1 and Zone 2, and 4Vs Offshore AOA 2. (n/a = no data available)*

| Area | Year | # of Samples | Avg. Round Weight(g) | Avg. Split Weight(g) |
|---|---|---|---|---|
| 4W Mid-shore | 2017–18 | 1,903 | 184 | 109 |
| 4W Mid-shore | 2016–17 | 1,702 | 164 | 101 |
| 4W Mid-shore | 2015–16 | 4,850 | 165 | 109 |
| 4W Mid-shore | 2014–15 | 2,174 | 202 | 102 |
| 4W Mid-shore | 2013–14 | 2,100 | 161 | 108 |
| 4W Mid-shore | 2012–13 | 299 | 191 | n/a |
| 4W Mid-shore | 2011–12 | 300 | 193 | n/a |
| 4W Mid-shore | 2010–11 | 100 | 248 | n/a |
| 4W Mid-shore | 2009–10 | 200 | 239 | n/a |
| 4W Mid-shore | 2008–09 | 160 | 351 | n/a |
| 4W Offshore Zone 1 | 2017–18 | 700 | 207 | 127 |
| 4W Offshore Zone 1 | 2016–17 | 1,310 | 214 | 126 |
| 4W Offshore Zone 1 | 2015–16 | 651 | 279 | 158 |
| 4W Offshore Zone 1 | 2014–15 | 700 | 182 | 120 |
| 4W Offshore Zone 1 | 2013–14 | 1,625 | 236 | 135 |
| 4W Offshore Zone 1 | 2012–13 | 199 | 247 | 217 |
| 4W Offshore Zone 1 | 2011–12 | 120 | 198 | 136 |
| 4W Offshore Zone 1 | 2010–11 | 120 | 284 | n/a |
| 4W Offshore Zone 1 | 2009–10 | 200 | 303 | n/a |
| 4W Offshore Zone 1 | 2008–09 | 120 | 399 | n/a |
| 4W Offshore Zone 2 | 2017–18 | 1,000 | 248 | 153 |
| 4W Offshore Zone 1 | 2016–17 | 700 | 221 | 139 |
| 4W Offshore Zone 1 | 2015–16 | 849 | 316 | 161 |
| 4W Offshore Zone 1 | 2014–15 | 1,000 | 225 | 155 |
| 4W Offshore Zone 1 | 2013–14 | 300 | 244 | 143 |
| 4W Offshore Zone 1 | 2012–13 | 120 | 221 | 203 |
| 4W Offshore Zone 1 | 2011–12 | 60 | 212 | n/a |
| 4Vs Offshore | 2017–18 | 1,600 | n/a | 357 |
| 4Vs Offshore | 2016–17 | 1,800 | n/a | 262 |
| 4Vs Offshore | 2015–16 | 380 | n/a | 357 |
| 4Vs Offshore | 2014–15 | 320 | n/a | 342 |
| 4Vs Offshore | 2013–14 | 400 | n/a | 349 |
| 4Vs Offshore | 2012–13 | 140 | n/a | 344 |
| 4Vs Offshore | 2011–12 | 220 | n/a | 344 |
| 4Vs Offshore | 2009–10 | n/a | n/a | 156 |
| 4Vs Offshore | 2008–09 | n/a | n/a | 279 |

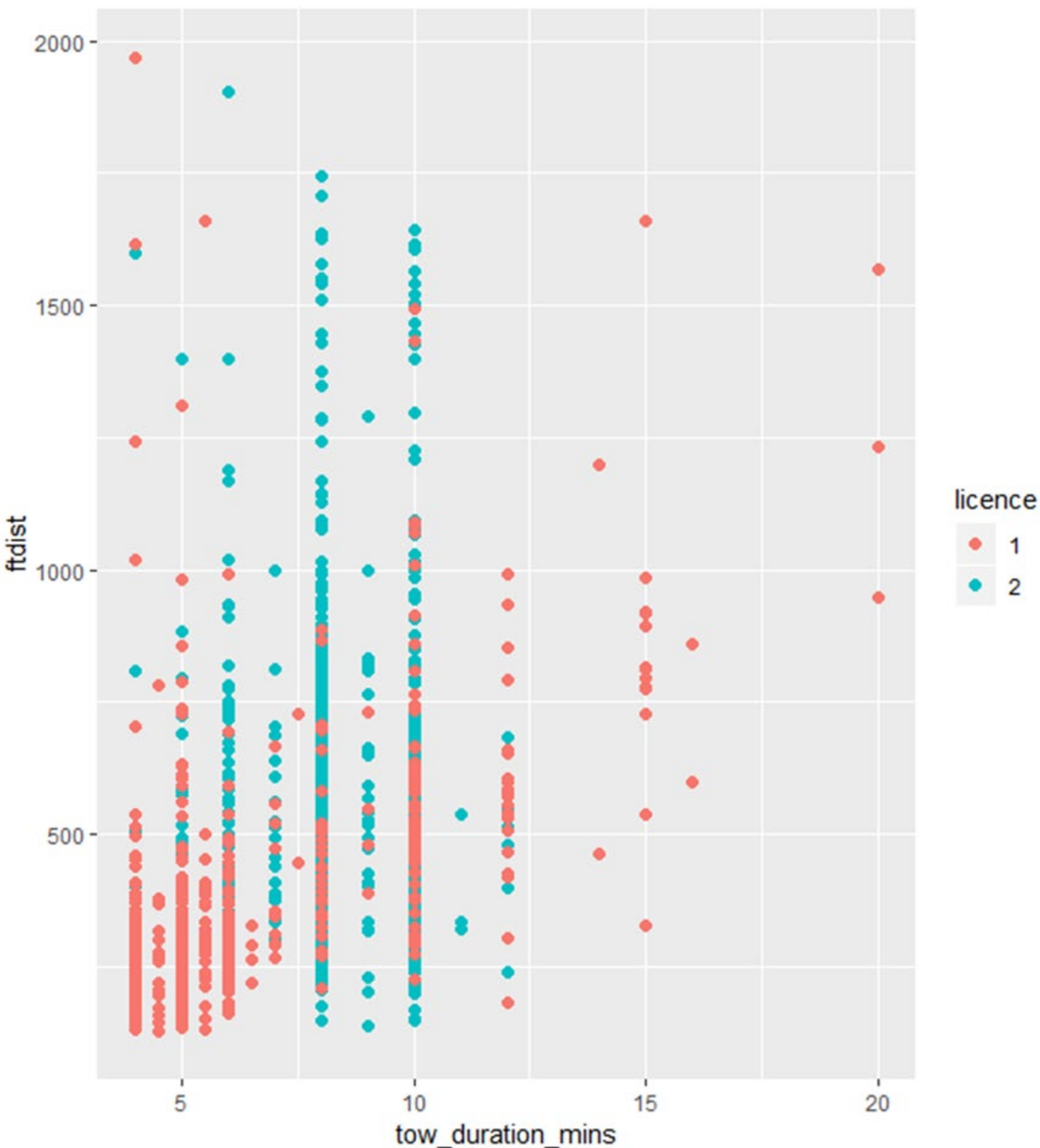


*Figure 13. Sea Cucumber tow distances (m) by tow duration (min) for each SWNB Sea Cucumber licence holder.*


*Figure 14. Tow distances (m) (left) and tow durations (min) (right) by year for each SWNB Sea Cucumber licence holder. Circles represent annual means for each licence holder.*


*Figure 15. Tow distances recorded by vessel captains (tow_dist_nm) compared to distance calculated from start and end coordinates (tdis_ll_m) for each SWNB Sea Cucumber licence holder.*

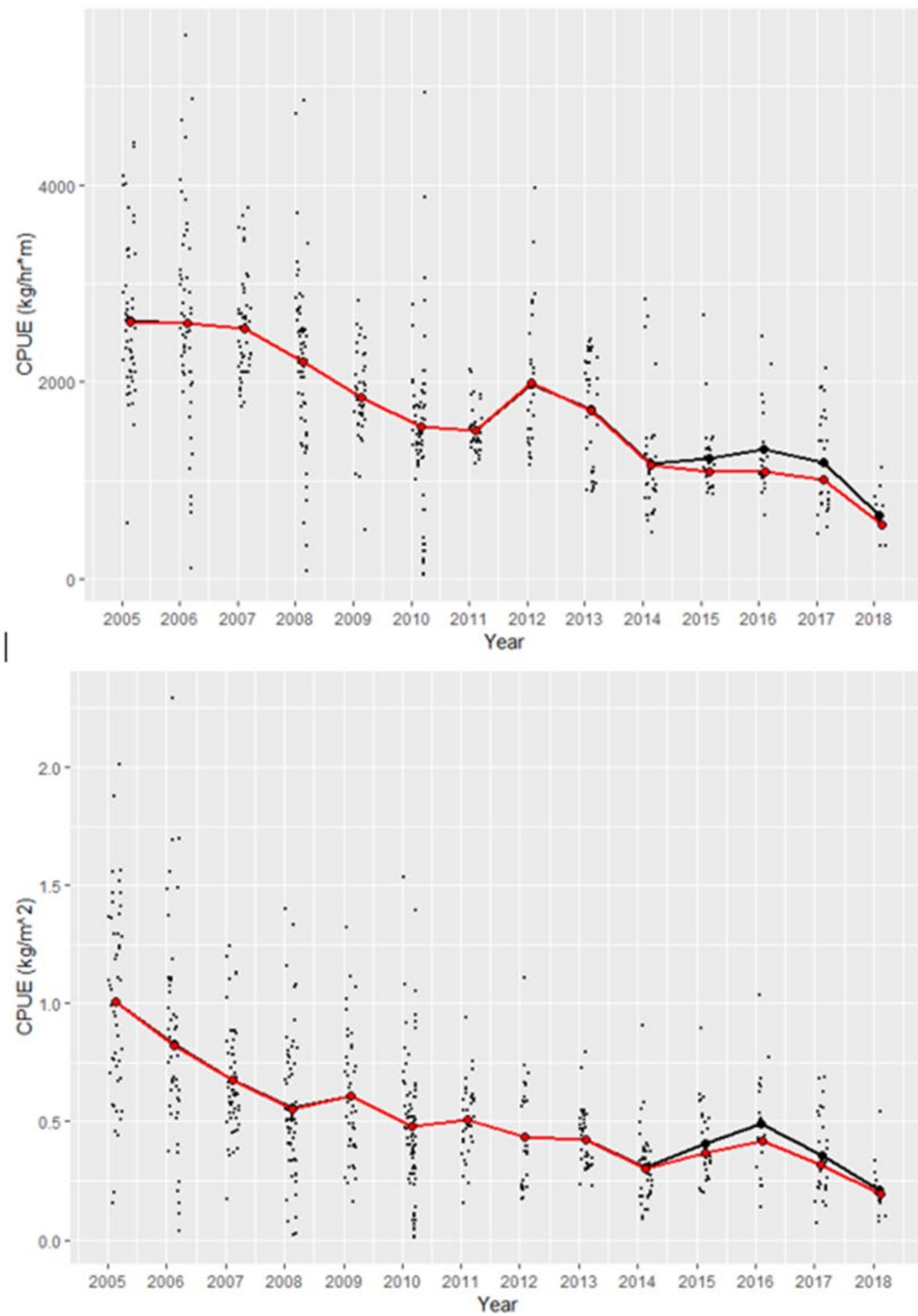


*Figure 16. Catch rates of Sea Cucumbers from SWNB Zone 1 for tows 3–20 minutes (red) and 3–10 minutes (black) for CPUE indicators kg/hr*m (top) and kg/m$^2$ (bottom).*

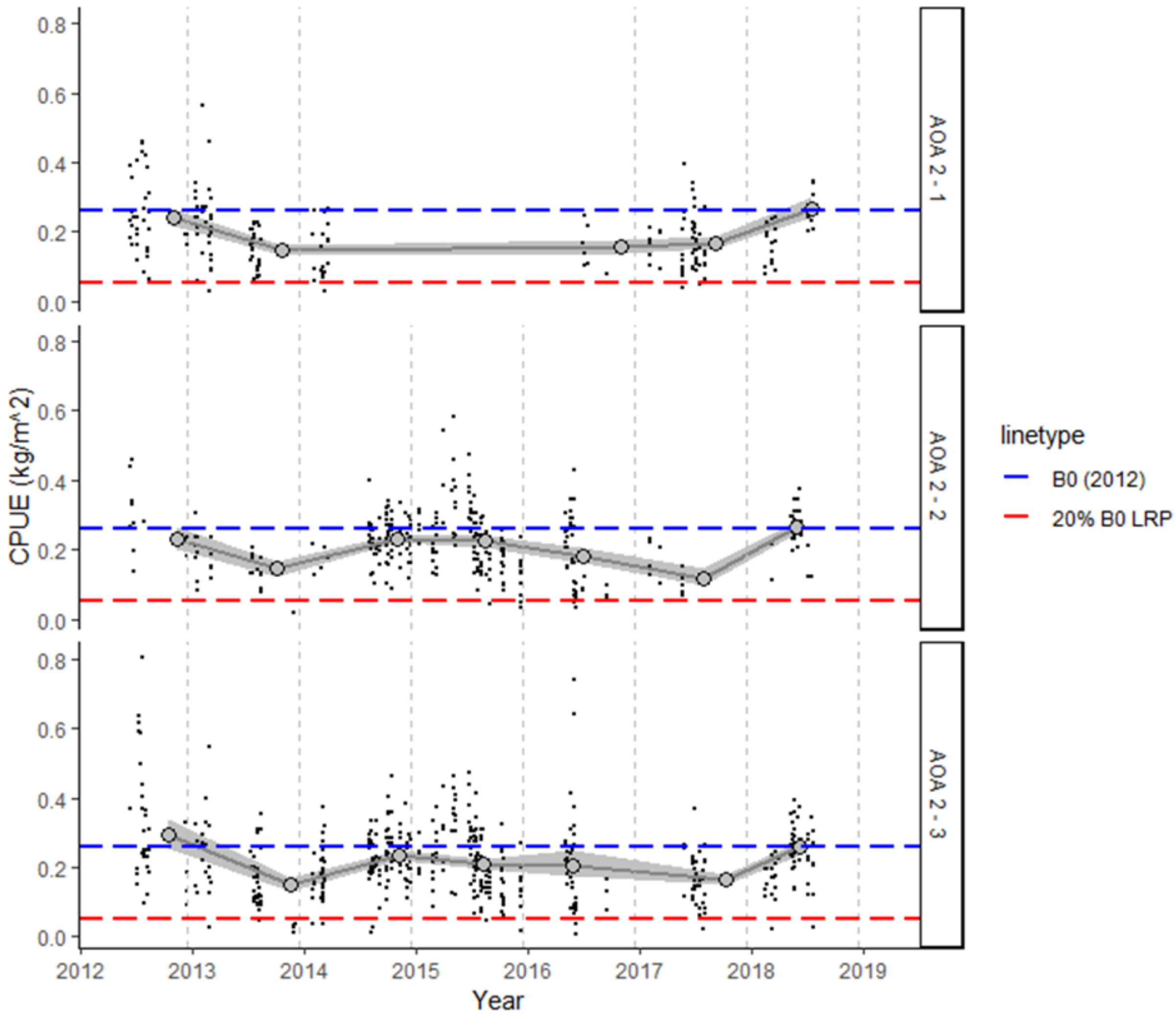


*Figure 17. The 2012–2018 catch rates (kg/m$^2$) of Sea Cucumber in sub-areas of 4Vs AOA 2 from fisheries logbook data. Small black dots are daily catch rates, and the larger grey dots represent yearly mean catch rates. The red line represents the Limit Reference Point of 20% of $B_0$ (virgin biomass), while the blue line represents the $B_0$ proxy. Grey vertical lines represent the start of fishing year.*

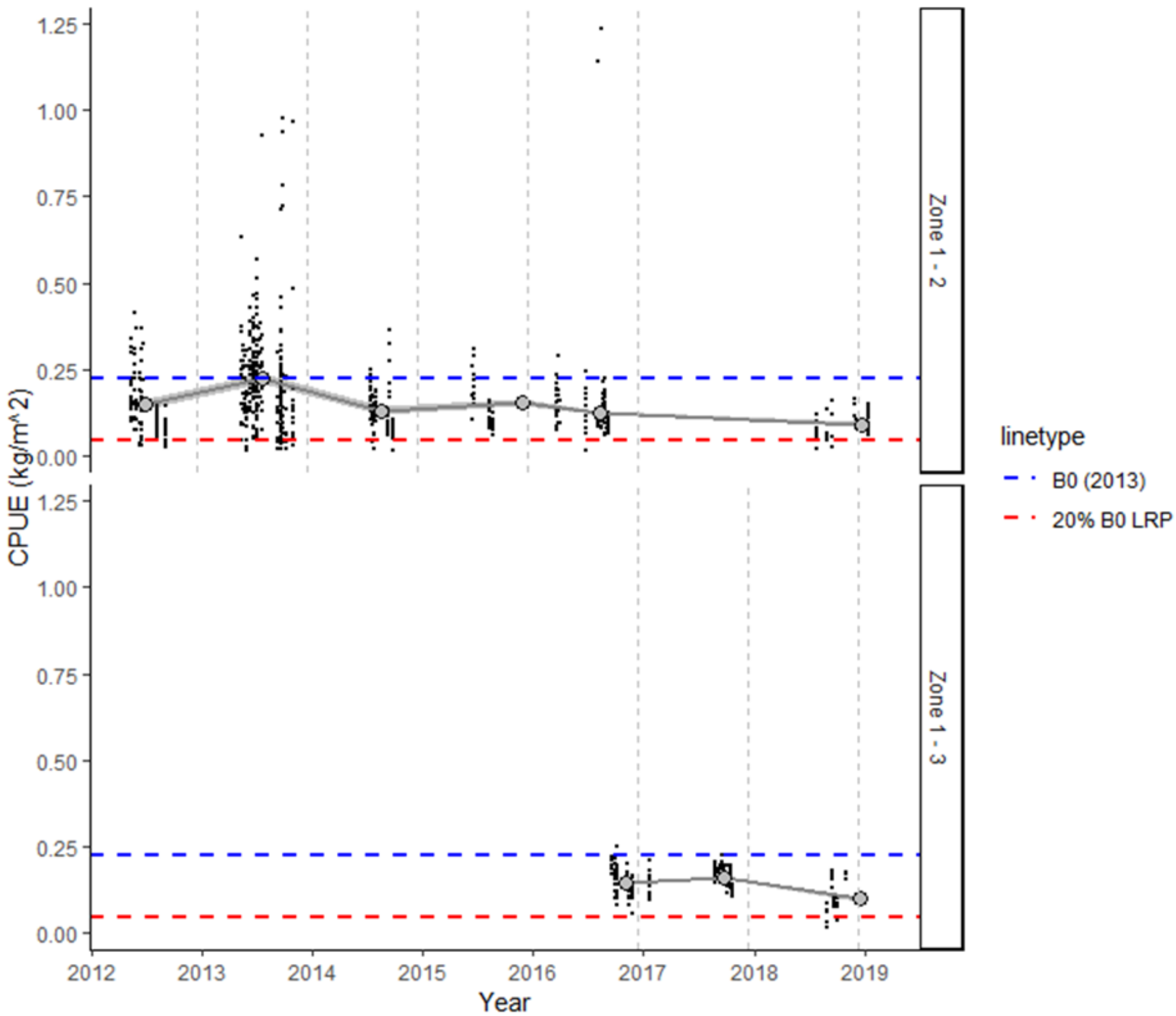


*Figure 18. The 2012–2018 catch rates (kg/m²) of Sea Cucumber in sub-areas of 4W Offshore Zone 1 from fisheries logbook data. Small black dots are daily catch rates, and the larger grey dots represent yearly mean catch rates. The red line represents the Limit Reference Point of 20% of B0 (virgin biomass), while the blue line represents the B0 proxy. Grey vertical lines represent the start of fishing year.*

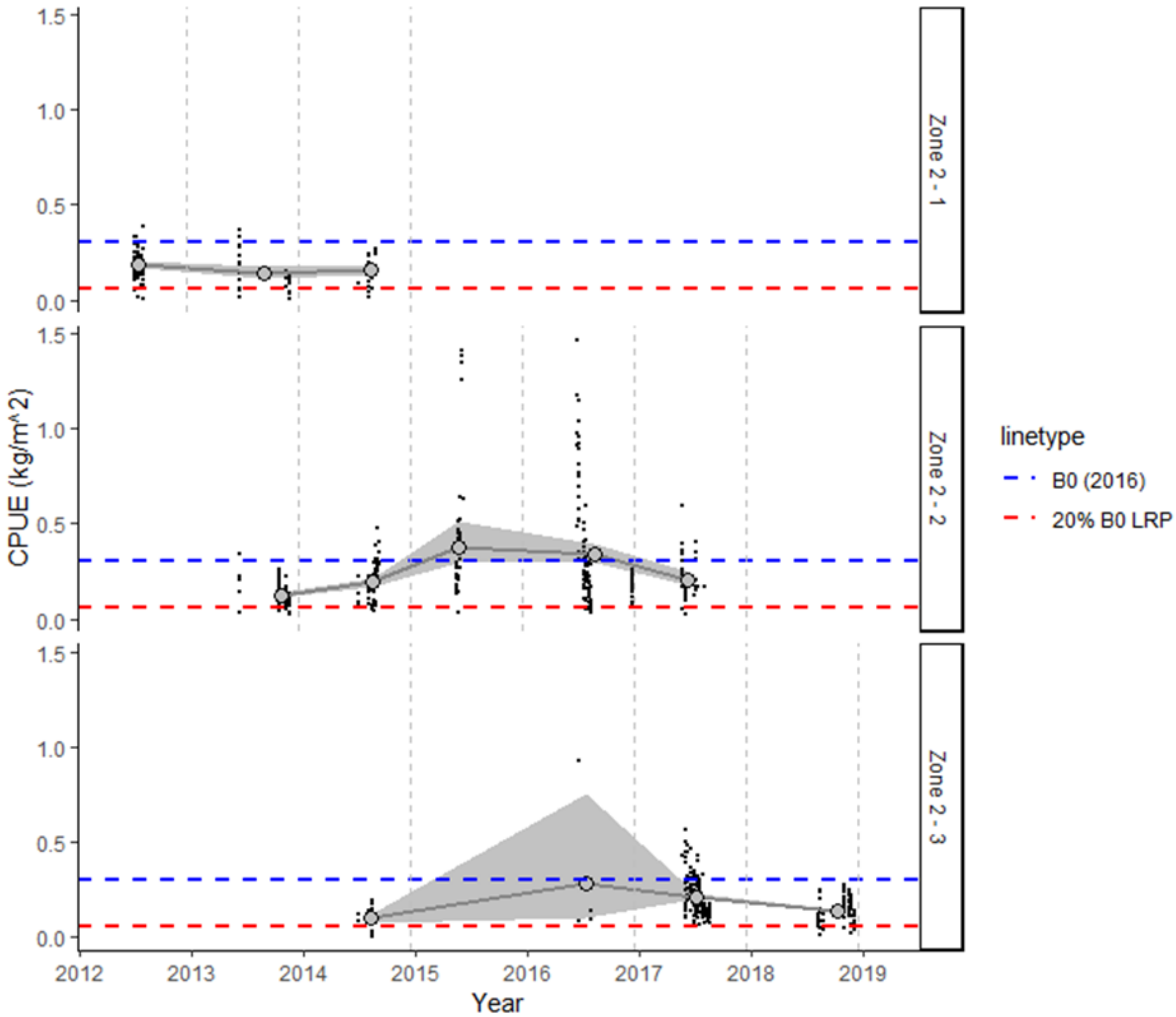


*Figure 19. The 2012–2018 catch rates (kg/m²) of Sea Cucumber in sub-areas of 4W Offshore Zone 2 from fisheries logbook data. Small black dots are daily catch rates, and the larger grey dots represent yearly mean catch rates. The red line represents the Limit Reference Point of 20% of $B_0$ (virgin biomass), while the blue line represents the $B_0$ proxy. Grey vertical lines represent the start of fishing year.*

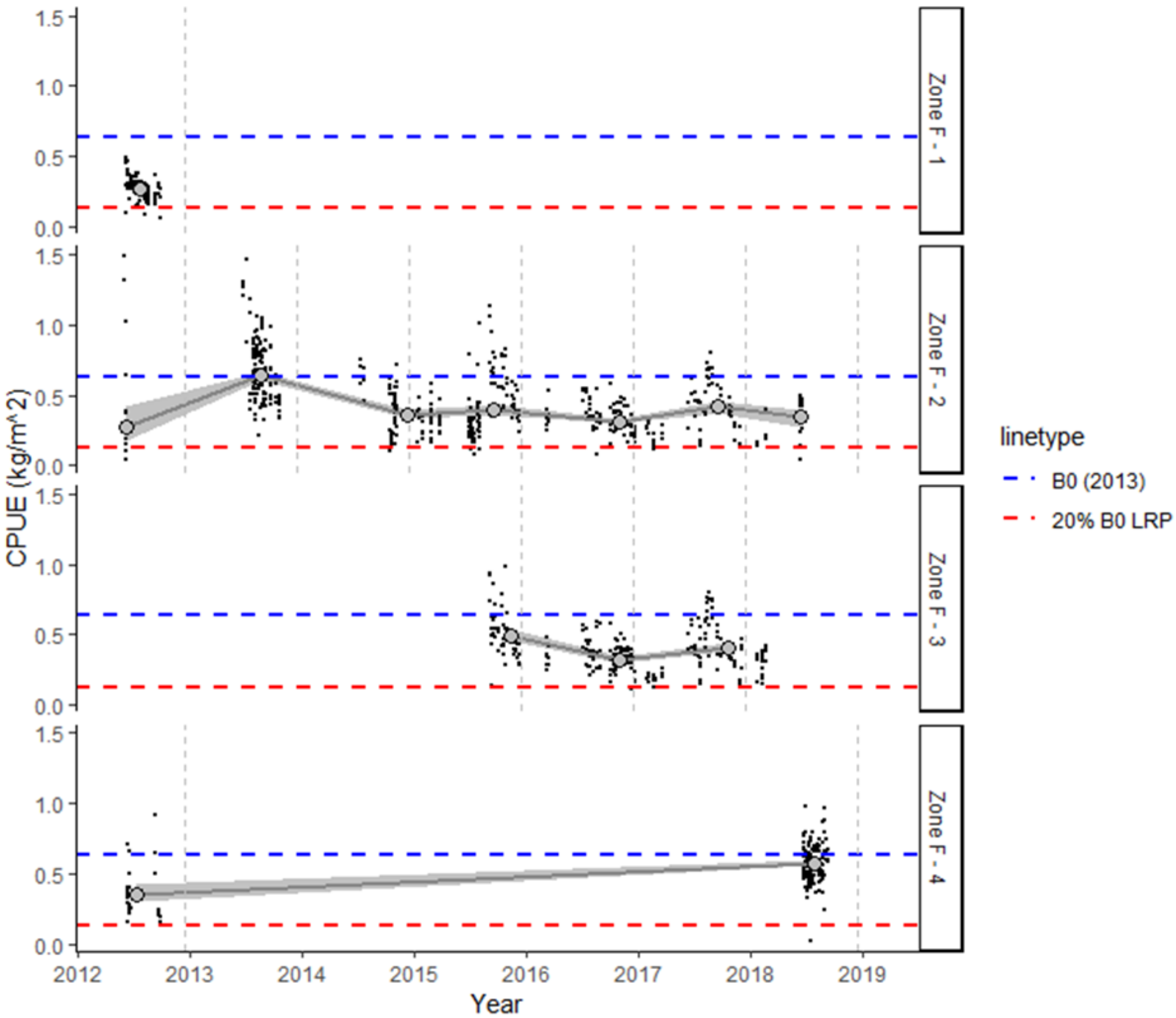


*Figure 20. The 2012–2018 catch rates (kg/m$^2$) of Sea Cucumber in sub-areas of 4W Mid-shore Zone F from fisheries logbook data. Small black dots are daily catch rates, and the larger grey dots represent yearly mean catch rates. The red line represents the Limit Reference Point of 20% of $B_0$ (virgin biomass), while the blue line represents the $B_0$ proxy. Grey vertical lines represent the start of fishing year.*

## REFERENCE POINTS

While the preferred approach to develop reference points and harvest control rules would use detailed information on stock biology and fishery characteristics, methods available to set reference points for the Maritimes Region Sea Cucumber fisheries are limited because there are no current estimates for abundance, recruitment, or growth. Only simplistic approaches to reference points that have been used for data-limited stocks with life history characteristics similar to those of Sea Cucumber are available. This includes approaches used for species with a larval dispersal phase and adults that are broadcast spawners, like other Sea Cucumbers, sea urchin and scallop.

Limit Reference Points (LRPs) were established for each Sea Cucumber fishing area in the Maritimes Region that is regularly fished, including 4W Offshore Zones 1 and 2, 4W Mid-shore Zone F, 4Vs AOA 2 (Figure 10), and SWNB Zone 1 (Figure 12). For each fishing area, the highest mean catch rate in the time series was used as a proxy for $B_0$ and the basis for setting

LRPs. The highest mean catch rate in the time series was used as the proxy for $B_0$, rather than the catch rate from the first year of fishing, based on the assumption that the catch rates in the early exploratory years of the fishery are not a true representation of potential catch rates.

The approach to setting LRPs in the Mid-shore and Offshore fishing areas was consistent. The LRPs were set as 20% of the $B_0$ proxy based on the kg/m$^2$ indicator. This is expected to be precautionary, corresponding to 50% $B_{MSY}$ (Hilborn and Stokes 2010). The basis for establishing 20% of $B_0$ was reached by defining $B_{MSY}$ as 40% of $B_0$, a generally accepted 'default' proxy for $B_{MSY}$ (Hilborn and Stokes 2010), and setting the LRP as 50% of $B_{MSY}$. Reference points for each zone are as follows:

- 4W Offshore Zone 1 - 0.045 kg/m$^2$
- 4W Offshore Zone 2 - 0.061 kg/m$^2$
- 4W Mid-shore Zone F - 0.127 kg/m$^2$
- 4Vs AOA2 - 0.052 kg/m$^2$

For SWNB Zone 1, the LRP was based on kg/hr*m. The highest catch rate in the time series was again used as the proxy for $B_0$ and the LRP was set at 30% of $B_0$ (811.53 kg/hr*m) (Figure 12). This is precautionary compared to the other Sea Cucumber fishing areas in the Maritimes Region, as catch rates and size-based indicators in SWNB have consistently declined over 15 years. There is also risk associated with fishing all known available Sea Cucumber habitat in SWNB.

Globally, 20% of $B_0$ has been commonly applied as an LRP in fisheries management for sea cucumber fisheries (Hart et al. 2018), however, some have suggested caution using this approach, as inaccuracies in estimating $B_0$ driven by the assumption of stationarity (i.e., no density-dependent processes) has resulted in critical thresholds set below the range of observations (Hilborn and Stokes 2010). Sea Cucumber populations in the Maritimes Region are likely density-dependent, however, an LRP of 20% $B_0$ was considered appropriate for the Mid-shore and Offshore fishing areas because: i) the catch rate indicators have been stable over their respective time series, ii) spatial reserves are currently in place for 4Vs Offshore with the option for licence holders to establish reserves in the other Mid-shore and Offshore fishing areas, and iii) fishers have the voluntary option to move fishing effort to other zones within their management area. In SWNB, indicators have been declining since the beginning of the time series and fishing is concentrated in Zone 1, with limited available habitat outside of Zone 1, therefore, a more precautionary LRP was set for SWNB Zone 1 at 30% of the $B_0$ proxy.

# ASSESSMENT OF SWNB SEA CUCUMBER

## DENSITY INDICATORS

In the SWNB Sea Cucumber fishery, there has been a decline in catch rates over the past 15 years (Figure 11, Figure 12). The decline in the kg/hr*m indicator from 2005–2019 was 66% (Figure 12), while the decline in kg/m$^2$ was 73% (Figure 11). It should be noted that catch rate indicators for the 2018 fishing season are considered unreliable, as unusual environmental conditions and mechanical problems with vessels affected fishing, and ultimately, catch rates. The catch rate based indicator is currently near the LRP and in the cautious zone. Focus should be on rebuilding the population.

## BODY WEIGHT INDICATORS

Indicators based on size including average split weight and round weight, have been declining since the time series began (Table 4; Figure 21). When the fishery began, round weight was recorded. Round weight is a problematic indicator as Sea Cucumbers' can absorb and dispel water, however, average round weight has declined 35% since the beginning of the time series in 2004 (Table 4). Split weight is considered a better indicator than round weight because it removed the problem of water retention; it has declined 25% since it began to be recorded in 2012 (Table 4). Annual split weight frequencies show a similar decline in the proportion of larger Sea Cucumbers and potential size class truncation (Figure 21).

Split weight frequencies may provide a means of detecting recruitment events, indicated by an increased proportion of smaller individuals in the catch, and allow for the estimation of recruitment rates. Determining rates of recruitment, would improve the target reference points for the SWNB catch rate indicators. However, a better understanding of growth rates, size and age at maturity, and stock structure is also necessary to reliably estimate recruitment rates.

*Table 4. Annual round weight and split weight averages of port sampled Sea Cucumber from Southwest New Brunswick for each licence holder. (n/a = no data available)*

| Licence | Year | # Samples | Avg. Round Weight(g) | Avg. Split Weight(g) | SE Split Weight(g) |
|---|---|---|---|---|---|
| 1 | 2019 | 2,522 | 166.6 | 132.8 | 0.77 |
| 1 | 2018 | 750 | 187.4 | 145 | 1.74 |
| 1 | 2017 | 660 | 183.4 | 142.5 | 1.48 |
| 1 | 2016 | 619 | 195.6 | 154.3 | 1.72 |
| 1 | 2015 | 619 | 201.5 | 163.4 | 2.23 |
| 1 | 2014 | 660 | 210.8 | 175.2 | 1.71 |
| 1 | 2013 | 660 | 216 | 173.9 | 1.77 |
| 1 | 2012 | 760 | 228.7 | 178.2 | 1.83 |
| 1 | 2011 | 640 | 207.9 | n/a | n/a |
| 1 | 2010 | 600 | 219.2 | n/a | n/a |
| 1 | 2009 | n/a | n/a | n/a | n/a |
| 1 | 2008 | 1,660 | 225.2 | n/a | n/a |
| 1 | 2007 | 1,140 | 236.2 | n/a | n/a |
| 1 | 2006 | 1,420 | 208.3 | n/a | n/a |
| 1 | 2005 | 1,699 | 235.6 | n/a | n/a |
| 1 | 2004 | 1,040 | 255.6 | n/a | n/a |
| 2 | 2018 | 2,600 | 154.8 | 124.8 | n/a |
| 2 | 2017 | 5,695 | 201.1 | 117 | n/a |
| 2 | 2016 | 140 | 172.8 | n/a | n/a |
| 2 | 2010 | 840 | 242 | n/a | n/a |
| 2 | 2009 | 660 | 202.6 | n/a | n/a |
| 2 | 2008 | 700 | 220.8 | n/a | n/a |
| 2 | 2007 | 496 | 243.1 | n/a | n/a |

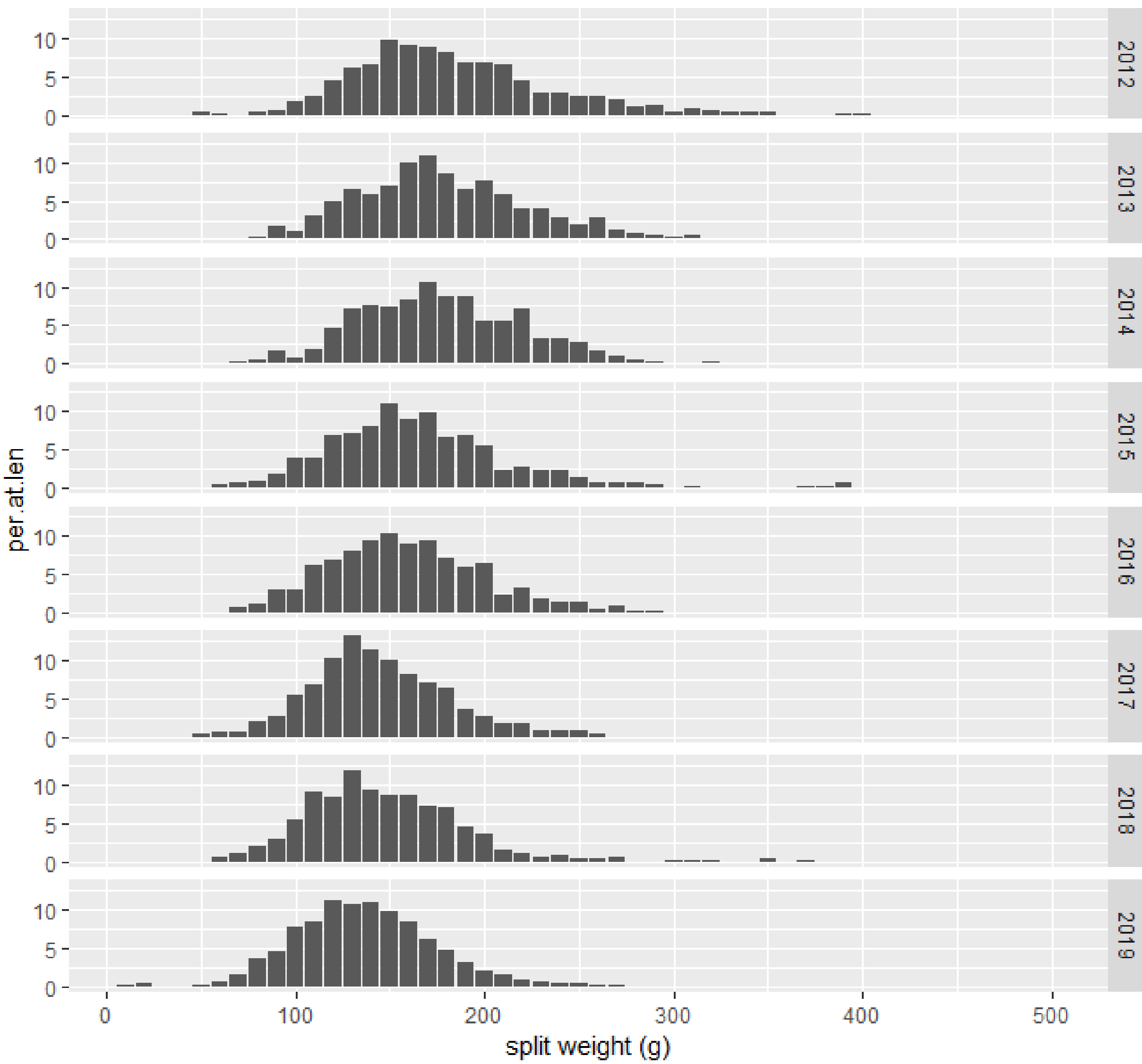


*Figure 21. Annual split weight frequency histograms of port sampled Sea Cucumber from Southwest New Brunswick Zone 1.*

## RESPONSE

Science advice was requested by Resource Management (November 2017) on the following questions regarding the status of the southwest New Brunswick (SWNB) Sea Cucumbers.

1. *What is the status of the SWNB Sea Cucumber population?*

The status of the SWNB Sea Cucumber population is unknown. There are challenges assessing and managing a Sea Cucumber fishery due to a lack of life-history data and gaps in the knowledge of the species' biology and ecology. There is no practical methodology for ageing the animals, which limits the use of models based on life-history. Rates of recruitment, growth, and mortality are also unknown. Due to their ability to change their body dimensions, by absorbing or expelling water and contracting muscles in their body walls, Sea Cucumbers are difficult to measure and weigh.

Catch rates and body weights have declined in SWNB Zone 1 since the start of the fishery. The density-based catch rate indicator, kg/hr*m, is near the LRP and in the cautious zone. Split weight has also been in decline since it started being recorded in 2012.

2. *What impact has the SWNB Sea Cucumber fishery had on the population?*

The fishery does not currently provide the necessary information for a detailed assessment and evaluation of the fishery's impacts on the SWNB Sea Cucumber stock. Despite the lack of data, the SWNB Sea Cucumber fishery has likely had an impact on the population in Zone 1, as catch rates and body weights have declined since the fishery began. Moreover, the impact could be worse than calculated due to hyperstability in the indicators, commonly associated with species that aggregate. The SWNB Sea Cucumber population is likely highly aggregated based on previous surveys and fishing patterns (Rowe et al. 2009).

Collection of better monitoring data would provide a necessary link between the catch rate data and the population in SWNB. Currently, there are no surveys available in the Maritimes Region that adequately sample Sea Cucumbers. Therefore, any assessment must be based on fishery-dependent data, such as catch rates, which can generate biased indicators of stock abundance. Camera surveys have been completed by industry in the 4W offshore area between 2015 and 2019 and are being further explored as a fishery-independent data source to estimate annual biomass. Indicators based on catch rates and split weights remain important until there is an adequate time series of fishery independent monitoring information.

3. *What are the risks to the SWNB Sea Cucumber fishery if fishing were to continue under existing management strategies?*

The risks to the SWNB Sea Cucumber fishery are unknown if it were to continue operating under existing management strategies. Management measures were updated recently, in response to declining indicators: Zone 1 TAC was reduced from 1,010 t to 500 t for the 2019 fishing season. Despite this TAC reduction, Sea Cucumbers are likely a density dependent species for whom the point at which serious and irreversible harm to the stock is difficult to calculate. As a result, their population recovery may be limited.

4. *If stock status has declined, what level of fishing in the near term would not cause further decline in stock status and that would allow for recovery within a reasonable timeframe?*

The SWNB Sea Cucumber fishery has persisted for 16 years, outlasting many other Sea Cucumber fisheries globally (Anderson et al. 2011, Feindel 2002, Toral-Granda 2005), but the levels of fishing that would not cause a further decline in stock status and allow for recovery within a reasonable time frame is highly uncertain. In general, life-history traits of holothurians, make them vulnerable to overfishing. They can have low or infrequent recruitment, high longevity, and density-dependent reproductive success. Globally, populations of Sea Cucumbers are slow to recover from moderate to high rates of exploitation even with widely dispersing larvae (Uthick 2004, Uthick et al. 2004). This provides evidence that Sea Cucumbers are a depensatory mortality species, meaning that reproductive success and recovery are far less effective when population density decreases (Uthicke et al. 2009). The reason for the slow recovery rates in Sea Cucumbers is unknown, but there are several processes that could contribute to depensation in stock production including competitive exclusion, low reproductive success, increased predation mortality at low stock size, and reduction of intraspecific diversity. To sustain these fisheries in the long-term, the fundamental goal should be to implement precautionary management (Shepherd et al. 2004).

## GUIDANCE FOR ESTABLISHING RESERVES

As described in the biological overview, *C. frondosa* exhibits life history traits that make it susceptible to over-exploitation, when there is not careful monitoring in place. These traits include late age at maturity, slow growth, suspected low recruitment rates, unknown spatial structure, and a largely sedentary nature. Globally, this has resulted in a large number of sea cucumber stocks experiencing rapid population decline (Purcell 2010). Data limitations and an inability to establish growth rates for *C. frondosa* make it difficult to assess using traditional approaches that establish targets based on Maximum Sustainable Yield (MSY). To limit the risk of overexploitation in many similar species, assessment and management practices have acknowledged a patchy, heterogeneous spatial distribution (Jonsen et al. 2009, Eriksson et al. 2013, Shackell et al. 2013). Particularly in sea cucumber fisheries, rotational or permanent fishery reserves have become commonly included in adaptive management plans (Plaganyi et al. 2015, Humble et al. 2007), considering their density dependent nature which makes it difficult to recover from overexploitation.

Reserves and rotational fishing may be one of the few strategies available to ensure sufficient breeding populations of sea cucumbers are present to allow for stock replenishment. Reserves would provide a buffer against the risks of unresponsive fishery dependent catch rate based indicators and the life history traits of *C. frondosa.*

Marine reserves for sea cucumber need not be large to protect breeding populations (Sale et al. 2005). Subpopulations of sea cucumbers are likely interconnected through dispersal of larvae from spawning events, and the spatial structure of stocks tends to persist over a long time (Purcell 2010). Reserve sizes of 0.5–3 $km^2$ have been suggested (Purcell 2010), although the quality and amount of habitat set aside is possibly more important for maintaining critical spawning density (Shackell et al. 2013, Purcell 2010). Guidance about the percentage of habitat that is important for the breeding stock's protection is limited, however, 30% may be sufficient to preserve sea cucumber stocks (Purcell 2010).

Further, although rotational fishing has shown to increase yield in some sea cucumber fisheries (Purcell 2010), marine reserves have been more controversial as there has been difficulty confirming their effectiveness for improving fisheries (Hilborn et al. 2004, Sale et al. 2005). Rotational fishing, or temporary reserves combined with conservative exploitation rates, are a more common practice in sea cucumber fisheries. In these cases, areas are not fished for a period of time to allow for population growth and are then harvested at an expected sustainable exploitation rate. Rotational closure times should be tested using density information from surveys conducted during fishing and closure periods. Rotational fishing should be considered risky without reliable survey data, as the density of the recovering population should be monitored to ensure that fallow periods are appropriate. If rotational fishing were attempted without a survey, conservative closure times would need to be put in place, and catch rates would need to be monitored closely.

In the 4Vs Offshore fishing area, Sea Cucumber reserves were designated in the 2018–19 fishing season (Figure 22), in response to DFO Science's 2017–18 review of industry indicator reports from previous seasons. The review highlighted concerns with fishing activities concentrated in one small area. More recently, spatial reserves have been proposed for the 4W Offshore Sea Cucumber fishing area.

To establish the reserves in 4Vs Offshore and to provide guidance on potential reserve placement in 4W Offshore, an 'expected habitat' map of *C. frondosa* was created (Figure 22). This map presents expected habitat classes for *C. frondosa*, classifying habitat as Primary, Secondary or Tertiary, based on DFO's annual Research Vessel (RV) Ecosystem and Snow Crab surveys. These data could not be used to create an indicator of biomass trends due to the limited samples collected from each expected Sea Cucumber habitat per year, however, they have been used here to establish general areas of persistent habitat. These habitat designations assume that Sea Cucumbers are general sedentary, which has recently been questioned. The maps are very coarse, and will require validation over time with more precise survey data to ensure their accuracy. Maps were created with limited techniques (interpolation), due to difficulty identifying the environmental factors that are the most important predictors of Sea Cucumber habitat. For example, fine scale benthic habitat variables would allow for more rigorous techniques like species distribution modeling. Broad guidance was given to set aside at least 30% of expected Sea Cucumber habitat from fishing activity.

Density layers, created using density per tow location (kg/m$^2$) (Figure 23), were interpolated from each survey independently using a Kernel Density tool with 7 km (RV Survey) and 5 km (Snow Crab Survey) radii (Figure 24). To combine the layers from each survey, density layers were classified into quantiles and then categorized into 'expected habitat classes':

1. Not expected to be habitat,
2. Tertiary Habitat,
3. Secondary Habitat,
4. Primary Habitat.

The two survey density layers were then merged, taking the maximum of the two layers (Figure 25). Areas without survey locations were clipped out of the map. To clip areas out of the layer, a 5 km buffer was created around each of the RV and Snow Crab locations. The buffers were then merged (Union function in ArcGIS) and used as an 'Erase' layer (ArcGIS tool, Erase).

To achieve the 30% protection target, protection of 30% of each habitat class was expected. Although reserves could be smaller with more precise survey data, these maps are expected to have limited precision and accuracy, thus large reserves at least the same size as fishing areas in 4Vs (approximately 270 km$^2$) were suggested. As more precise survey data becomes available, these reserves could be reduced in size, as long as sufficient breeding habitat is still set aside.

At the request of the industry, fishing areas in 4Vs were changed from round to square when reserves were implemented, as square areas are easier to visualize while at sea. Other requirements of reserves were to:

- avoid Ecologically and Biologically Significant Areas,
- survey the reserve sites with camera or trawl to ground truth areas and verify that they would be considered Primary, Secondary or Tertiary 'expected *C. frondosa* habitat'

The expected habitat map should be updated, and reserves validated, as more information becomes available.

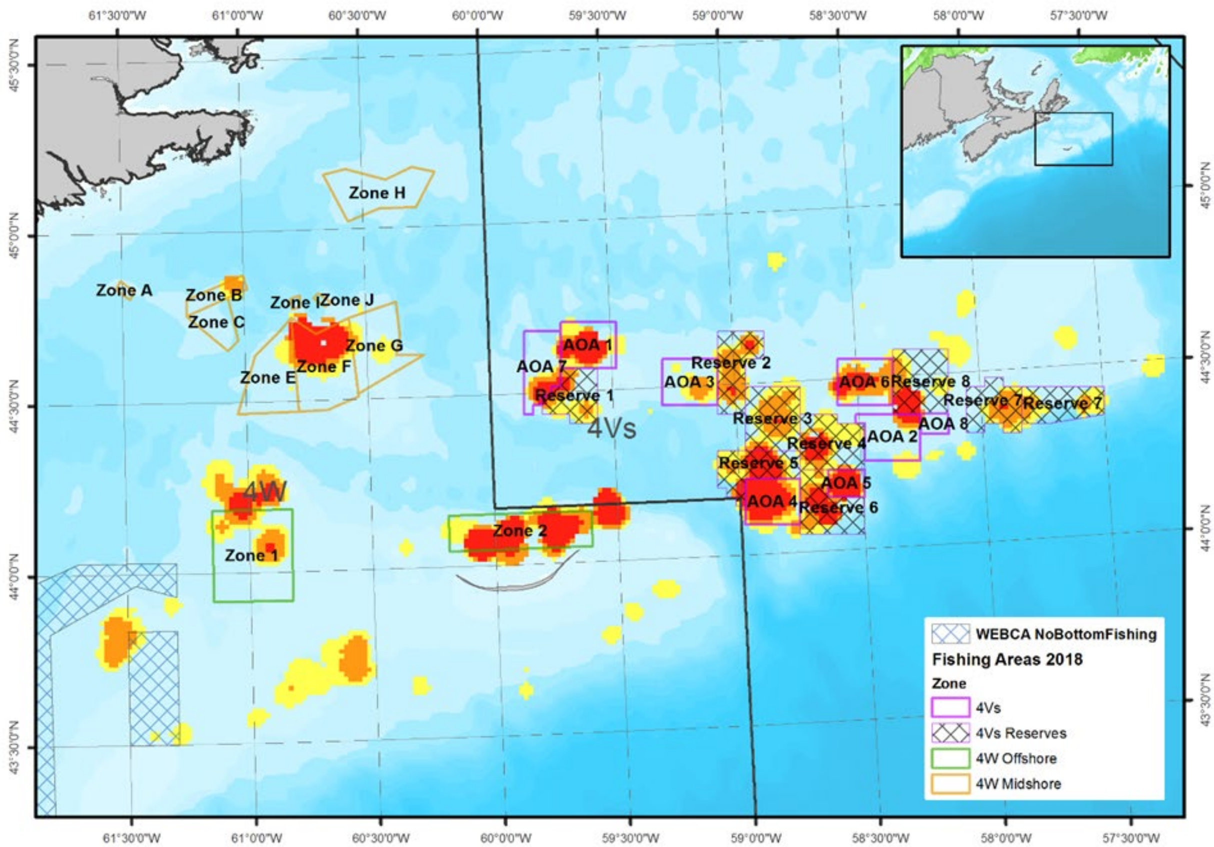


*Figure 22. The current distribution of Sea Cucumber fishing Zones, Areas of Access (AOA) and reserves in NAFO Divisions 4W and 4Vs, overlayed onto the the final expected C. fondosa habitat map, classified into Primary, Secondary and Tertiary habitats.*

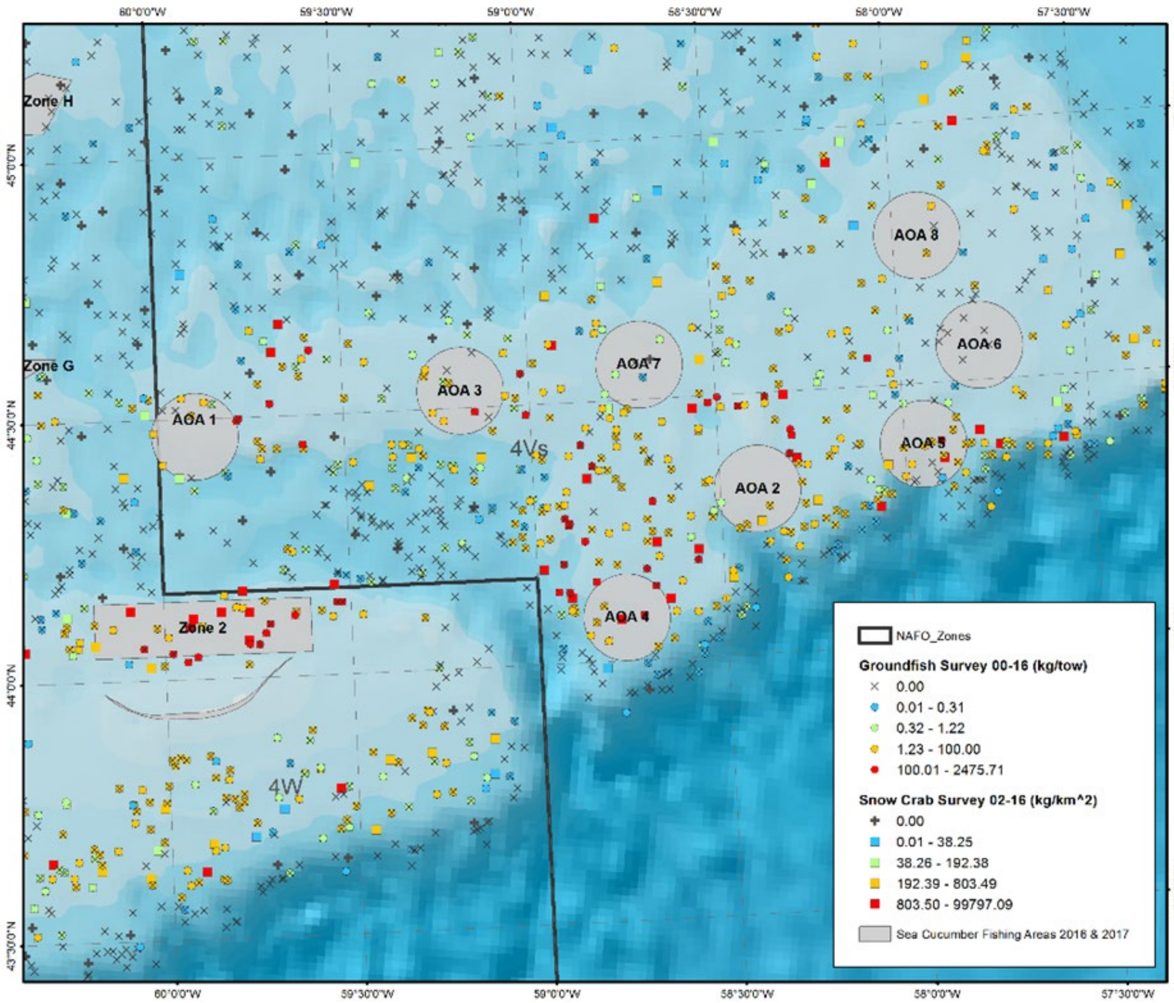


*Figure 23. The spatial distribution of Sea Cucumber (kg/tow) in the DFO RV (circles) and Snow Crab Surveys (squares) in 4Vs Offshore.*

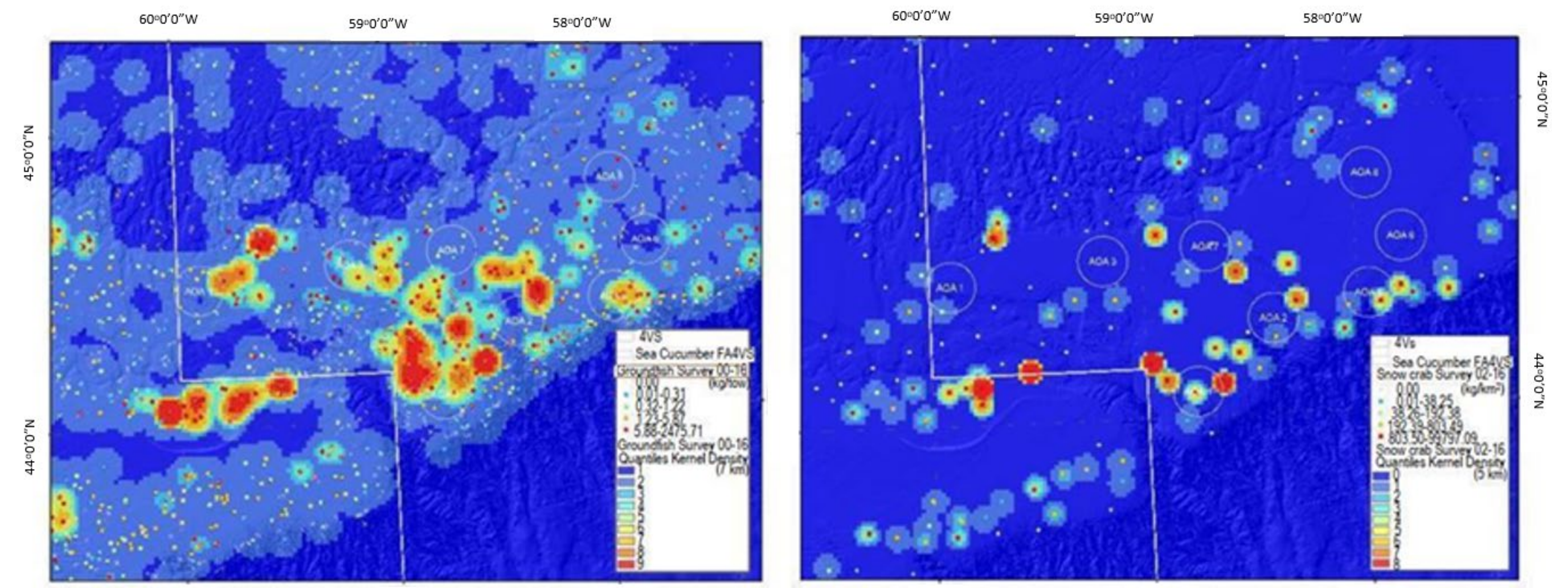


*Figure 24. RV Survey kernel density layer created using a 7 km radius (left) and Snow Crab Survey kernel density layer using a 5 km radius (right).*

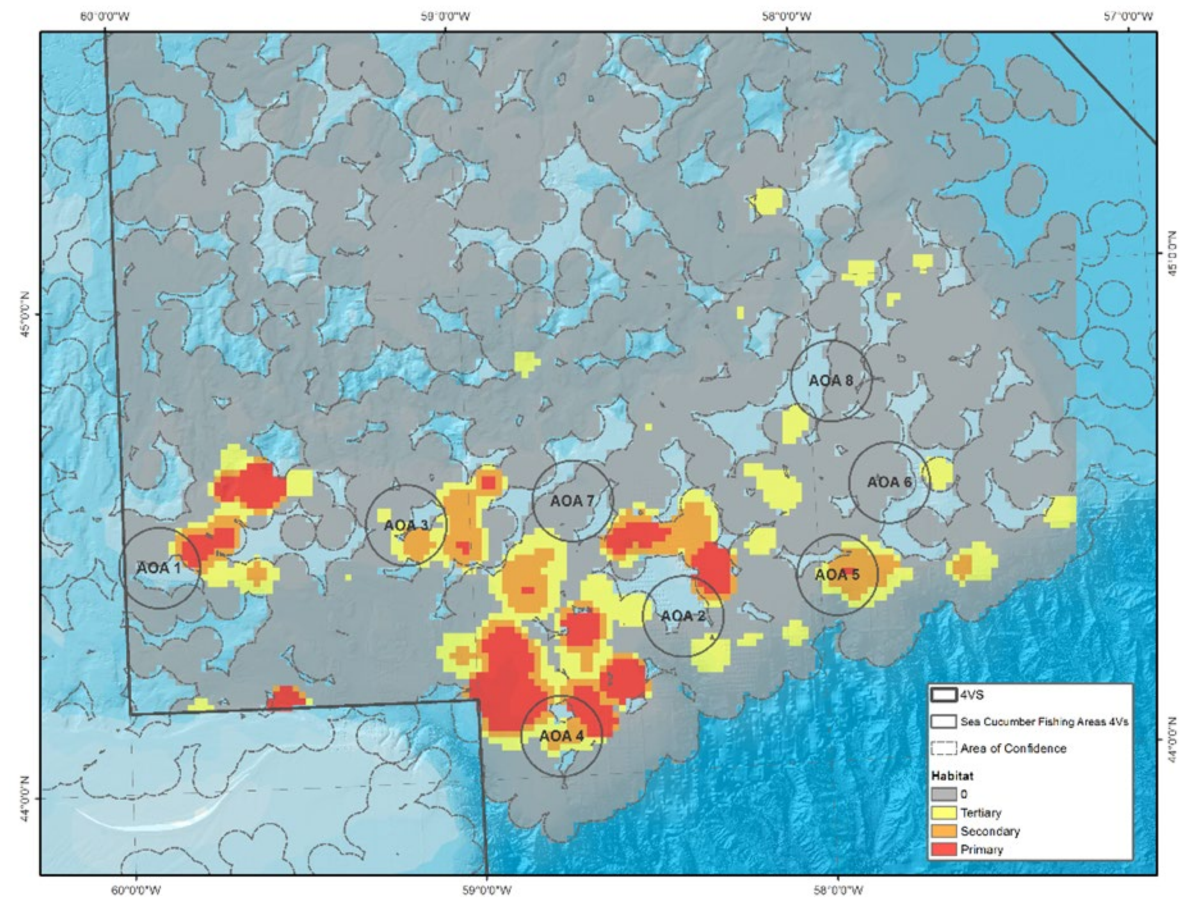


*Figure 25. The final expected C. fondosa habitat layers for 4Vs Offshore showing the distribution of habitat classes: Primary, Secondary and Tertiary.*

## CONCLUSIONS

Current stock status indicators for Sea Cucumbers in the Maritimes Region are based on fishery dependent information, catch rates and port sampled split weights. Indicators are presented for all fishing zones and areas that are regularly fished, including SWNB Zone 1, 4W Offshore Zones 1 and 2, 4W Mid-shore Zone F and 4Vs AOA2. Catch rates for all areas are presented in kg/m$^2$, and an additional catch rate indicator, kg/hr*m, was presented for SWNB Zone 1. Average round and split weights are available for all fishing areas and provide an additional size-based indicator to monitor in conjunction with catch rates.

LRPs were established for all areas based on the highest catch rates from their respective time series ($B_0$). The LRPs for 4W Offshore Zones 1 and 2, 4W Mid-shore Zone F, and 4Vs AOA2 were set as 20% of the $B_0$ proxies. The LRP for SWNB Zone 1 was set at 30% of the $B_0$ proxy. Reference points for SWNB Zone 1 are more precautionary due to the risk associated with fishing all known available habitat. Reference points should be re-evaluated as fishery independent information becomes available and is verified.

The SWNB Sea Cucumber fishery has been in operation for 20 years in a relatively small harvesting area, outlasting many other Sea Cucumber fisheries globally, however, the level of fishing that would not cause further decline in the stock and allow for recovery within a reasonable time frame is highly uncertain. In 2019, the SWNB Zone 1 TAC was reduced to

500 t, however, the catch rate indicator remains near the LRP. Further, split weights indicate the commercial catch's size distribution has shifted to a composition with a higher proportion of smaller animals than it had previously. Current levels of removals have not positively impacted the growth of the population. To promote growth, exploitation should be further reduced.

Reserves and rotational harvesting are two options that can be used as effective spatial management tools for assumed low mobility species such as Sea Cucumber (Purcell 2010). If reserves are used, a broad guidance for data-limited fisheries is to set aside at least 30% of expected Sea Cucumber habitat from fishing. A map of expected *C. frondosa* habitat has been used as guidance for setting aside 30% of habitat on the Scotian Shelf (Figure 22). The map should be updated, and reserves validated, as more information becomes available. Any strategy to set aside areas from fishing should be re-evaluated every 3–5 years to ensure objectives are being met.

It is recommended that a full assessment and review of reference points for the Maritimes Region Sea Cucumber fisheries be undertaken in five years or earlier if significant changes in indicator trends or fishing practices occurs. Otherwise, informal updates should be provided to DFO Resource Management on an annual basis.

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# APPENDIX A: SAMPLING PROTOCOL

In all, 100 Sea Cucumbers must be sampled from every trip. All data should be linked to a **Date**, **Trip #**, **Licence #**, **Fishing Zone** ID, and **Latitude/Longitude**, as close to actual as possible. If more than one fishing zone is fished in a given trip, effort should be made at sea to set aside 100 Sea Cucumbers from each zone. Samples set aside from different zones should be labelled with the appropriate Fishing Zone ID.

Steps to complete sampling are as follows. **Please record weights in grams**.

1. Round Weight - Weigh and record total weight of each individual Sea Cucumber.

2. Split Weight - Slice each animal down the middle, drain water and remove viscera, leaving the head/flower attached (no need to pay dry). Weigh and record each individual split Sea Cucumber.

Date:____________________ Licence #:____________________ Latitude: ______________________

Trip #: __________________ Fishing Zone ID:______________ Longitude:_____________________

| Round (g) | Split (g) | Round (g) | Split (g) | Round (g) | Split (g) | Round (g) | Split (g) | Round (g) | Split (g) |
|---|---|---|---|---|---|---|---|---|---|
| **1.** | | **21.** | | **41.** | | **61.** | | **81.** | |
| **2.** | | **22.** | | **42.** | | **62.** | | **82.** | |
| **3.** | | **23.** | | **43.** | | **63.** | | **83.** | |
| **4.** | | **24.** | | **44.** | | **64.** | | **84.** | |
| **5.** | | **25.** | | **45.** | | **65.** | | **85.** | |
| **6.** | | **26.** | | **46.** | | **66.** | | **86.** | |
| **7.** | | **27.** | | **47.** | | **67.** | | **87.** | |
| **8.** | | **28.** | | **48.** | | **68.** | | **88.** | |
| **9.** | | **29.** | | **49.** | | **69.** | | **89.** | |
| **10.** | | **30.** | | **50.** | | **70.** | | **90.** | |
| **11.** | | **31.** | | **51.** | | **71.** | | **91.** | |
| **12.** | | **32.** | | **52.** | | **72.** | | **92.** | |
| **13.** | | **33.** | | **53.** | | **73.** | | **93.** | |
| **14.** | | **34.** | | **54.** | | **74.** | | **94.** | |
| **15.** | | **35.** | | **55.** | | **75.** | | **95.** | |
| **16.** | | **36.** | | **56.** | | **76.** | | **96.** | |
| **17.** | | **37.** | | **57.** | | **77.** | | **97.** | |
| **18.** | | **38.** | | **58.** | | **78.** | | **98.** | |
| **19.** | | **39.** | | **59.** | | **79.** | | **99.** | |
| **20.** | | **40.** | | **60.** | | **80.** | | **100.** | |

*Figure A.1. Biological sampling protocol (revised January 2019)*

## APPENDIX B: CHOLORPHYLL CONCENTRATIONS

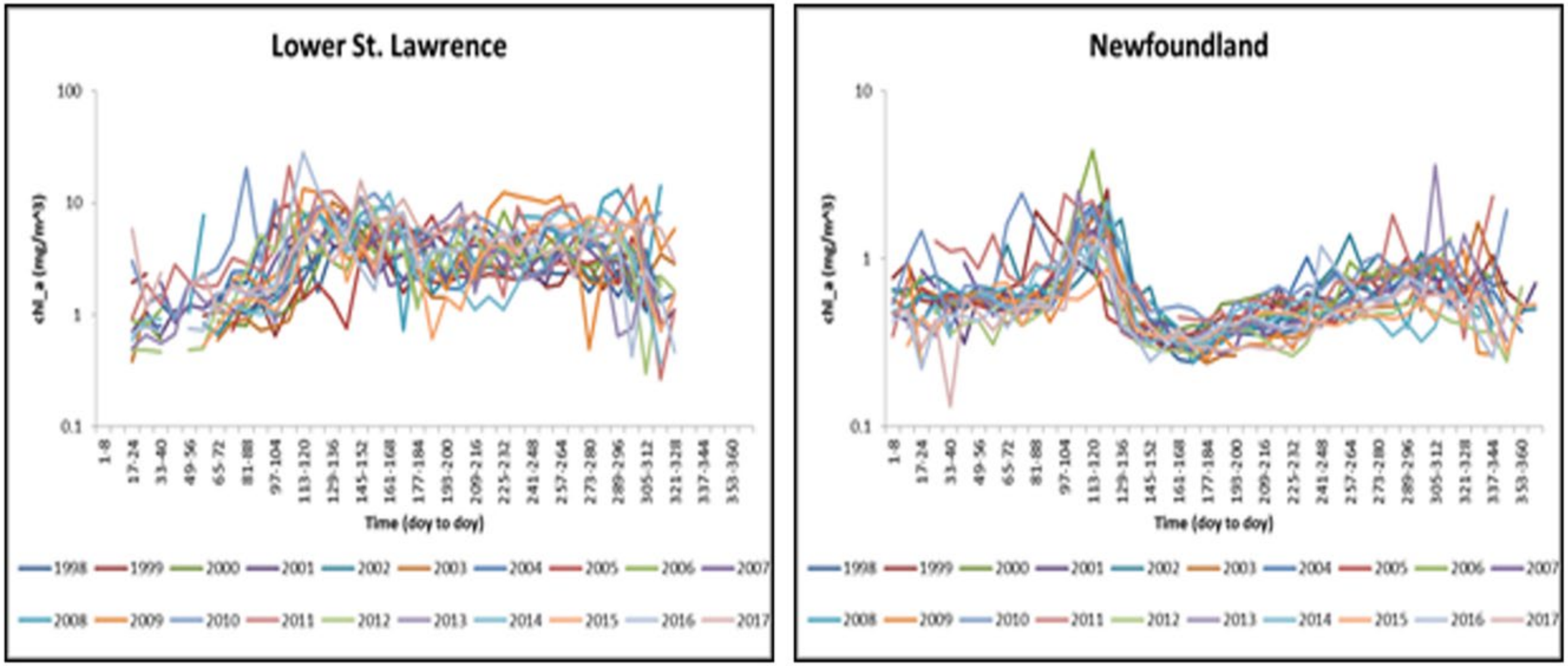


*Figure B.1. Chlorophyll Concentration - Lower St Lawrence (left) and Newfoundland (right).*

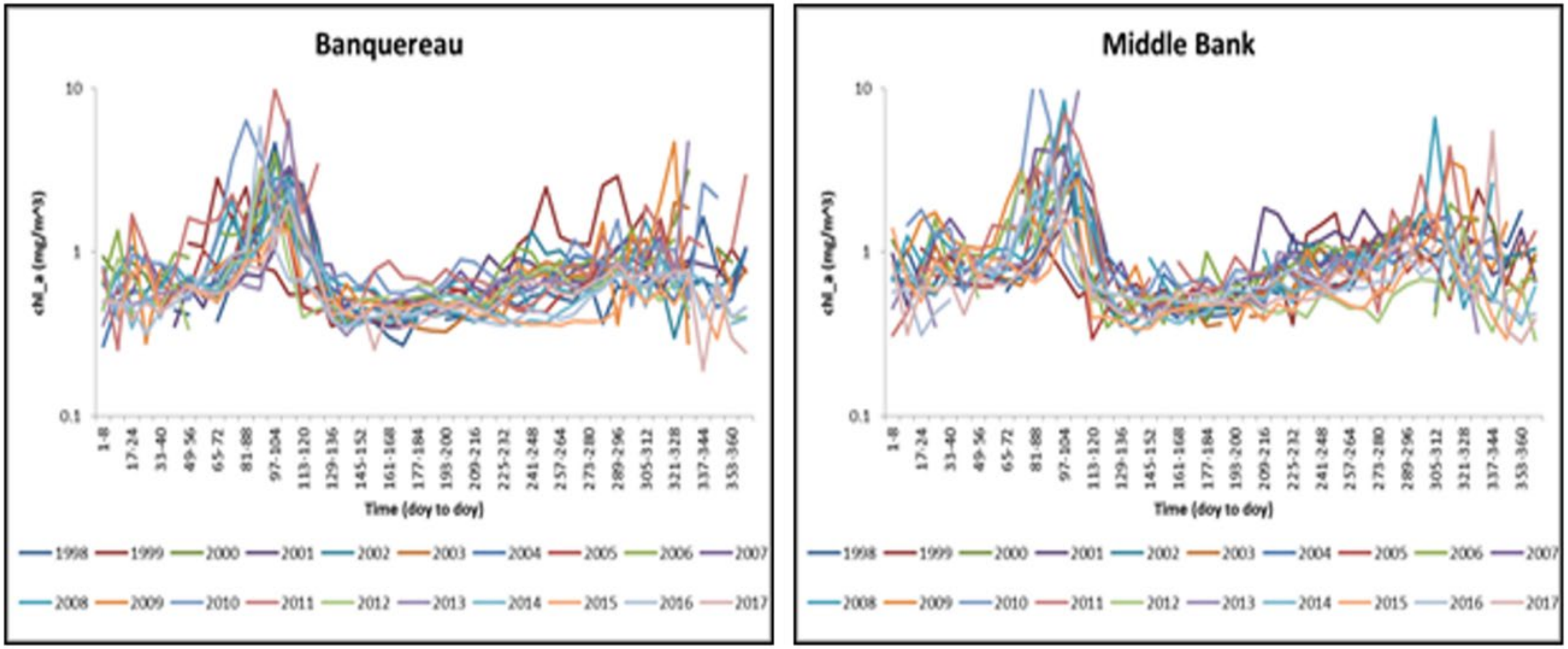


*Figure B.2. Chlorophyll Concentrations - Banquereau (left) and Middle Bank (right)*

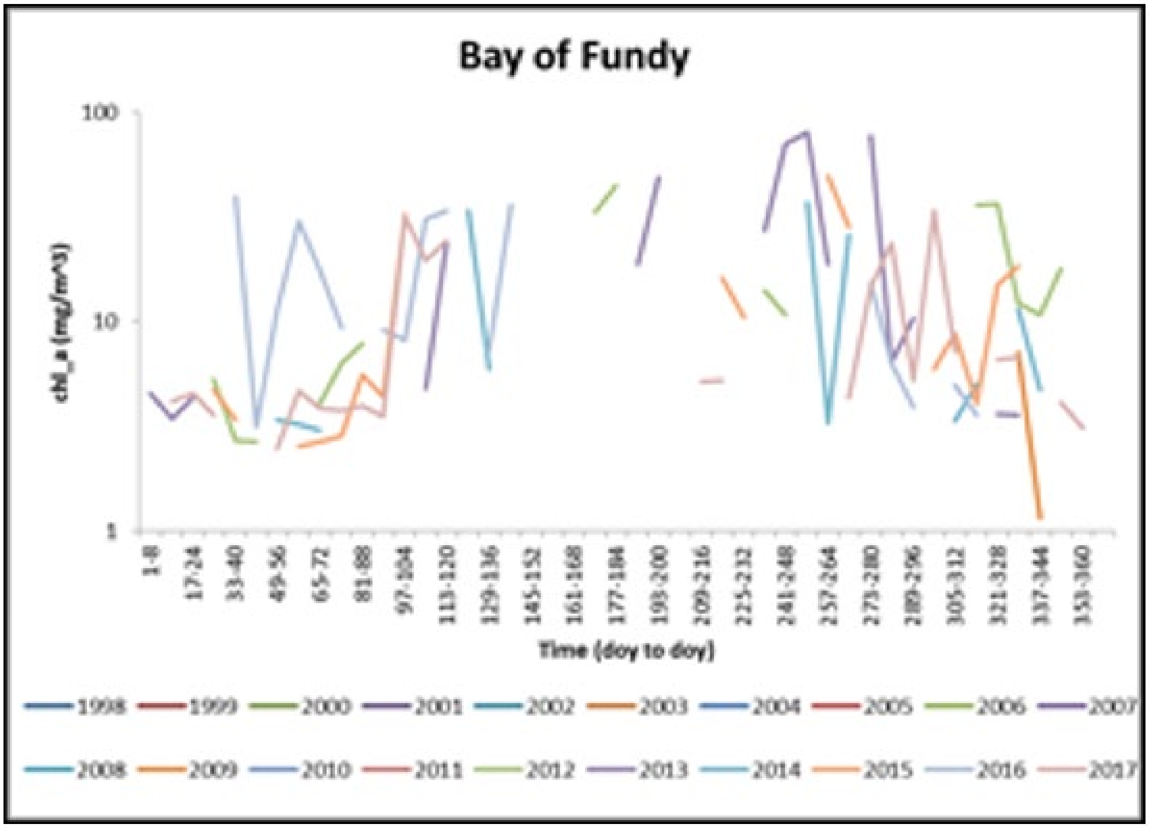


*Figure B.3. Chlorophyll Concentrations - Bay of Fundy*