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Stock assessment of the American lobster stock (*Homarus americanus*) in the French archipelago of Saint Pierre & Miquelon

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Résumé étendu en français

1. Introduction

Le projet ATLANTILES vise à étudier les interactions et synergies entre le tourisme et la pêche artisanale dans l'archipel de Saint-Pierre et Miquelon (SPM). En effet, des études récentes (Le Floc'h and Wilson 2019) ont montré l'importance et le potentiel de développement pour le territoire qu'offre ces synergies entre la pêche artisanale et le tourisme, ainsi que leur exploitation. L'archipel Iles de la Madeleine, un archipel aux caractéristiques sensiblement similaires à l'archipel de Saint Pierre et Miquelon, a su développer une offre touristique en rapport direct avec la pêche artisanale du homard (Fisheries and Ocean Canada 2018). La pêche du homard est de plus en plus pratiquée sur l'archipel. Premièrement, les pêcheurs artisans de l'archipel se sont tournées vers cette ressource suite aux baisses de rendement de la pêche artisanale au crabe des neiges (*Chionocietes opilio*). Ensuite, la pêche récréative est très pratiquée au sein de l'archipel depuis de nombreuses années (Pinget 1981), et spécifiquement la pêche au homard, au casier ou en plongée. Ce stock représente donc une ressource pour les habitants de SPM, mais aussi un potentiel de développement économique pour les pêcheurs artisans et l'archipel. L'étude du stock de homard et son évaluation parait donc un bon point de départ pour le futur développement d'activités économiques autour de cette pratique de pêche, mais aussi pour la gestion durable de la ressource afin de préserver ces rentrées économiques.

Le homard est un animal vivant l'été sur les côtes de l'archipel, à des profondeurs n'excédant pas 70 mètres. L'hiver il vit en métabolisme ralenti (Aiken and Waddy 1976) à des profondeurs où la température est plus stable. Il se reproduit l'été, lorsque la carapace des femelles est molle à la suite de la mue (Waddy and Aiken 1990). Les femelles portent ensuite les œufs pendant 10 à 11 mois (Holthuis 1991) avant de relâcher les larves, qui vivront une vie pélagique de quelques semaines avant de s'installer sur le fond. La reproduction s'effectuant pendant l'été, lorsque les homards sont remontés vers les côtes pour s'alimenter, il est vraisemblablement peu probable que les homards de l'archipel de Saint-Pierre se reproduisent avec les homards situés à Terre-Neuve. Le stock de homard de SPM est considéré comme un stock unique dans cette étude.

Au canada, la pêche du homard est fortement règlementée (Parsons and Lear 1993; Roy 1997; Government of Canada 2016b, 2016c, 2017, 2018a, 2018b; Branch 2019; "Côte de granit de Terre-Neuve - Zone 12" n.d.; "Côte Ouest de Terre-Neuve - Zone 13A" n.d.; "Côte Ouest de Terre-Neuve - Zone 13B" n.d.; "Côte Ouest de Terre-Neuve - Zone 14A" n.d.; "Côte Ouest de Terre-Neuve - Zone 14B" n.d.; "Côte sud de Terre-Neuve - Zone 11" n.d.) et très suivie tout au long des saisons de pêche. Les licences de pêche payantes y régulent l'accès à la ressource. Enfin, la pêche récréative y est interdite. Les débarquements totaux s'élèvent à 90 000 tonnes par an au Canada. A SPM, le TAC global de 30 tonnes (Secrétaire d'Etat à la Mer 2014) n'est pas divisé en quota individuels. Les licences ne sont pas payantes, et la pêche récréative est autorisée. De plus, la pêche professionnelle est très peu suivie, puisque les log-books ne sont pas complétés. La pêche récréative manque également d'un suivi et de contrôles, puisqu'il n'y a pas d'obligation de s'enregistrer en tant que pêcheur récréatif, ou même de déclarer ses captures. Enfin, les observateurs en mer de l'archipel n'ont jamais réalisé de suivi sur le stock de homard.
Dans le but de mieux connaitre la pêcherie de homard sur l'archipel de SPM, des sondes environnementales ("Capteur SP2T - Recopesca" 2010; "MASTODON" 2011) ont été installées dans les casiers. Des systèmes Recopesca d'Ifremer ont également été installés à bord des homardiers de l'archipel. Ces données permettront de caractériser l'environnement des zones de pêche du homard, et également de cartographier les zones de pêche exploitées par les pêcheurs artisans de SPM. Enfin, des relevés biologiques en mer ont été réalisés dans le but de définir les caractéristiques biologiques du stock, et d'alimenter un modèle d'évaluation de stock (Chassot et al. 2008) avec des données structurées en taille.

2. Matériel & méthodes

Le site d'étude sélectionné est l'archipel de SPM, situé au sud de Terre-Neuve, Canada. C'est un archipel français de 242 kilomètres², et 6000 habitants.
Les pêcheurs artisans de l'archipel pratiquant la pêche du homard sont majoritairement situés à Miquelon. Des sondes Recopesca ainsi que leurs concentrateurs respectifs ont été installés à bord des bateaux, et permettront le suivi environnemental et la cartographie des zones de pêche. En plus de ces données, des observations en mer du homard de l'archipel ont été réalisées. Les tailles des homards, ainsi que leurs sexes ont été relevés, ainsi que la zone dans laquelle ils ont été pêchés. Ces données structurées en taille ont été analysés et étudiées via un algorithme (Jamshidian and Jennrich 1997; McLachlan and Krishnan 2007) permettant d'extraire de multiples lois normales au sein d'une distribution polymodale. De la structure de taille, cet algorithme a permis d'extraire les caractéristiques de taille (moyenne et écart-type) des différentes cohortes présentes dans l'échantillonnage. Une cohorte représente les individus nés la même année. Ainsi, ces données structurées en âge ont été entrées dans un modèle dévaluation de stock par la méthode des pseudo-cohortes corrigé (Chassot et al. 2008). Cette méthode permet l'intégration des variations d'effort, la pêche du homard s'étant développé il y a peu, mais également des changements d'abondance du stock. Ces changements d'abondance ont été calculés à partir des données log-books, mais également à partir de données d'un pêcheur récréatif qui note à chaque sortie le nombre de homard débarqués. Ce dernier utilise le même nombre de casier, placés aux mêmes endroits depuis 2002. Les différents indices d'abondance calculés ont été standardisés grâce à un modèle glm. L'indice de pêche récréative comportant une valeur pour l'année 2019, c'est celui-ci qui a été utilisé dans le modèle de pseudo-cohortes.
Une dernière méthode d'évaluation de stock data-poor a également été mise en place (ICES 2012). Cette méthode se base sur l'étude des traits de vie du stock pour donner un diagnostic sur l'exploitation du stock. Les points de références sont calculés à partir de la distribution en taille du stock.

3. Résultats & discussion

D'après les données GPS, la pêche au homard se distribue le long de la côte ouest de Miquelon-Langlade, ainsi qu'à l'est de Miquelon. Les conditions environnementales dans les deux zones diffèrent. En effet, la température moyenne relevée par les sondes environnementales montre une température plus élevée à l'ouest. De plus, la température à une même profondeur est très variable sur une journée dans la zone est. D'autres facteurs environnementaux, comme une prédation plus importante par la population de phoques située à l'est, ou encore la présence de rochers à l'ouest, pourraient expliquer les différences de caractéristiques de taille entre les deux zones. En effet, les homards pêchés à l'est sont significativement plus petits. Ces observations peuvent également être dus à une exploitation de la zone est qui dure depuis plus longtemps, à la fois par la pêche professionnelle mais aussi par la pêche récréative, et qui a entraîné la réduction des tailles des homards à l'est. En revanche, les autres paramètres biologiques des homards au sein des deux zones ne diffèrent pas : les femelles œuvées sont présentes dans les mêmes proportions dans les deux zones. Ces résultats infirment l'hypothèse selon laquelle il existeraient deux stocks de homards à l'est et à l'ouest de Miquelon-Langlade.

D'après les résultats du modèle d'évaluation du stock de homard de l'archipel de SPM, les deux zones présentent un diagnostic très différent. Le stock, lorsqu'on l'examine dans sa totalité, semble bien se porter et même être exploité en dessous du F_{max}, un proxy du F_{MSY}. En revanche, lorsque le diagnostic est différencié par zones, il semble que la zone EST subisse une pression de pêche beaucoup plus forte que la zone ouest, et centrée sur l'exploitation des individus les plus jeunes (les individus entre 87 et 100 mm de longueur de carapace). Compte

tenu du caractère très sédentaire du homard, des pressions de pêche différentes sur 2 zones d'un même stock pourraient entrainer une différence dans le diagnostic. Si par exemple une zone est beaucoup plus fortement exploitée qu'une autre, les tailles moyennes observées dans la zone la plus exploitée seront logiquement plus faibles. C'est bien ce que l'on observe dans le cas du homard à SPM. La zone est est exploitée depuis une plus longue période, entrainant des différences dans les caractéristiques des captures. En revanche, on ne peut pas conclure que les 2 zones constituent des stocks différents, encore une fois.
Enfin, la deuxième méthode d'évaluation du stock par une méthode basée sur les traits de vie conduit à un diagnostic dans la même tendance, même s'il tend à être plus pessimiste que le modèle précédemment commenté. En effet, d'après les résultats de cette deuxième méthode, le stock dans sa globalité est légèrement surexploité. La zone est semble être en surexploitation tandis que la zone ouest est exploité de façon durable et au rendement maximum durable.

Pour finir, le diagnostic de la population de homard de SPM est un résultat à prendre avec précaution, car l'impact de la pêche récréative n'est pas quantifié et n'a pas pu être quantifié durant ce stage. L'étude de la pêche récréative du homard est la prochaine étape de l'évaluation du stock de homard. Le diagnostic, bien que présentant des résultats cohérent avec la réalité des observations scientifiques et des observations des pêcheurs artisans de SPM, manque clairement de données sur la pêche récréative qui est très pratiquée partout autour de l'archipel, et depuis bien plus longtemps que les professionnels.

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ATLANTILES – Analyse des Territoires Localisés en Atlantique Nord ouest et de leur Trajectoire : les ILES de Saint Pierre et Miquelon

CL – Carapace Length

CPUE – Catch Per Unit of Effort

DFO – Department of Fisheries and Oceans Canada

EEZ – Economical Exclusive Zone

FT – Terminal Fishing mortality

GPS – Global Positioning System

IFREMER – Institut Français pour les Recherche et l'Exploitation de la MER

LFA – Lobster Fishing Area

M – Natural Mortality rate

SPM – Saint-Pierre et Miquelon

USA – United States of America

UTC – Coordinated Universal Time

Introduction

1. Atlantiles project context

The Atlantiles (Analyse des Territoires Localisés en Atlantique Nord ouest et de leur Trajectoire : les ILES de Saint-Pierre et Miquelon) project is a multidisciplinary project, bringing together researchers from different disciplines such as biology, economics and geography, and actors of the fishing industry. For the long term, the project aims to study the socio-economical trajectory of small insular territories after a deep crisis in the exploitation of natural resources. Moreover, this project aims to investigate and understand the interaction between artisanal fisheries and tourism.

Figure 1 – Map of the region of Saint-Pierre & Miquelon (Google Maps)

The French archipelago of Saint-Pierre & Miquelon (SPM), located at the south of Newfoundland, Canada (Figure 1), was chosen as the field for work. The SPM economy was mainly driven by the industrial exploitation of the 'Newfoundland' cod (*Gadus morhua*) stock until the 1992 Canadian moratorium. Suddenly, most of the jobs in the archipelago were cut, suppressing at the same time the most important source of income for the territory. Nowadays, the artisanal fleet, consisting of vessels less than 12 meters long, has developed at the expense of the industrial fleet at SPM. Preliminary studies (Le Floc'h and Wilson 2019) have shown that the interaction between tourism and artisanal fishing could be a lead to enhance the local economy and create employment. There have been successful examples of the exploitation of the interaction between fishery and tourism, the closest to SPM being at the Magdalen islands (Fisheries and Ocean Canada 2018). The lobster fishery is the base of an entire economy. Given the similarities between the two archipelagos, the study of the American lobster population at SPM seemed like a great way to start the researches in the territory. These results could, for the long term, provide information on the SPM lobster population and also provide tools to fishers for the management of the stock.

There is very little literature available on both the artisanal fishery sector and the tourism sector at SPM. The necessity to assess both sectors appears then mandatory, in order to first gather information on the artisanal fishing sector, and then eventually provide management advices to the local management bodies.

Artisanal fishing and fishery-related data collection is carried out by French management bodies. However, the logbooks were not entered in a database until last year. Paper logbooks are archived, but are not digitized yet. These data are not exploited to compute any time-series to monitor the different fisheries. Therefor there are no and has never been any CPUE (catches per unit of effort) computations or stock assessment computed for the SPM fisheries. The lack of data exploitation, as well as the lack of field monitoring for some of the species targeted, such as the American lobster (*Homarus americanus*), entails a high risk of stock overexploitation. There is a real need for field-related scientific monitoring for the SPM-EEZ (Economic Exclusive Zone) included stocks in order to build a sustainable, scientifically based, resource management.

The 3 main species targeted by the artisanal SPM fleet are the snow crab (*Chionoecetes opilio*), the cod (*Gadus morhua*), and the American lobster (*Homarus americanus*). Facing the decline of in snow crab landings in the recent years, the American lobster fishery is now developing, and has recently emerged as the new target species in the archipelago. Moreover, the global warming of the water temperature modifies the distribution and local abundance of the lobster. American lobster populations might be benefiting from global warming in some of the colder zones. Indeed, abundance indices are rising on the Canadian coast whereas declining at the south of Maine, USA (United States of America) (Le Bris et al. 2018). SPM is located near the Gulf of Saint Lawrence, where the abundance indices are rising due to climate change. If the SPM lobster fishery is well monitored and managed, it might become a reliable source of income and employment in the territory. However, a stock assessment has yet to be computed in order to support a cautious resource and stock management.

In this context, the goal of this project was to gather as much data as possible and to make a first assessment on the lobster fishery at SPM.

2. Biology and life cycle of the American lobster (*Homarus americanus)*

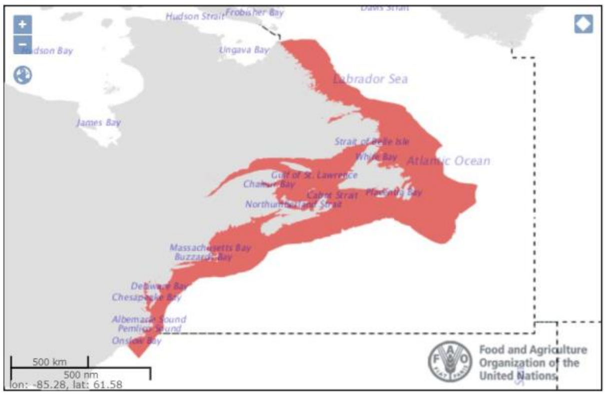


Figure 2 – Distribution of the American lobster (FAO Fisheries & Aquaculture 2019)

American lobsters are distributed on the North East American coast (Figure 2), from North Carolina, USA to the North of Canada. Female lobsters spawn between late summer and early fall after carrying eggs during 10 to 11 months (Holthuis 1991). The planktonic phase of newly hatched larvae lasts for between 2 to 4 weeks (Holthuis 1991; Annis 2004). During this stage, only 0.1 % of the total hatched larvae survive (Scarratt 1973). After settlement, post-larvae lobsters are mostly found in shallow rocky bottoms (Hudon 1987), where they are protected from currents and predators. Migration occurs at a very limited scale for the adult lobsters (Holthuis 1991). Given the shortness of the planktonic phase, the very specific sea currents around the archipelago (Lazure et al. 2018), and the specific post-larvae habitat requirements (Hudon 1987), it is very unlikely that larvae would settle outside the archipelago.
Juvenile lobsters (between 25 and 76 mm of carapace length (CL)) usually live in shallow rocky bottoms, where they have settled during early fall. Juvenile lobsters have a very specific habitat needs (Hudon 1987; Cowan et al. 2001). At the beginning of this stage, their molt rate is very high – 9 times on their first year (Hughes and Matthiessen 1962), but this molt frequency slows

to 0.91 to 0.98 molt per season during the adult stage (lobsters > 76 m CL), regardless of sex (Comeau and Savoie 2001).

Adult lobsters (CL > 76 mm) are nocturnal sedentary animal. During spring and summer, lobsters are mainly found in shallow waters (Parsons and Lear 1993), at depths ranging from 10 to 70m. They usually live in crevices (Campbell 1983), (Cooper and Uzmann 1980) or in seaweed forests (Fisheries and Ocean Canada 1984). Although sediment type and depth have a great influence on lobster's distribution, temperature has the greatest influence on the adult American lobsters distribution (Chang et al. 2010). Lobsters can tolerate temperature between 0 and 27 °C, but their optimal temperature range is between 10 and 20 °C (Quinn 2017). When the temperature gets below 5°C, during winter, lobsters' metabolism slows down to the point where molting is inhibited (Aiken and Waddy 1976). Lobsters then live in deeper habitats where the temperature is less influenced by the air temperature and weather conditions. Temperatures above 8 °C are known to allow the maturation of ovaries (Chang et al. 2010), and then so reproduction. Moreover, reproduction occurs mainly when female lobsters are molting, as their shell is softer (Waddy and Aiken 1990). Reproduction occurs then mostly during late summer. Female lobsters can either spawn their eggs right after molting, or they can store male reproductive material waiting to spawn (Quackenbush 1994). Although male and females have the same molting frequency, male lobsters have a higher average molt increment (Ennis 1972). Indeed, they have more energy left for growth, whereas females allocate more energy to the reproduction.

Fisheries and Oceans Canada identifies multiple Lobster Fishing Area (LFA). The management rules are LFA-specific. However, these LFAs are very large and might be constituted of multiple stocks. Indeed, lobsters reproduce during summer, where they live on shallow rocky bottoms. Each population is then clearly separated while mating.

3. American lobster fisheries in Canada and France (Saint-Pierre & Miquelon)

a. Canadian American lobster fisheries

The lobster fishery is the most valuable single-species fishery throughout the North East American coast. In Canada, the lobster fishery is one of the most important job providers in some regions (Magdalen Islands, Gaspé, …). As an important part of the Canadian economy and culture, the fishery needs to be assessed regularly, and strict management rules must be implemented to maintain jobs, and to correctly manage the lobster populations. The management rules in 3 Canadian regions are presented in Table 1.
The management system differs from the European management system in that it is mainly based on harvest-control rules. There is a limited number of traps per LFA (Lobster Fishing Areas), and a defined fishing season, both slightly differ between LFAs. Canadian lobster fishing seasons however take place mainly during spring. Seasons can be lengthened by the Department of Fisheries and Oceans Canada (DFO) when landings, or other indicators of the stock status, lead to a more optimistic diagnosis in the course of the season. Unlike many of European fisheries, the Canadian lobster fishery is only accessible through paid licenses. Their cost varies among LFAs and might even be higher than the prices reported by DFO. The fishery is not accessible for recreational fishery.

The SPM American lobster fishery is equivalent to half a day of production in Canada. Despite its small global importance in the worldwide American lobster fishery, it sustains and provide jobs and stimulates the local economy with a local production.

Table 1 – Main management rules for the lobster fishery in 3 Canadian LFAs and at SPM (Pinget 1981; Parsons and Lear 1993; Roy 1997; Fogarty and Gendron 2004; Government of Canada 2011; Coughlan et al. 2012; Ministère de l'Agriculture, des Pêcheries et de l'Alimentation 2012; Secrétaire d'Etat à la Mer 2014; Government of Canada 2016b, 2016c, 2016d, 2017, 2018a; Jaugeon 2018; Government of Canada 2018b; Branch 2019; "Côte de granit de Terre-Neuve - Zone 12" n.d.; "Côte Ouest de Terre-Neuve - Zone 13A" n.d.; "Côte Ouest de Terre-Neuve - Zone 13B" n.d.; "Côte Ouest de Terre-Neuve - Zone 14A" n.d.; "Côte Ouest de Terre-Neuve - Zone 14B" n.d.; "Côte sud de Terre-Neuve - Zone 11" n.d.; Government of Canada n.d.; "Homard | Guide des espèces" n.d.; "Homarus americanus, American lobster : fisheries" n.d.; "Lobster Facts – Maine Lobster" n.d.)

	Saint Pierre & Miquelon	**Newfoundland & Labrador**				**Gaspésie**			**Magdalen Islands**
	LFA 11, 3PS AREA	LFA 3 – 6	LFA 7–10	LFA 11-12	LFA 13-14	LFA 19	LFA 20	LFA 21	LFA 22
Number of licenses		2450				168			325
Fishing hours									5am to 9pm
Season	1st May – 31st Aug & 15th Oct – 15th Nov	8 weeks between April and July				71 spring days	69 spring days		
Licensing fees	-	389$/ton + 130 to 200$		389$/ton + 200$		389$/ton + 200$			389$/ton + 840$
Trap limitations	-	100 to 425 depending on local management				250	235-435		273
Authorized gear(s)	Traps & snorkeling								
Line characteristics									YES
Trap characteristics	YES	YES							YES
Trap haul per day						1			1 (except on Sunday)
Release of berried females	YES	YES				YES			
Minimal catch size (CL, mm)	87	82.5				83	82		83
Maximal catch size (CL, mm)							145		
Average commercial size (CL, mm)						96.8	88	96.3	92 – 93.1
TAC (tons)	30								
2018 landings (ton)	27	225	30	1200	1300	105	1577	152	3486
CPUE (kilograms & ind per trap)						1.61//2.15	0.48//0.82	2.54//--	0.57//0.83
Exploitation rate						30%	71.6%		63.8-65.4%

b. American lobster fishery in SPM

In the French archipelago of SPM, there are 7 vessels targeting the American lobster, distributed in the 2 islands. The American lobster season for professional fishers lasts from May 1st to August 31st. A short fall season is permitted at SPM, from October 15th to November 15th. There are no trap limitations, and fishers own around 300 traps each, which are hauled individually at sea. Unlike Canada, the minimal catch size is 87 mm (Secrétaire d'Etat à la Mer 2014), like in Europe for the European lobster (*Homarus gammarus*). Traps are baited with herring bought from a sea-food wholesaler at Fortune, Newfoundland. SPM fishers also sells their catch to the Canadian wholesaler, where prices are negotiated by Canadian fishers. The local market cannot soak up the entire lobster production, partly because of the widely practiced lobster recreational fishery. Artisanal professional fishers sell their lobster and snow crab production to a Canadian sea-food wholesaler located at Fortune.

In addition to the travel time to Fortune, fishing zones are located at a long distance from the port. Indeed, the recreational fishing of lobsters is widely practiced, and located for practical reasons near the villages of Saint-Pierre and Miquelon. In addition, professional lobster fishery is a recently developed fishery, but recreational fishery has been taking place for a very long time (Pinget 1981). The professional fishery takes place at the east coast of Miquelon, and at the west coast of Miquelon-Langlade.

Recreational fishers fish the lobsters with traps, but also snorkel. They are allowed to own 6 traps per vessel, and are authorized to land a maximum of 4 lobsters per day (Secrétaire d'Etat à la Mer 2014), but are however allowed to own fishponds. There are no licensing or registration policies for the lobster recreational fishery in SPM. As so, there are no data available on recreational fishery. Since the recreational lobster fishery stops however on August 31st, the production of the professional fishers is sold locally during fall.

In addition to the fishing zones exploited by recreational fishers, there are no-fishing zones (Figure 3) around the coasts of Saint-Pierre and Miquelon-Langlade (Jaugeon 2018). These zones also reduce the available zones for professional fishers.

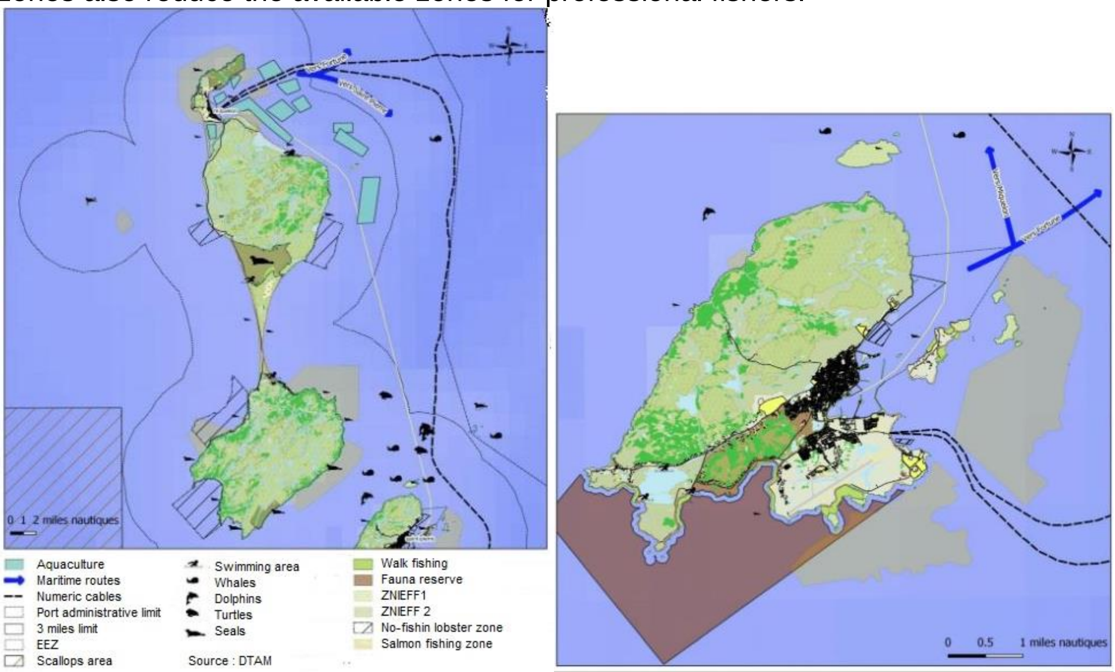


Figure 3 – Administrative map of the archipelago of SPM, adapted from (Jaugeon 2018)

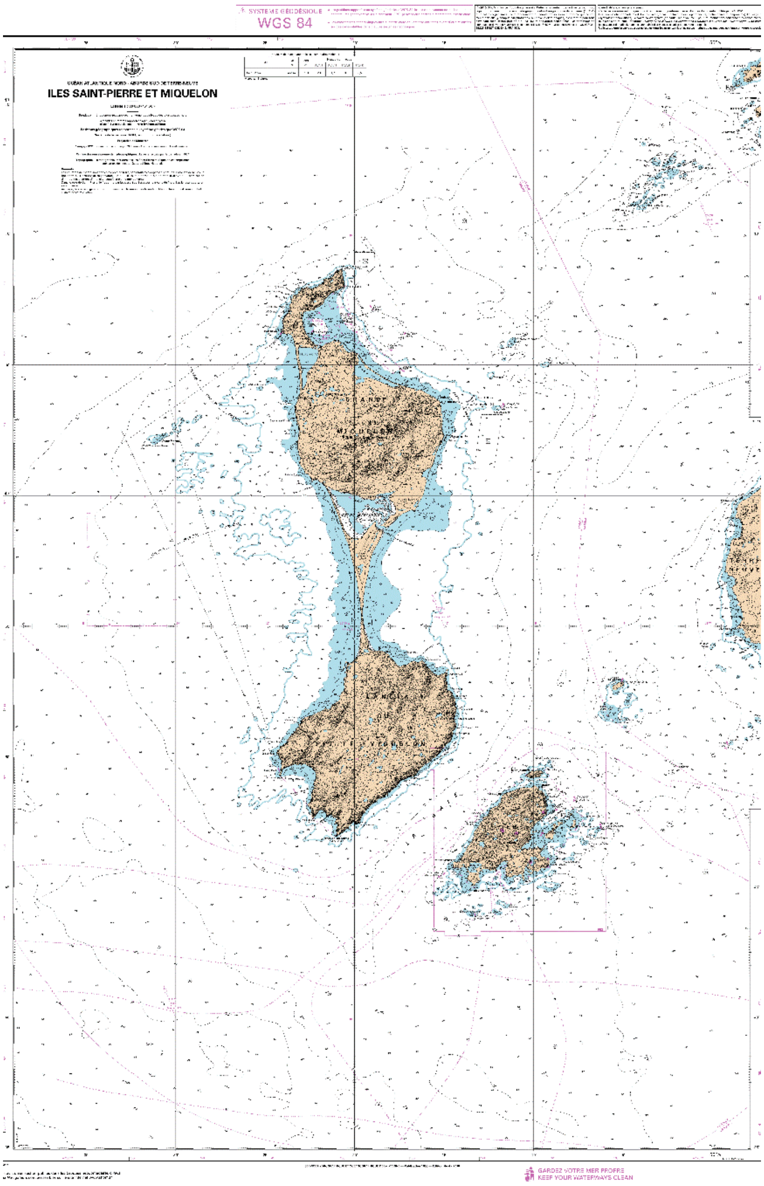


Figure 4 – Map of the depth around the SPM archipelago ("Le Pourquoi pas ?" 2018)

Finally, lobsters are found in shallow habitats. The coasts of SPM are characterized by very low depths, that are suitable habitat for lobsters (Figure 4).

Both the recreational and professional fisheries lack information and data. Recreational fishers are not registered, nor they have the obligation to declare their catches. Log-books are for the most part not fully completed, and lack for the fishing effort (i.e. number of traps hauled per fishing trip). It is then no possible to even compute CPUE to monitor the fishery. As a result, scientific advice on the stock is not an easy task to complete. Field-work and interviews on the field are necessary in order to fill-in the lacking information. In addition, as there has never been any data recorded or any at-sea observations on the SPM lobster stock, there are no data available on the historical size structure, or on any other biological characteristics of the stock. The environment and environmental characteristics of the lobster fishing zones are also scarcely known.

Aiming to better manage the American lobster stock for future generations, fishers from the archipelago, local authorities and locally-based Ifremer (Institut Français de Recherche pour l'Exploitation de la MER) staff had a will to organize a data collection focused on the lobster stock. The goal of this study was then to get in contact with actors of the SPM lobster industry in the archipelago in order to gather various types of data (at sea sampling, landings from professional and recreational fishery). Using data-adapted modelling and evaluation techniques, this study presents a scientific report on the lobster population of the archipelago of Saint-Pierre & Miquelon.

In addition, a longer-term monitoring of the lobster fleet and the environmental characteristics of the fishing area around the archipelago will make it possible to monitor more closely the lobster fishery. The distribution of the fishing effort, as well as some biological characteristics of the lobster stock will be investigated in this report. The first results of this monitoring will also be presented. The goal of this project was to collect and analyze data from multiple sources and variable quality, in order to assess the SPM American lobster stock.

Materiel & Methods

1. Study site

The French archipelago is in the North-East American coast (Figure 1), at the south of Newfoundland Canada. The field work (i.e. at-sea sampling, interviews and data collection) was conducted during 3 months from May 1st to July 31st.

2. Recopesca & Mastodon probes

2 types of environmental probes were installed on board the fishing vessels targeting the American lobster during the 2019 summer season all along the fishing zone.
A Recopesca ("Capteur SP2T - Recopesca" 2010) probe was installed on a trap for each fishing vessel. This type of probe senses both water pressure and water temperature on a regular basis. They communicate with a device, a concentrator, placed on each vessel which stores the data from the probe, and record the GPS position of the boat and its speed. Speed is calculated by the distance between 2 GPS positions, and the time spent in each 1' by 1' square is pooled to produce a map of the fishing time. Data stored in the concentrator were manually downloaded every time it was possible at Saint Pierre and at Miquelon. Data were then sent to Ifremer and entered into the Recopesca system. Individual per boat GPS data could not be included in this report as they constitute personal and sensible data. A global map of the fishing effort, with the 6 boats pooled together, is presented in the Results part.

Between 4 and 5 Mastodon ("MASTODON" 2011) probes were also installed in the trap of 2 volunteer boats, as the captain had to keep track of the GPS (Global Positioning System) position of the probe at every fishing trip. These probes also recorded water pressure and water temperature. These probes were in the traps for about 2 months, and data recorded in these probes were downloaded through a specific software. Out of the 13 probes initially at-sea, only 5 could be included in the analysis of the temperature of the lobster environment, as well as data from 3 Recopesca probes placed in lobster traps.
Data from the 8 probes was pooled together and analyzed. It was possible to track the daily average temperature per fishing zone, as well as the tide cycle. These results will be presented in the next part.

3. Data collection (available data & at-sea sampling)

Available data

In order to compute a time-series of landings and monthly and annual CPUE between 2012 and 2018, logbooks data kept in the Affaires Maritimes were retrieved. The paper logbooks were manually entered in an excel file, because logbooks prior 2018 were not digitized. In the logbooks, the weight landed per trip, as well as, when these data were recorded, the number of trap and the fishing area were gathered. When some information was lacking in the logbooks, face-to-face individual interviews were conducted. Individual interviews have already proven to be very useful in the assessment of small islands fisheries (Gill et al. 2019). The interview baseline is presented in Appendix 1. However, it should be noted that the interviews were not directed, and fishers were not guided nor influenced in their answers.

To compute CPUE (1), the number of traps per trip was used when available. Fishers have estimated that half of their traps are installed in each zone (at the east and west of Miquelon, the number of traps used per boat is presented in Appendix 2). Given the travel time to reach the fishing zone, it is not possible for lobster fishers to haul the traps in both zones for one day.

If the number of traps was not written in the logbook, the estimated number of trap obtained via interviews per year divided by 2 was used to compute CPUE. Usually for fisheries using this type of gear (traps), CPUE is set to represent the average catch of 100 traps.

$$CPUE_{(y,m)} = \sum_{t=1}^{T(m,y)} \frac{L_{(y,m,t)}}{E_{(y,m)}} * 100, \text{ (1.1)}$$

with : $E_{(y,m)} = \sum_{t=1}^{T(y,m)} TH_{(y,m,t)}$ (X), or $E_{(y,m)} = \frac{TH_{(y)}}{2} * T_{(y,m)}$ (1.2)
y the year of the computation
m the month
t the fishing trip and Tm, y the total number of trips for month m and year y
L the landings
$TH(m, y, t)$ the number of traps hauled for month m year y and trip t.

An interview of a recreational fisher was also conducted. This fisherman uses the same number of traps placed at the same location each season and keeps track of its landings for every fishing trip.

At-sea sampling

To get the size structure of the stock, and of the carrying females, on-board sampling of the carapace length of the lobster caught was conducted following the schedule in Appendix 3. Each caught lobsters' sex and carapace length (CL, see Appendix 4) was measured and entered in a database (see Appendix 5). It was also noted if the females were carrying eggs or were v-notched (see Appendix 6).

From the on-board sampling, CPUE (individual/trap), CPUE of carrying females were computed using the same methodology presented in the previous section. Catches per size or cohort (see 4.) were also computed. Demographic indicators, such as average landing size and weight, as well as proportion of jumbo lobsters and sex ratio, used in the Canadian stock assessments (Government of Canada 2016c) (Government of Canada 2016b) (Government of Canada 2016d) could be calculated.

4. Age determination

The stock assessment method chosen here requires catch at age data. However, from the at-sea sampling, only the size structure of the catches was available. There are many methods that can be used to determine the age of marine animals from their size. The Von Bertalanffy growth curve or growth parameters are usually used. However, the use of a continuous function to describe a discontinuous growth, like the lobster growth, has been debated and might can introduce bias in the age determination of lobsters (Breen 1994; Stewart and Kennelly 2000). Moreover, lobsters are very hard to age animals because their growth rate varies widely depending on water temperature (Bergeron 2011; Raper 2012; Raper and Schneider 2013). There are other methods such as protein dosages, that are usually uncertain and that were impossible to use because of the limited materials in the archipelago.

Age classes were determined using the size distribution of the lobsters. The sampled population is constituted of multiple cohorts, forming a multimodal distribution. Cohorts are assumed to follow a normal distribution of mean $\mu(c)$ and standard deviation $\sigma(c)$. Male and female lobsters are treated apart as their growth rate differs significantly. Since lobsters grow once a year, and at the same time, each cohort determined is a year distant from the next cohort.

The function 'mix' (packages 'mixdist') uses a combination of 2 different methods to determine the unobserved parameters of a mixture distribution using user-defined input parameters and their respective user-defined constraints. The EM (Expectation-Maximization) algorithm (McLachlan and Krishnan 2007), a very popular step-by-step algorithm, maximizes the likelihood (or log-likelihood) of the estimated parameters, when an observed distribution X depends on unobserved variable(s) Y. It however converges at a very slow speed, and is often combined with Newton-type or quasi Newton-type accelerators (Jamshidian and Jennrich 1997). In the 'mix' function, a Newton-type accelerator is combined to the EM algorithm in order to maximize the log-likelihood of the estimated parameters, and the parameters.

Since it is considered here that the mixture distribution is a multivariate normal mixture, the model depends on 3 types of latent variables the means, standard deviations and relative proportions of each normal distribution in the size-structure (i.e. for a specific cohort c, the mean size $\mu(c)$, the standard deviation $\sigma(c)$ around the mean, and the proportion $p(c)$ of lobsters falling in that normal distribution). The means were defined using the mean growth increment of lobsters in Newfoundland (Ennis 1972) : between 8 and 9 mm for females and between 9 and 10.9 for males. The mean size for cohort 1 was set to be one of the 5 first observed size. The function 'mix' was run for lobsters between 69 mm and 130 mm. Lobsters over 130 mm of carapace length were grouped into a '+' group as they were scarcely represented in the sample These initial parameters were set in the 'mix' function as follows (Table 2) :

Table 2 – Initial parameters of the multi modal distribution set in the 'mix' function. ('-' : no constraints applied)

	1	2	3	4	5	6	7	8
μ ♀	71	79	87	95	103	111	119	127
μ ♂	74	83.5	93	102.5	112	121.5		
σ ♀	3	3	3	3	3	3	3	3
σ ♂	3	3	3	3	3	3		
p ♀	-	-	-	-	-	-	-	-
p ♂	-	-	-	-	-	-		

The constraints applied to the initial parameters were set as follows (Table 3) :

Table 3 – Constraints on the initial parameters of the age determination model

μ	'**MGC**' : the means follow a growth model (that is, the output means can vary slightly around the input parameter)
σ	'SEQ' : all the standard deviations are equal (Macdonald and Pitcher 1979)
p	-

5. Corrected pseudo-cohort model (Laurec and Santarelli-Chaurand 1986)

a. Initial parameters

Natural mortality M was set to 0.2, as there was no clear estimate for this parameter available in the literature. Estimates were found to be as low as 0.025 year^{-1}, a value no cohesive with the biological reality of marine species. However, multiple values of natural morality were tested, values tested ranged between 0.009 and 0.3. The terminal fishing mortality (FT) was arbitrarily set to 0.1 year^{-1}, because trap targets only on a size interval, and the catchability of such gears on the highest sizes in the catch is lower. Tested values were between 0.09 and 0.4.

b. Methodology process (Laurec and Santarelli-Chaurand 1986)

When assessing marine stocks, the most commonly used method is the virtual population analysis. In VPA, a cohort is monitored from its recruitment to the last age. This method estimates fishing mortalities and fish numbers at each age for each cohort present in the

analysis. It then requires multiple years of data, in order to follow a cohort throughout its lifetime.
This method uses the catch (5) and survival (6-a) equation to reconstruct the fishing mortality and numbers, initializing the calculations with a terminal fishing mortality, and then iteratively using both equations to reconstruct the fishing mortality and numbers.

$$C_{(Y,a)} = \frac{F_{(Y,a)}}{F_{(Y,a)}+M} N_{(Y,a)} * (1 - exp^{-(F_{(Y,a)}+M)}) \text{ (5)}$$

$$N_{(Y+1,a+1)} = N_{(Y,a)} * exp^{-(F_{(Y,a)}+M)} \text{ (6-a)}$$

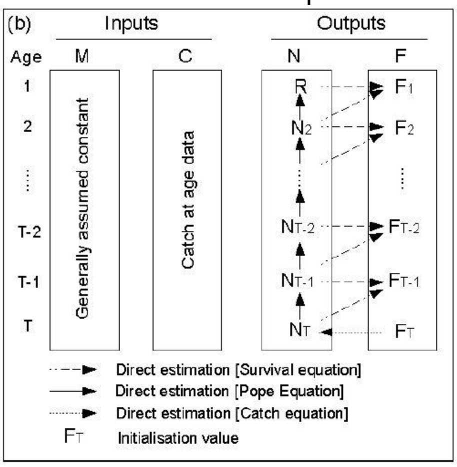
with : C the catch value,
F the fishing mortality,
M the natural mortality, assumed to be constant for each year and each age,
N the fish numbers,
Y the year of the assessment (there is only 1 year in this case),
a the age.

Because the catch equation does not have an analytical solution when used in this type of model, a solution to this equation, and an estimation of the fish number N at each age can be obtained with the Pope equation (Pope 1972) (7), allowing for an estimation of the fish numbers at each age.

$$N_{(Y,a)} = N_{(Y+1,a+1)} * exp^{M} + C_{(Y,a)} * exp^{\frac{M}{2}} \text{ (7)}$$

with : C the catch value,
M the natural mortality,
N the fish numbers,
Y the year of the assessment (there is only 1 year in this case),
a the age.

In this study, only the catch at age data from 2019 were available. The pseudo-cohort method can then be used, if the fishery verifies 3 main hypotheses : the mortality rates (fishing and natural) must be considered constant throughout the analysis, the recruitment must be also considered constant, and finally the exploitation diagram (i.e. the size structure of the catches) has also to be considered constant. Then the cohorts present in a year can be compared and can be considered to represent the evolution of a classic cohort.



This method uses also the catch (5) and survival equation (6-a), but however is computed for a year only to reconstruct fishing mortalities and fish numbers for a theoretical cohort. The iterative process is presented in Figure 5.

Figure 5 – Schematic representation of the iterative process of a pseudo-cohort analysis using the (Pope 1972) equation (Chassot et al. 2008)

The SPM American lobster fishery has developed during the recent years, in response to the decline in snow-crab landings (Government of Canada 2016a). Some vessels have started to target the lobster, and some of the vessels already targeting lobster have increased their effort : more fishing trips and more traps per season. The fishing effort cannot then be considered constant during the 9-year timeframe of the study. Moreover, lobsters have been proven to benefit from the increasing temperatures in the Canadian regions due to climate change (Howell et al. 2005; Le Bris et al. 2018). In some Canadian regions, the increasing temperature, which is the most determining parameter for the lobster distribution, has resulted in increasing landings and increasing abundance indices (Government of Canada 2016b, 2016c, 2016d). Therefore, the recruitment of the SPM lobster fishery cannot be considered constant throughout the 9-year timeframe of the assessment.

The corrected pseudo-cohort analysis (Laurec and Santarelli-Chaurand 1986) allows to include in a pseudo-cohort analysis the variations of the fishing effort and of the recruitment. Since the fishing mortality cannot be considered constant, and that the fishing mortality is the catchability of the fishing gear multiplied by the effort, this method considers only the catchability of the fishing gear constant. The effort variation are taken into account, as well as the variation of the recruitment in the survival equation (6-b).

$$N_{(Y,a)} = R_y * exp^{-((\sum_{k=1}^{a-1} q_{(k)} * E_{(Y-(a-k))}) + M)} \quad \text{(6-b)}$$

The effort time-series was obtained through logbook data and is measured in number of traps hauled * number of fishing trip. The variation of recruitment was assumed to follow the abundance trend. 3 different abundance indices were calculated

Log-book data were also used to compute 2 yearly stock abundance indices. It is commonly considered that, in fisheries using trap gears and other dormant gears, the landings and the CPUE constitute both a great estimate of the average stock abundance. If the trap is placed every time at the same location or in the same fishing zone, then both CPUE and landings should constitute a great estimate for the average yearly stock abundance. Both indices were computed using a glm model (X), using, for the first one the average CPUE calculated like previously detailed, and for the second one the declared landings. These indices were then compared to confirm that landings and CPUE represents a great estimate of the stock abundance. Both indices were obtained using the same data and the same glm modelling technique and formula. The method developed as follows was also used to compute an abundance index using the recreational fishery data, only the boat effect was removed from the model.

$$\log(X_{(y,m,b)}) = \alpha + Y_{(m,b)} + M_{(y,b)} + B_{(y,m)} + \epsilon_{(y,m,b)} \quad (2)$$

with : Y the effect of year and y the year indice
M the effect of month and m the month indice
B the effect of boat and b the boat indice
ϵ the residuals, where $\epsilon \sim N(0, {\sigma_{res}}^2)$
α the model's intercept

For consistency, professional logbook data were sorted in order to achieve a better fit of the models. Factor combinations (i.e. observations for a boat, one month of a particular year) observed less than 5 times were eliminated. Boats present only on one year were eliminated because they would artificially increase the 'boat effect' on the glm. Months not observed every year were taken off the analysis as well. Finally, if the landings were higher than 400 kilograms, these observations were taken off the data. More than 400 kilograms landed on one day is very unlikely considering the size of the boats, and the number of traps hauled each day. Landings higher than 400 kilograms were either an error in the database computation or represented multiple fishing trips pooled in one declaration. Overall, the cleaned database contained 99.2% of the total recorded trips.

In the glm models, the effect of year y and month m were investigated (2). In addition, for the professional abundance indices, a boat effect b was added. All 3 distributions were hypothesized to follow a log-normal distribution. X symbolizes the raw data entered in the model : professional CPUE for the first model, professional landings for the second model and recreational CPUE for the abundance index model. The indices were calculated using the following equations (3 & 4)

The link function for a normal distribution is the identity function. In this case, since the distribution chosen is the lognormal distribution, the computation of the standardized data is calculated as follows :

$$\log\left(\widehat{X_{(y,m,b)}}\right) = \hat{\alpha} + \widehat{Y_{(y)}} + \widehat{M_{(m)}} + \widehat{B_{(b)}} \quad (3)$$

$$SI = \exp\left(\log\left(\widehat{X_{(y,m,b)}}\right)\right) * \exp\left(\frac{{\sigma_{res}}^2}{2}\right) \quad (4)$$

with : $\hat{Y}$ the estimated effect of year and y the year indice
$\hat{M}$ the estimated effect of month and m the month indice
$\hat{B}$ the estimated effect of boat and b the boat indice
${\sigma_{res}}^2$ the estimated residual variance in the residuals
$\hat{\alpha}$ the estimated model's intercept
SI the estimated standardized index derived from X

The abundance index derived from the recreational fisheries data was kept, as it was the only index with an estimate for 2019.

c. Yield per recruit

Yield Y quantifies the average production of a theoretical cohort throughout its life. It represents the contribution of a cohort to the production of the stock during its lifetime. In the equation (8), Y is divided by the recruitment R, representing then the average contribution to the production of the stock of an individual throughout the course of its life. During the time interval $t_{(a)}$ - $t_{(a+1)}$,

$$Y_{(a)} = F_{(a)} * N_{(a)} * exp^{-\left(\left(F_{(a)}+M\right)*\left(t_{(a+1)}+t_{(a)}\right)\right)} * \overline{W}_{(a)} \quad (8)$$

For this study, R was assumed to be the number of fish for the first age, calculated in the pseudo-cohort model previously introduced. The fishing mortality vector used in the equation was the values obtained in the pseudo-cohort model. To visualize the effect of a global change in the fishing effort applied to the stock, the fishing mortality vector is multiplied by a fishing effort multiplier mE. mE was set between 0 and 2, with a step of 0.1. The individual weight of the lobsters was calculated using the formulas determined by (Thomas 1973), and then averaged for each age class to obtain $\overline{W}_{(a)}$ the mean weight per age.

The fishing mortality corresponding to the maximal Yield, F_{max}, can be used as an estimate of F_{MSY}, when it is not possible to estimate directly a Maximum Sustainable Yield.

2 types of exploitation rates were also calculated according to the formulas in Table 4.

Table 4 – Formulas and references for the calculations of exploitation rates

Reference	Formula
(Beverton and Holt 1956)	$\overline{F} / (M + \overline{F})$
(Government of Canada 2016c)	$\frac{nb\ males\ cohort\ n°4}{nb\ males\ cohort\ n°3}$

6. Approach based on life-history traits (WKLIFE – 2)

When studying data-poor stocks, it is important to compare multiple methods in order to have a better idea of the stock status. A cohesive diagnosis from multiple methods is more likely to be accurate and to fit the biological reality of the stock. The ICES working group WKLIFE works on the development of assessment methodologies based on life history traits for data-limited stocks (ICES 2012). The SPM American lobster stock has never been assessed yet. The available data consists of the professional landings from 2012 and 2018, the 2019 size structure of the stock, and an abundance index from 12 recreational fishery traps from 2002 to 2019. Since the survival rate for this species, and most of the crustacean species, is very high, this analysis was only conducted on landings, not the total catch. A total of 4 length-based reference points, and the mean length L_{mean} of the landings are calculated in this analysis.

L_c is the length associated with half the maximum of the catches, like shown in Figure 6.

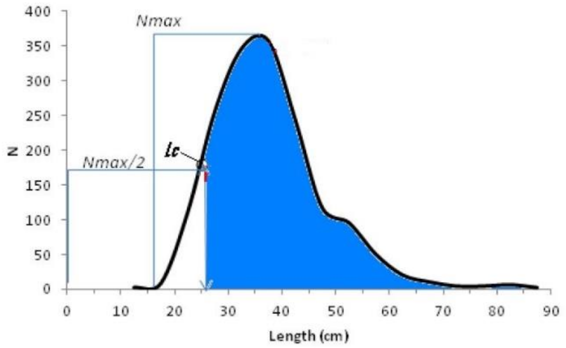


Figure 6 – Calculation of L_c from the length frequency of the North Sea turbot, adapted from (ICES 2012)

Because female lobsters carry eggs every 2 years, it was considered that all females were mature when 50% of them were carrying eggs. L_{mat} was then set according to the data collected for this stock. The size frequency of berried females is presented in the Results.

L_∞ was set to the highest size observed in the sample.

L_{mean} is the mean size in the sample, weighed by its frequency in the sample.

$L_{(F=M)}$ is calculated as shown in equation 9, and can be used as an estimate for L_{MSY}, if it is considered that $F_{MSY} = M$. This reference point can also help to estimate and compare F to M. If $L_{(F=M)} > L_{mean}$, F is likely to be larger than M.

$$L_{(F=M)} = (3 * L_c + L_\infty)/4 \quad (9)$$

The analysis was conducted for the total fishing zone and for the zone East and zone West of Miquelon.

7. Software used

The version 3.6 of R-64 bits was used throughout this report. A list of the packages used is available in Appendix 7.

And these data could be used to compute a standardized yearly abundance index in a glm model (2).

Results

1. The SPM lobster fishery : fishing zones

a. GPS data : distribution of the fishing effort

The fishing time, calculated from 28,712 GPS positions from the Recopesca concentrators of the 6 SPM boats, was summed 1' per 1' squares (Figure 7). The intensity of the color represents the intensity of the fishing effort. Circled areas indicate the lobster fishing areas (in blue the West area and in orange the East area). The fishing zone located at the very south correspond to a snow crab fishing are. The blue zone at the very top of Miquelon is a whelk fishing zone.

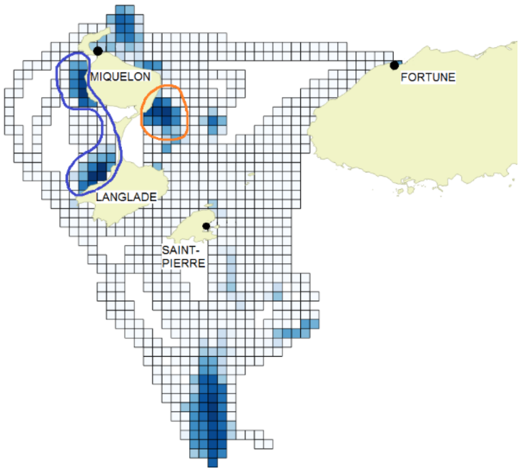


Figure 7 – Map of the total fishing effort of 6 artisanal fishing boats located at SPM in 2019 from May to July

SPM fishing boats are small, and it can take up to 2 hours to reach their fishing zones (Table 5)

Table 5 – Travel times to lobster fishing zones

Port of origin	Travel time to East	Travel time to West
MIQUELON	2h 05	2h 08
SAINT-PIERRE	2h06	2h 15

Table 6 – Travel to Fortune characteristics

# boat	# of trips to Fortune	# of fishing trips	Total # of trips	% trip to Fortune	Travel time to Fortune	Port of origin
4	11	49	60	20	2h 53	MIQUELON
1	8	34	46	17	2h 52	MIQUELON
2	13	33	45	28	4 h	SAINT PIERRE
3	4	19	23	17	3h 52	SAINT PIERRE
6	2	28	30	6	3h 37	MIQUELON
5	8	42	50	16	2h 07	MIQUELON

The boats have been anonymized and assigned a random number that is consistent throughout this report. Except for 1 vessel, which sells most of its catch locally, and does not fish for snow crab, each boat spends about 20% of their trip going to Fortune (Table 6), Canada. It takes 4 hours for boats from Saint-Pierre and about 2h 30 from Miquelon to travel to Fortune, Canada.

b. Environmental characteristics

Recopesca probes recorded water temperature in the lobster traps. 70289 observations from both mastodon and Recopesca probes were grouped by day (Figure 8).

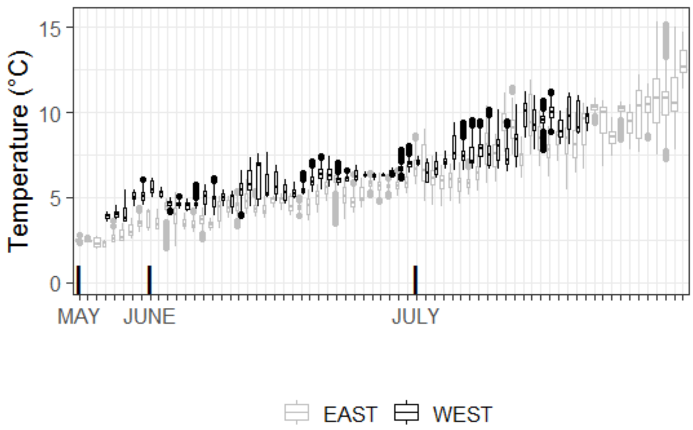
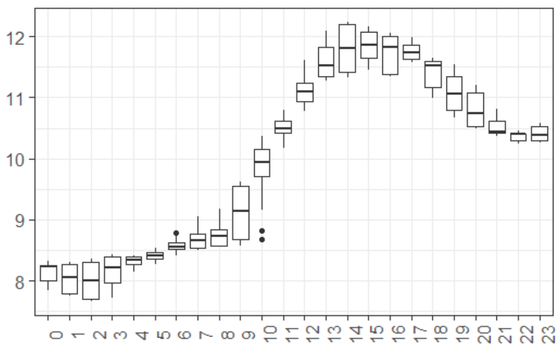


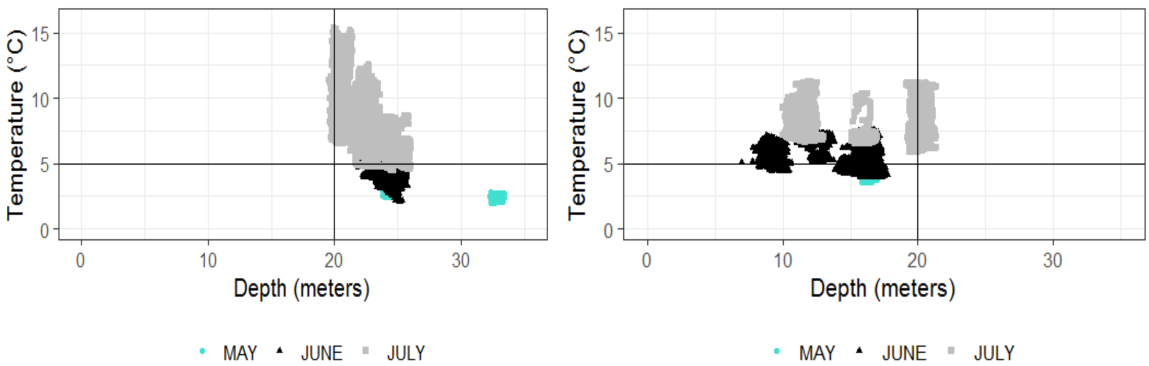
Figure 8 – Daily bottom temperature of the 2 fishing zones at the East and West of Miquelon, from May 24th, 2019 to July 31st, 2019.

The general tendency is similar between zones. However, temperatures were slightly higher at the West in May and early June, but this difference is less visible in July. Temperature are highly variable at the east of Miquelon, and can vary of 7°C during a day. The average temperature is significantly different between zones (t-test, p-value < 0.01).



In late July, the temperature is highly variable, and these variations can be up to 4°C at 20-meter depth in a single day (Figures 9, 10 & 11).

Figure 9 – Temperature variations in a 24-hour time frame during late July at the same depth



Figures 10 & 11 – Bottom temperature depending on depth in the east (left) and west (right) fishing zones

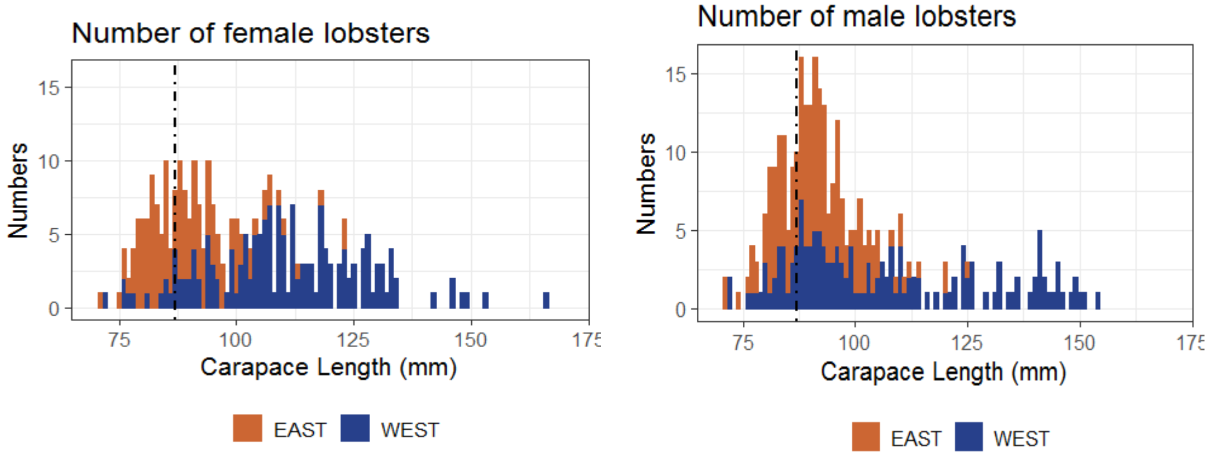
The temperature at a constant depth is varies widely in July, from 7 to 15 °C at the east of Miquelon, whereas the temperature range at the west is not very different from that of June. Daily July temperature is highly variable in the east zone.

2. Biological characteristics

The sample is constituted of 615 individuals measured during 5 fishing trips in all the different fishing zones around Miquelon. Half of the individuals were measured in each zone. Logbooks well completed indicates that landings are similar between both fishing zones (47% at the east and 53% at the west).

a. Demographic indicators (size structure, sex ratio)

The size structure of the catches was gathered at-sea. Sizes of males and females are separated (Figures 12 & 13).

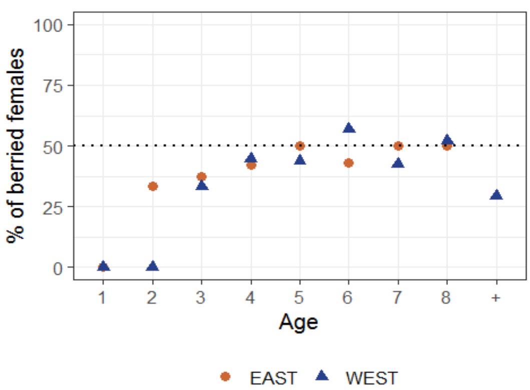


Figures 12 & 13 – Size structure of the sampled female (n = 294, left) and males (n = 321, right) in 2019 at SPM

22 % of the females and 23 % of the males sampled were smaller than the 87 mm minimal catch size. % lobsters in total were smaller than 87 mm. However, the mean size is significantly different between zones (t-test, p-value < 0.01). The mean catch size at the west is 108 mm whereas it is 90 mm at the east.

There are an equilibrated quantity of females and males in total, and in both fishing zones, the total sex-ratio being for the total stock at 1.09. Males and females mean catch size is not significantly different.

b. Productivity indicators



The percentage of berried females in 5 mm size classes in presented in Appendix 8. The proportion of berried female (Figure 14) is commonly used in Canadian stock assessments.

Figure 14 – Percentage of egg-carrying female lobster depending on age.

Observations indicate that females are 50% berried at the 3rd cohort observed in the catches, or at a size of 90 mm. There are however no differences in the percentage of berried females between zones (t-test, p-value = 0.6169). In addition to discarded berried females, lobsters under 87 mm of CL are also discarded. The total proportion of discards reaches up to 50% in the east zone, and 45% in total (Table 7).

Table 7 – Composition and proportion of discards

	TOTAL	EAST	WEST
% of lobsters < 87 mm	23	36	11
% of berried lobsters	22	17	27
% of total discards	45	53	38

c. abundance indicators

Professional fishery

Data consisted is 7 years of the professional logbook declaration. 1750 fishing trip were entered in a database, and after cleaning the data according to the procedure detailed in the previous section, 1532 fishing trips were used to compute average yearly landings, CPUE and standardized abundance indices.
The TAC is set to 30 tons at SPM for ore than 10 years. Yearly landings (Figure 15) have recently increased and even exceeded the TAC in 2017.

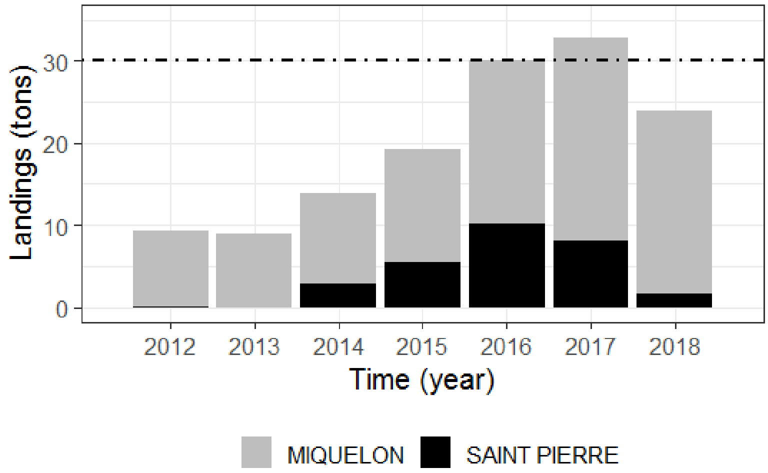


Figure 15 – Lobster landings at SPM from 2012 to 2018.

In addition, the average daily landings per year (Figure 16) have also slightly increased, as well as the average daily CPUE (Figure 17).

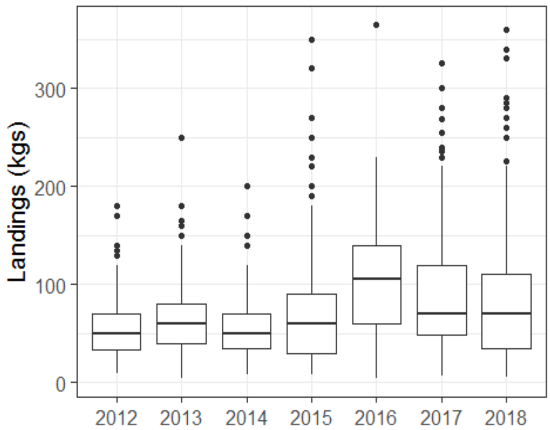


Figure 16 – Daily landings (kilograms) grouped per year for the professional lobster fishery from 2012 and 2018

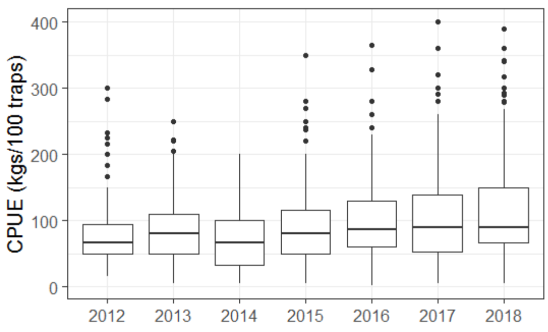


Figure 17 – Daily CPUE (kilograms/100 traps) grouped per year for the professional fishery at SPM from 2012 to 2018

CPUE differ also significantly per year.
Monthly landings and CPUE are presented in Appendices 9 & 10, respectively.

The distribution of the CPUE and Landings are presented in Appendix 12, and is assumed to follow a log-normal distribution. This distribution was visually verified (see Appendix 13), and plots of raw data can be found at appendix 14 & 15. They show an effect of the different levels of the variables in the models. The glm coefficients of both models are presented in Appendices 16 & 17, respectively. The glm models using the professional fisheries data explained 34 and 33% of the total variance, respectively.
The standardized index derived from the landings values present however a maximum value in 2016, that is not present for the index derived from the CPUE. Both standardized abundance indices follow the same trend except for a slightly more important difference for 2014 and 2016 (Figure 18).

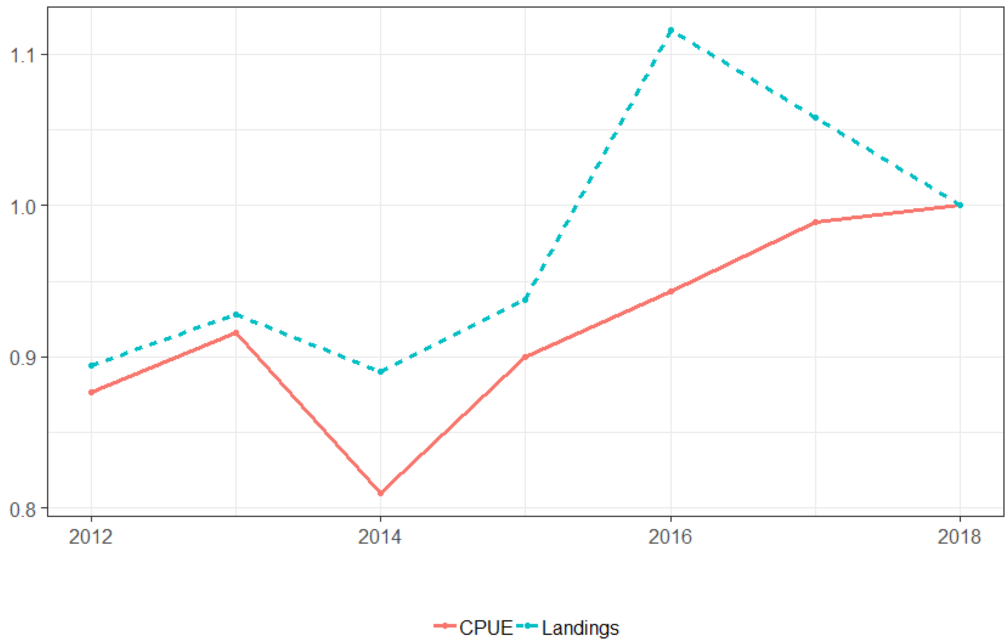
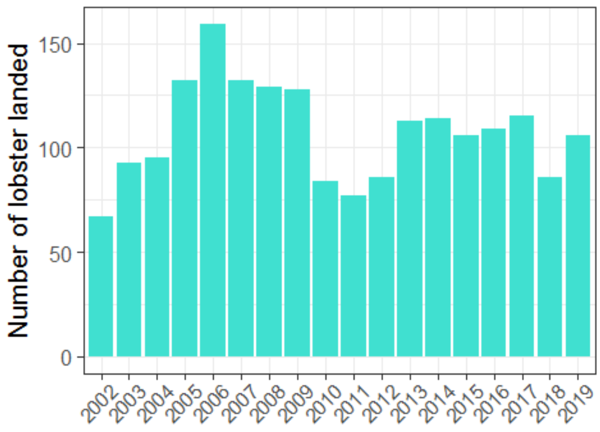


Figure 18 – Standardized abundance index derived from the professional CPUE (red lines) and landings data (blue lines) data and corrected of a year, month and boat effect. All variables were significant and kept in the model (anova, p-values < 0.01).

Recreational fishery



18 years of data, and 654 fishing trip were gathered to compute average landings and CPUE (individuals per traps).

Yearly landings have increased between 2002 and 2009 (Figure 19), the maximum catch value being 2006 with 153 lobster landed. Landings are stable around 100 lobsters per year since 2012.

Figure 19 – Number of lobsters landed per year from May 2002 to July 2019 by a recreational fisher

The distribution of the CPUE from recreational fishery is presented in Appendix 19, and was visually verified in normality diagnosis plots (Appendix 21). The model indices are presented in Appendix 22.
Raw recreational CPUE follow the same trend than annual landings and are stable around 0.25 individuals per trap (Figure 20). Both recreational and professional CPUE rates are presented in Appendix.

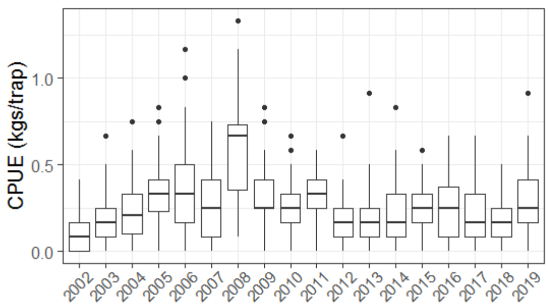


Figure 20 – Number of lobsters landed per trap

The glm model allowed for the computation of standardized yearly abundance indices (Figure 21). Both the year and month had a significant effect on the CPUE, and were kept in the model (anova, p-values < 0.01).
The standardized index abundance is stable in the recent years. 23% of the total variance is explained by the model.

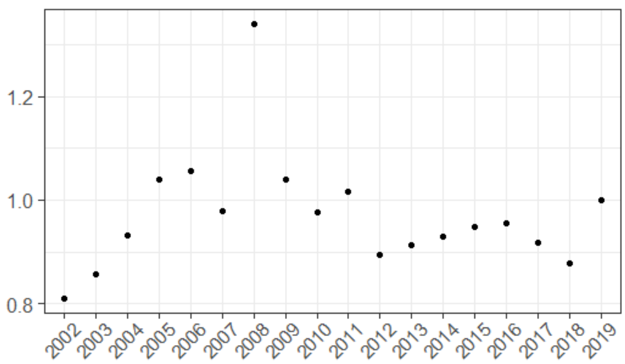


Figure 21 – Standardized abundance index derived from the recreational fisheries data and corrected of a year and month effect.

Comparing the 3 abundance indices computed, the indices derived from the professional raw data and the index derived from the recreational data (Figure 22) do not follow the same trend for the most recent years. The recreational index is quite higher than the 2 others between 2012 and 2016, but . 2019 index is only available for the standardized recreational fishery data. 2018 was set to 1 for comparison purposes. However, since only he recreational fishery index was computed for 2019,it was used as a recruitment index in the corrected pseudo-cohort model.

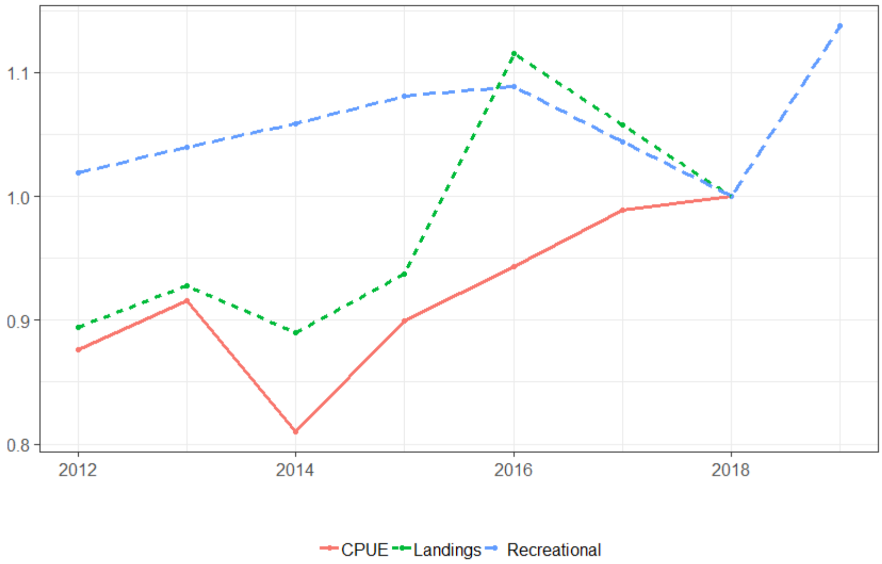
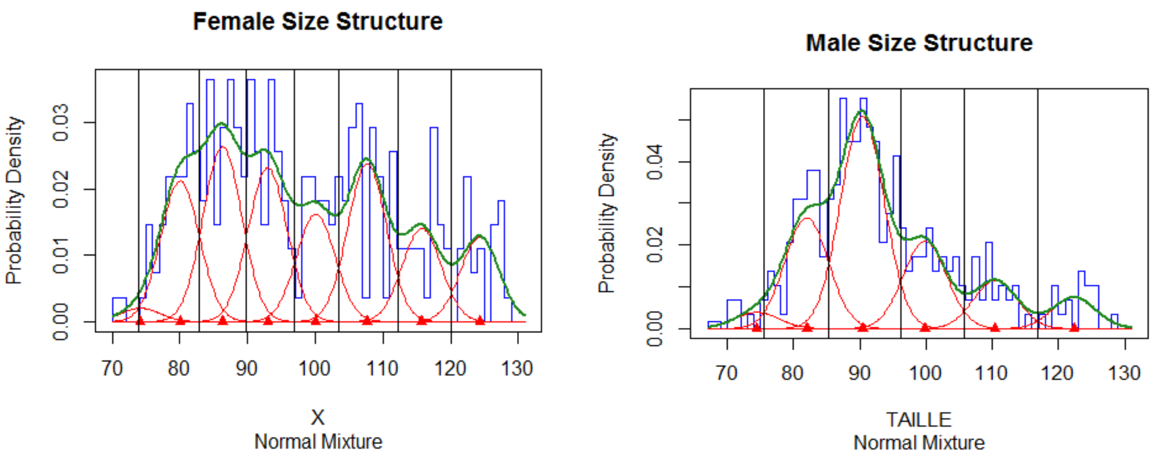


Figure 22 – Standardized abundance indices from the 3 GLM models. 2018 was set to 1 for comparison purposes

3. Age determination

a. Model fit

In both size structure cohort decomposition (Figures 23 & 24), the blue histogram represents the raw data. Red triangles are the mean sizes µ for each cohort. The red distribution is the estimated normal distribution of the size for each cohort. The green bold line represents the cumulated estimated density for each size.



Figures 23 & 24 – Female (left) and male (right) size structure age decomposition using a multi-normal mixture decomposition.

b. 2019 professional lobster catches

For 2019, the catch-at-age data were obtained (Figure 25). The first 2 cohorts or first 2 ages in the catches are constituted of lobsters smaller than the minimal catch size. In the older cohorts, discards are constituted of berried females.

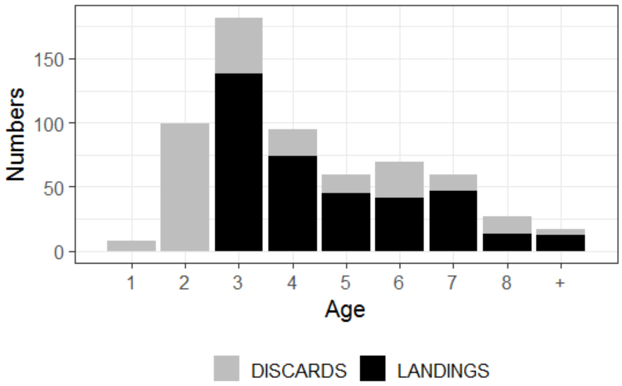


Figure 25 – 2019 lobster catches per age

4. Corrected pseudo-cohort model

a. Sensibility to the natural mortality initial parameter

A total of 8 mortality rates were tested for the diagnosis of the total zone (Figure 26). All mortality rates lead to the same trend in the estimation of the fishing mortality. However, the peaks at age 3 and 7 are less important for mortality values from 0.2 to 0.3.

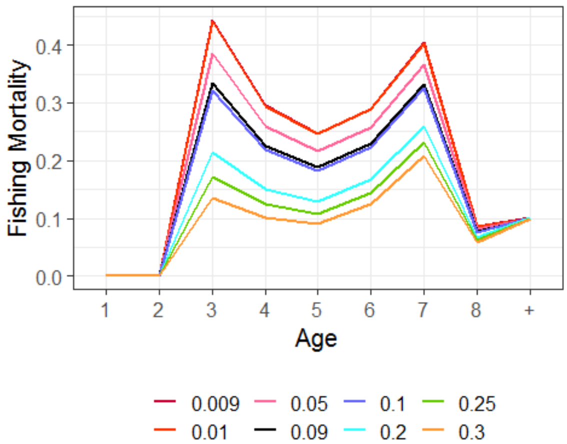


Figure 26 – Sensitivity analysis of the estimation of the fishing mortality to the natural mortality estimate.

b. Sensibility to the terminal fishing mortality estimate

A total of 9 different values of the terminal fishing mortality (FT) were tested (Figure 27). All FT estimates lead to the same pattern in the fishing mortality trend. The peak observed for the age 7 is however more prominent for FT values ranging from 0.15 to 0.4 year^{-1}. The FT value chosen for the analysis (0.1 year^{-1}) leads to a less exacerbated peak for the fishing mortality at age 7. Also, trap gear have a low catchability at the end of the size interval it targets on. A low value of catchability, and of FT, since the effort for 2019 is set to 1, was chosen and kept during the analysis (0.1 year^{-1}).

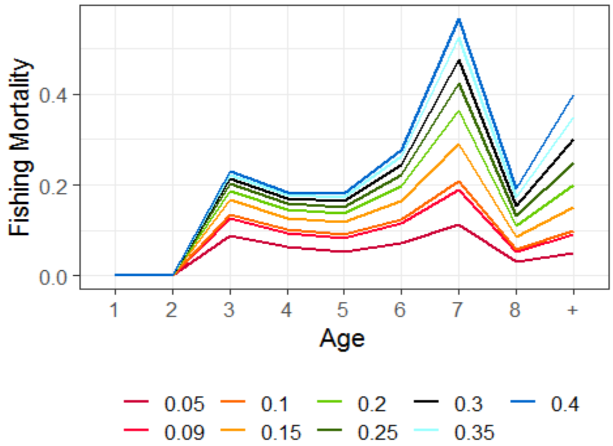
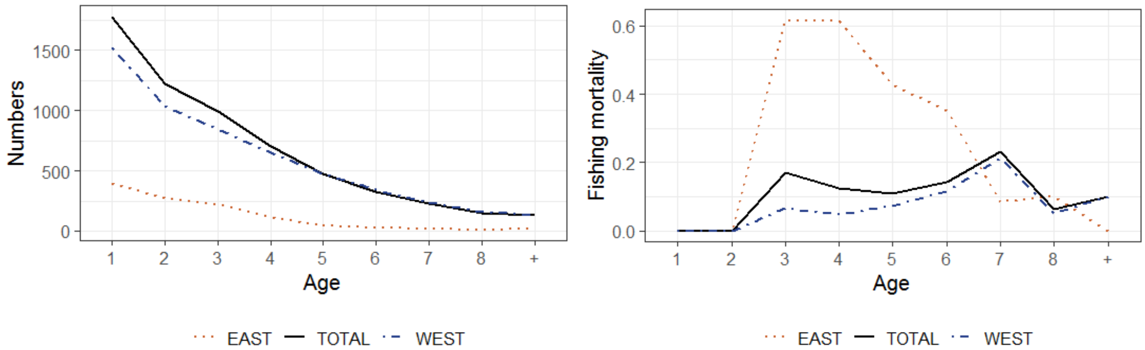


Figure 27 – Sensitivity analysis of the pseudo-cohort model estimation of the fishing mortality to the estimate of the terminal fishing mortality.

c. Estimated numbers and fishing mortality

The pseudo-cohort model provides then, after the setting of the initial parameters, an estimate of the fish numbers and fishing mortality (Figures 28 & 29). The diagnosis was independently conducted for the total zone, as well as for the EAST and WEST zones.



Figures 28 & 29 – Estimated lobster numbers (left) and fishing mortality (right)

The pseudo-cohort model estimates a significantly lower number of lobsters in the east zone than in the west zone. Moreover, older lobsters are estimated to only live in the west zone. Fishing mortality and numbers were estimated based on the landings taking into account the survival rate of discarded lobsters.

d. Yield per recruit

The yield per recruit was then calculated using the output numbers and fishing mortality from the pseudo cohort model. This diagnosis was also conducted for the total fishing zone (Figure 30) and for the 2 different fishing zones as well (Figure 31).

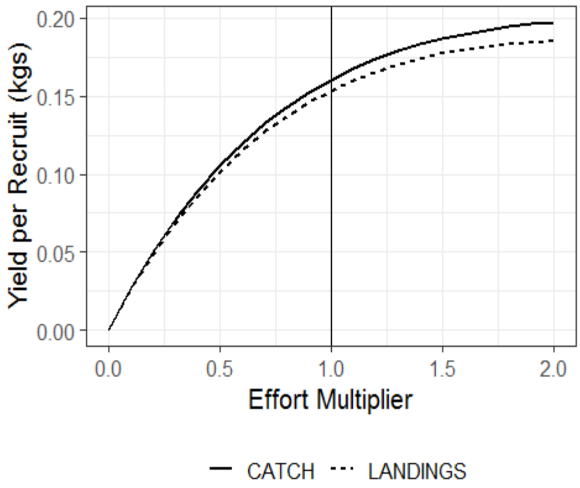


Figure 30 – Global yield per recruit (kilograms per recruit) for the SPM lobster stock.

The yield per recruit of the SPM lobster stock reaches its maximum at an effort multiplier of 1.75.

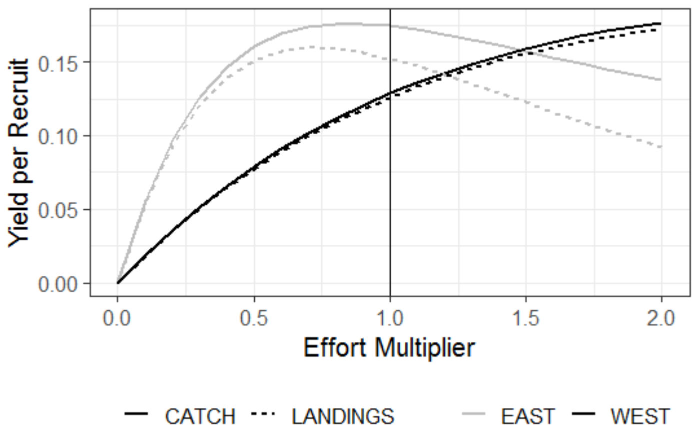


Figure 31 – Yield per recruit (kilograms per recruit) of the SPM lobster stock per zone.

On the total stock, the maximum yield per recruit is reached at an effort multiplier of 1.7. However, the zone-separated diagnosis shows that this maximum is reached for the east zone at 0.6 whereas at a value higher than 2 for the west zone. F_{max} is higher than F_{actual} the current fishing mortality in the east zone and lower than F_{actual} in the west zone.

The different measures of the exploitation rates also confirm that the exploitation is higher in the EAST zone (Table 8).

Table 8 – Different measures of the exploitation rate on the SPM lobster stock

	TOTAL	WEST	EAST
$\bar{F}$ year^{-1}	0.12	0.08	0.31
Exploitation rate (Beverton and Holt 1956)	37 %	28 %	60 %
Exploitation rate (Government of Canada 2016c)	65%	67%	60%

5. Length based reference points

Another method of stock assessment in data poor situations was also investigated. The diagnosis was conducted for the total zone, and for the EAST and WEST zones independently (Figures 32, 33 and 34, respectively).
The x axis represents the sizes of lobsters. For the 3 diagnosis plots, the number of observations per size (blue curve) was smoothed using the 'loess' method.
For the total zone and the east zone, the mean landings size is lower than the $L_{(F=M)}$ and L_{opt}. For the west zone, L_{mean} equals L_{opt} and $L_{(F=M)}$. Both the $L_{(F=M)}$ and L_{opt} are estimation of the mean length that would be reached if the stock was fished at the Maximum Sustainable Yield.

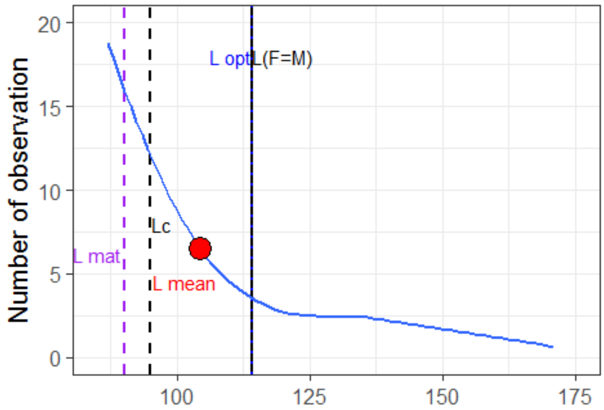
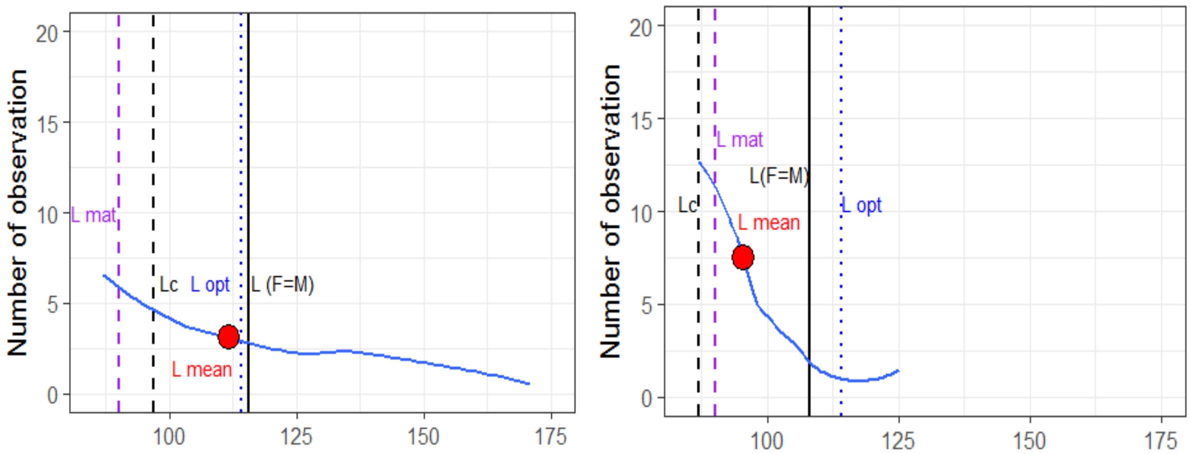


Figure 32 – Diagnosis plot of the SPM lobster stock using the length-based reference point for the total SPM stock.



Figures 33 & 34 – Diagnosis plot of the SPM lobster stock using the length-based reference point for the WEST (left) and EAST (right) zone.

Discussion

1. Stock borders & limits

The fishing effort at SPM on the lobster stock is distributed between 3 different zones (Figure 7). Even though the at-sea sampling did not make it possible to collect quantitative information on the distribution of the recreational lobsters' fishery, qualitative information was gathered through formal and informal interviews. The recreational fishery is distributed near the village of Miquelon, at the east coast of Langlade as well as all around the Saint-Pierre island. These areas are overcrowded with traps and are not available for professional fishers.
No professional fishing effort was observed between the 2 effort patches at the west (Figure 7). The travel time being already important to reach the west fishing zones (Table 5), it appears then logical that professional fishers exploit the closest available zone.
In addition to the travel time to reach the fishing zone, both lobsters and snow crabs are sold to a sea-food wholesaler located at 45 kilometers of the archipelago. The travel time can be up to 4h depending on the location of departure (Table 6). The delivery of the catches represents about 20% of the total number of fishing trips, except for one boat from Miquelon which sells mostly locally in the archipelago.

During interviews of actors of the lobster fishing industry at SPM, the 2 fishing zones mentioned were the east and west zone of Miquelon-Langlade. This report will focus on the diagnosis of the lobster population, both considering the total SPM stock, but also investigating the difference in the environmental characteristics of the east and west zones, and the lobsters' different biological characteristics.

Temperature is one of the most defining parameters of the lobster distribution (McLeese 1956; Aiken and Waddy 1976; Cooper and Uzmann 1980; Hudon 1987; MacCormack and DeMont 2003; Dove et al. 2005; Bergeron 2011; Raper 2012; Quinn 2017; Le Bris et al. 2018; Han et al. 2019). The global trend in the daily temperature during the period of sampling is similar in both zones (Figure 8). The average temperature is significantly higher at the west zone (Figure 9). Higher temperatures could accelerate the spring lobster's movement to the coast. Indeed, lobsters usually slow their metabolism during winter, at temperature lower than 5°C. When the temperatures exceed this threshold, lobsters' metabolism is not inhibited anymore, the animals start to seek for food and move to the shore. Temperatures higher than 5°C are reached sooner in the west zone. Lobsters are then more likely to be found sooner in this zone.

The late July temperature is highly variable in the east zone, varying by up to 7°C in a day (Figure 9). This temperature variation is observed at the same depth (Figure 10). Lobsters are thought to prefer temperatures between 10 and 20 °C, but do not well tolerate sudden changes in temperature (Quinn 2017). High temperature variations could disfavor lobster abundance at the east of Miquelon. The temperature at the west zone is less variable for a constant depth (Figure 11) and is more suitable for lobsters.
In this study, it was hypothesized that lobsters from both zones had the same growth parameters. However, it has been proven that the temperature of their environment has a great influence on the growth rate of lobsters (Bergeron 2011; Raper 2012; Raper and Schneider 2013). An improvement to this hypothesis could be to verify in the field the growth parameters of the lobsters from both zones, for example by a catch-release study.

In addition, studies have shown that lobsters from southern regions are suffering from climate change and global warming of the water temperatures, whereas lobsters in Canadian regions seems to benefit from the rise in temperature ("Warming ocean temperatures push lobster populations north | NOAA Climate.gov" n.d.; Caputi et al. 2013; Wahle et al. 2015; Le Bris et al. 2018; Han et al. 2019). The abundance of lobsters at SPM in the future could be rising. It will then be important to monitor and keep track of the landings and CPUE to quantify this variation and eventually improve the stock assessment models or the monitoring of the fishery. Canadian stock assessments are mainly based on indicators of the stock status, which allows for a management more closely related to the actual stock status.

Moreover, the environmental conditions being more favorable at the west zone, the seasonal repartition of the fishing effort should also follow the same trend. Indeed, if lobsters are thought to arrive sooner in the west zone because of higher temperatures, then fishers would start the lobster season by the west zone. The Recopesca data, will provide information in the future on the seasonal variation of the fishing effort.

The presence of an important rocky cluster at the west could also help better protect lobsters when the weather is less favorable and provide a suitable habitat for lobsters.
Pollution might also cause differences in the abundance of lobsters. An important seal population lives next to the east lobster fishing zone and are responsible of a pollution of the area that could render the seafloor anoxic and poorly fitted for the survival of benthic marine species. Moreover, the pollution could also impact the food supply of lobsters. In addition, seals are known to feed on lobsters and could heighten the mortality rate of lobsters at the east (Gales and Pemberton 1994; Stone 1995; Lelli and Harris 2006). A lower food supply and a higher predation rate could have an impact on the size structure of lobsters at the east zone. These parameters added to a high fishing pressure would lower the average size of lobsters because of a higher total mortality rate.

Finally, the west part of Miquelon-Langlade is more susceptible to difficult weather and sea conditions. Indeed, this zone is directly influenced by the Saint Lawrence current, whereas the east coast is protected by the island of Miquelon Langlade. This moderates the influence of other environmental parameters. The west zone has a general higher temperature and contains protected areas such as rocky substrates, whereas the east zone is more susceptible to high temperature variations but is less susceptible to difficult climatic conditions.

Further investigations on the influence of oceanic currents, the occurrence of climatic events and a mapping of the seafloor would improve and complete this diagnosis of the environmental environment in the SPM archipelago. Indeed, besides from temperature, there are other environmental variables such as the presence of rocky substrates that influence greatly the distribution and abundance of lobster.

There are no lobsters caught at the top zone of Miquelon. This could mean that there are no adult lobsters in this zone. However, to define the limits and borders of a stock, the larval connectivity is an important factor to integrate. Lobsters larvae are pelagic for up to 4 weeks (Holthuis 1991; Annis 2004) and could travel with the sea currents between the 2 zones. In addition, when settling, juvenile lobsters have very specific habitat needs (Cooper and Uzmann 1980; Hudon 1987; Cowan et al. 2001) that might prevent them to settle at the north and south of Miquelon. Sea currents around the archipelago during summer indicates that a strong larval connectivity is very likely at SPM (Lazure et al. 2018). Then, the 2 zones cannot be considered as 2 different stocks. However, considering the highly sedentary life of an adult lobsters, it is possible to observe locally differences in some biological characteristics. In this study, there is evidence that the mean catch size is significantly different between zones (Figures 12 & 13). However, other characteristics such as the sex-ratio or the proportion of berried females are not different between zones (Figure 14). A proportion of berried females of 50%, since female lobsters carry eggs every 2 years, is thought to be a good indicator for the stock status. The global catches size structure can also be helpful to assess the status of lobster stocks, and these indicators are widely used in Canadian stock assessments.

It was also possible to compare the size-structure of the catches between SPM and some Canadian LFAs. This element can also provide information on the stock status. A reduced size-structure is often the sign of a highly exploited stock. In this case, the size-structure of the stock at SPM ranges in a wider interval than the size-structure of the Magdalen islands (Figure 35).

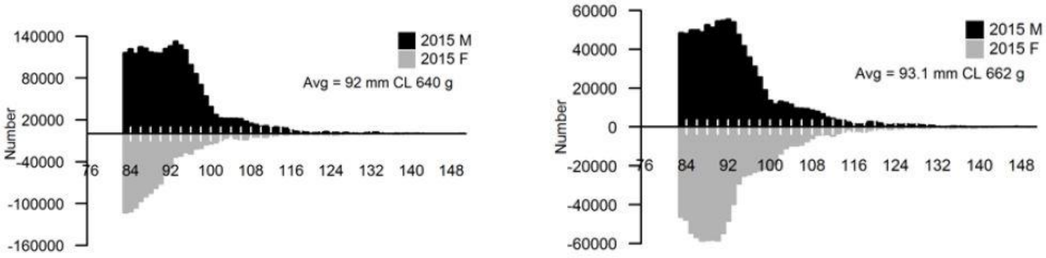


Figure 35 – Size structure of lobsters in the North (left) and south (right) parts of the Magdalen islands (Government of Canada 2016c)

The average catch size in SPM is 90 mm at the east and 108 mm at the west. The minimal catch size in the Magdalen islands is 83 mm. Even though the minimal catch size at SPM is higher, the average Magdalen islands catch size is still higher than that of the east zone of SPM. A decreasing and low mean catch size could lead to decreasing CPUEs if the stock is not correctly managed. The average catch size at the east zone is very close to the minimal catch size and is concerning for the stock status in the east zone. If the average catch size is decreasing, the CPUE could decrease to a critical point for the stock. However, it was not possible to know whether the average catch size was decreasing in the east zone, since there have never been any scientific observations on the lobster stock.

2. CPUE and indicators of stock status

The difference in productivity between the zones could also be monitored. However, the fishing zone is often not specified in the logbooks, and it was not possible to compute a CPUE time series for the 2 fishing zones separately. The global landings show however an increase in the recent years (Figure 15)
It was possible to compute average landings and CPUE (Figures 16 & 17), and per month (Appendices 9 & 10), for the global SPM lobster stock. During interviews, it was specified by fishers the number of traps exploited every year, and that half of their traps were in each zone. CPUE were then calculated following this hypothesis, when the logbooks were not complete. According to the Recopesca probes, 3/5 of the fishing time was located at the west, and 2/5 at the east. It should however be noted that the total fishing season is not registered, and that some of the boats have turned off the concentrator multiple times during the period. In addition, only a few logbooks were available for 2019, with a total of 12 fishing trip targeting lobsters. The few logbooks available could not confirm that landings were equal between zones because the trips available do not represent a sample big enough to represent the season.

The average landings (Figure 16) and average annual CPUE (Figure 17) follow the same trend but are however different for each year. First, Saint-Pierre vessels have started to land lobsters in 2014. The lower average landings and CPUE in 2014 could be caused by lower landings and CPUE for the Saint-Pierre fishers. In addition, according only to the landings data, 2016 was a year of great production.
This production peak is not confirmed by CPUE. Fishers have probably increased the number of their fishing trips. If the fishing pressure is suddenly increased on a stock, the average catches should increase immediately, before the stock reaches another equilibrium situation.

It is also interesting to compare the raw CPUE values to those of the most productive LFAs in Canada. CPUE raw values are significantly higher at SPM than in the some productive LFAs of Canada. The examples of CPUE rates below are those of a Gaspésie LFA (LFA 20, Figure 37) and off the Magdalen islands (LFA 22, Figure 38).

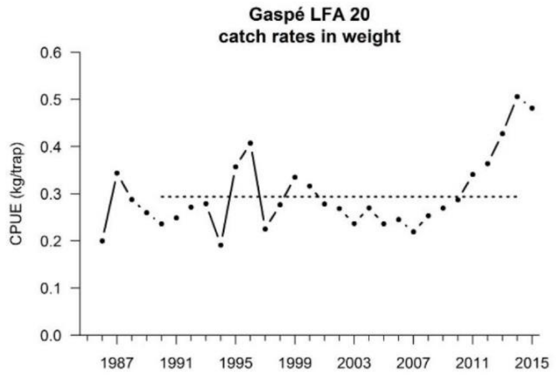


Figure 36 – CPUE (kilograms/trap) in the Gaspé LFA 20 from 1985 to 2015 (Government of Canada 2016b).

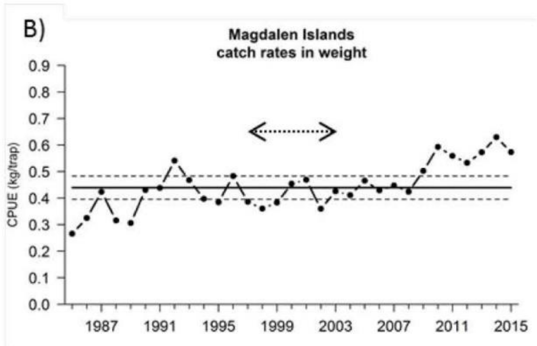


Figure 37 – CPUE (kilograms/trap) in the Magdalen islands, LFA 22 from 1985 to 2015 (Government of Canada 2016c).

The average CPUE for the SPM stock was 0.8 kilogram/trap between 2012 and 2015, whereas it is under 0.5 kilogram/trap in the Gapsé LFA 20 (Figure 36), and under 0.7 kilogram/trap in the LFA 22 (Magdalen islands, Figure 37). According to the average annual CPUE in weight, the SPM stock is more productive than Canadian LFAs.

In fisheries using traps, both the CPUE and the average landings can be used as abundance indices. Indeed, the fishing power of these gears do not increase or decreases, if they are placed every year at the same location or in the same fishing zone. Moreover, the fishing strategy in these kinds of fisheries using traps do not vary significantly between years. A standardized abundance index was computed using the CPUE (Appendix 15) calculated following the hypothesis based on the fishers' declarations of effort, and another standardized index was calculated using the declared landings (Appendix 16). The abundance indices could be compared because they were both corrected of the fishing power of each boat. This way, each monthly CPUE is estimated if all boats had the same fishing power. The data were assumed to follow a lognormal distribution. Diagnosis plots confirming this hypothesis are presented in Appendix 13.
The 2 glm models derived from the CPUE and landings data achieved a good fit of the data, achieving to explain respectively 34 and 33% of the variance. The diagnosis plots of the residuals of the 2 models are presented in Appendix 18.

The standardized abundance indices derived from the professional fishery data (Figure 18) confirms that 2014 was a year of lower production. It could also mean that the stock production was low this year. The 2016 peak observed in the raw landings is also less visible in the standardized index derived from the landings data. When compared, the 2 standardized indices derived from the logbooks data appear to follow the same general trend, except for the 2016 peak. As a result, it appears that the average daily landings could represent a good way to monitor the abundance of the stock, if the number of traps is not entered in the logbooks.

Another type of data regarding the lobster stock was available. A recreational fisher agreed to participate in the project by giving the landings data he has been recording for 18 years (Figure 19). The average annual catch is around 100 lobsters. However, there is a peak in 2006 that might be caused by an increased abundance in the SPM lobster stock. CPUE (Figure 20) show the same 2006 peak, meaning that the period between 2005 and 2009 was a period of high abundance of lobsters at SPM. The traps used are placed every year at the same locations, and the number of lobsters caught is recorded for every fishing trip. It represents then a great time-series to complete and improve the professional time-series.

The CPUE of this recreational fisher could not be compared directly to the professional CPUE, since the professional CPUE's unit is kilogram and the recreational CPUE's unit is individual/trap. Even if the distribution of the CPUE of the recreational fishery was more consistent with a gamma distribution, it was necessary to use the same method for the 3 glm models, and the distribution of the CPUE of the recreational fisher was assumed to follow a lognormal distribution, diagnosis plots can be found in Appendix 20. The recreational CPUE were standardized using the same method as that of the standardization of professional data.
The index from recreational fishery (Figure 21) data seems stable during the last 10 years. The peak in landings and CPUE observed in 2006 is still present but smoothed by the standardization.

In order to compare the 3 standardized indices, 2018 was set to 1 (Figure 22). The indices do not follow the same trend. However, since the data for 2019 were available in this case, the standardized abundance index entered in the pseudo-cohort model is the standardized abundance index derived from the recreational fishery data.

3. Corrected pseudo-cohort model : initial hypotheses

a. Recruitment and effort time series

First, the analysis was conducted only on the landings, because lobsters and crustacean in general have a good survival rate when they are discarded.

2 time series were also integrated to the model to consider the variations of recruitment and effort. The lobsters are thought to benefit from the rise in temperatures due to climate change (Howell et al. 2005; Le Bris et al. 2018). It is then very important to integrate the variation in abundance in the model. The corrected pseudo-cohort method integrates only the recruitment variations. This kind of data were not available for the SPM zone. There is a recruitment index for Canadian LFAs in place ("Lobster Recruitment Index Project" 2018). However, this kind of data was not available for the Newfoundland regions, and there was no data for 2019. It was then hypothesized that an abundance index could be used in this study, also considering the lack of data at SPM. This study is only the first assessment ever to be made on this stock. A study on recruitment and larval connectivity and drift could enhance significantly the quality of this assessment. However, these kinds of precise data were not available, and the abundance index of the recreational fishery was chosen and integrated in the model.

An effort time series was also included in the model. This time-series represents the estimated number of traps hauled per year, and the 2019 year is set to 1. It is possible that the effort is underestimated, because the fishers might not declare all their landings or all their fishing trips. In addition, the number of traps per trip is an estimate by the fishers, because logbooks are not completed, and the number of traps hauled in each fishing trip is generally lacking.

Models like the corrected pseudo-cohort model need however catch at age data. Lobsters are very hard to age animals (Wahle et al. 1996; Sheehy et al. 1999; Ouellet and Allard 2002; Bergeron 2011; Kilada et al. 2012) even with laboratory works, since the only hard part of a lobster that could keep track of their age like scales or otoliths is renewed every year.

b. Catch-at age data : cohort assignement

The size structure of the SPM lobsters was decomposed into multiple normal distributions. Each normal distribution's parameters were then used to assign an age to a size interval. The age 1 of the analysis is the first age in the catches but does not represent the actual first year of the lobster's life. Lobsters of 83 mm are 7 to 8 years old. In this study, the goal was not to determine the actual age of lobsters, but to differentiate all the cohorts in the sampling.
In addition, molting in lobsters have been estimated multiple times to be once a year (Hughes and Matthiessen 1962; Cobb et al. 1982), or sometimes less (Campbell 1983) in less favorable environments. It was hypothesized here that lobsters molted once a year, and molt increments, i.e. the average growth per molt, as so per year, used are those of a population of Newfoundland (Ennis 1972). The growth increments were assumed to be the annual growth of lobsters, and cohort were assumed to be a year distant. However, the study would benefit from a study of the growth parameters of lobsters at SPM.

A simpler method would have been to gather information on the Von Bertalanffy (VB) parameters of lobster stocks nearby. However, there are few studies on the growth of lobsters using this technique (Bergeron 2011; Raper 2012), since the VB growth curve models a continuous growth and lobsters grow discontinuously by molts (Breen 1994; Stewart and Kennelly 2000). In addition, the VB parameters found in the literature (Ennis 1972; Campbell 1983; Raper and Schneider 2013) were not consistent with the size range of the data gathered in 2019.
There are however multiple studies measuring the average growth increment per molt for lobsters in different regions. The growth increment values selected (Ennis 1972) belonged to the closest stock, which was facing the most similar temperature constraints, temperature having the greatest effect on growth of lobsters.

The result of the normal mixture decomposition was computed separately for females (Figure 23) and males (Figure 24). The first cohort of the size structures is constituted of very few individuals, and it is likely that these individuals belong to the second cohort of the size distribution. However, for consistency, and since both cohorts 1 and 2 were 100% discarded, the cohort 1 was kept in the analysis. Moreover, the cumulative proportion of the polymodal decomposition (the green curve in Figures 23 & 24) achieves a great fit to the raw data (blue histograms in Figures 23 & 24). However, the limits between the sizes of 2 cohorts were set to the intersection between the 2 normal distributions. Since the mis-assignations on both sides of the borders are quite similar, it was thought that lobsters were globally well assigned in their cohort of belonging.

Finally, a cohort '+', grouping all lobsters taller than 130 mm was created. There were too little individuals in this size range to fit these individuals in the decomposition procedure and achieving a great fit of the cohort decomposition to the raw size distribution data.

The age determination allowed for the analysis of the 2019 lobster catches (Figure 25). The 2 first cohorts caught in the traps have a size smaller than the minimal catch size of 87 mm. There is a total of 23% of lobsters smaller than the minimal catch size, and a total of 45% of discards, when the berried females are included (Table 7).

c. Initial mortality parameters : natural mortality M & terminal fishing mortality FT

The effect of the 2 input parameters was explored.
There is little available literature on the natural mortality rates of lobsters (Chen et al. 2005; Kanaiwa et al. 2008). The parameters that were found were not consistent with the life constraints of a marine species like the lobster. Natural mortality rates of 0.04 to 0.08 $year^{-1}$ are not consistent with a high predation rate, and it was hypothesized that lobsters at SPM had a greater natural mortality rate. In addition, the natural mortality rates estimated in the literature are estimated with a great uncertainty, and were thought to be unconsistent with the biology of the SPM stock. Estimated natural mortality rates in other species of lobsters were, in addition, often reported very low and imprecise. In addition, SPM shelters an important seal population that can target the lobster. This seal population is also responsible for a high pollution mainly at the east lobster fishing zone.

The investigation of the natural mortality rate estimate's influence on the estimation of the fishing mortality (Figure 26) showed an increased peak of fishing mortality for the 3^{rd} and 7^{th} cohort. M estimates of 0.1 $year^{-1}$ or lower led to an estimation of fishing mortalities at 0.3 $year^{-1}$ or higher. M estimates higher than 0.2 $year^{-1}$ reduced the importance of peaks at the 3^{rd} and 7^{th} cohort. It was hypothesized that the less important peaks in fishing mortalities were more plausible for the estimation of the fishing mortality on the total zone, given the that the stock is fished on a wide size range. An estimate of M at 0.2 $year^{-1}$ was kept throughout the analysis. Since there is a seal population on the EAST zone, it could also be interesting in the future to investigate the difference in mortality rates between the 2 zones.

Because the catchability of trap gears is lower for older and larger lobsters, the parameter FT was thought to be between 0.01 and 0.2 $year^{-1}$. M was set to 0.2 $year^{-1}$, while investigating the influence of the terminal fishing mortality on the estimation of the fishing mortality rates (Figure 29). A peak in fishing mortality for cohort 7 was observed for FT values higher than 0.15 $year^{-1}$. Again, a peak in fishing mortality for one of the oldest cohorts was not thought to be plausible considering the high exploitation of smaller lobsters, especially at the east zone. A value of FT = 0.1 $year^{-1}$ was thought to represent a low catchability rate for the cohort '+' in the model. Moreover, the cohort '+' does not represent a lot of individuals (17 individuals, 2% of the total sample). The convergence property of such ascendant analysis allows for the achievement of the same trend in the fishing mortality estimation for all the test values of FT. For the further analyses, M was set to 0.2 and FT to 0.1, as these values were the most consistent with the observations of the catches. Indeed, catches are equilibrated in the size interval between the 3^{rd} and 7^{th} cohort. High fishing mortality estimations for one or both cohorts are unlikely.

4. Corrected pseudo-cohort model : diagnosis and conclusions

The initial parameters were set as previously developed. The model was run on the total catch at age data, for the total stock and independently for each zone (EAST and WEST). The catches in weight and in number are similar in both zones. The sample was assumed to well represent the 2019 catches, and the size structure of the stock was assumed to be have remained constant in the recent years. The model estimated a significantly different abundance of lobsters between zones (Figure 28). In the east zone, the abundance of lobsters is very low compared to the west zone. In addition, the estimated number of lobsters after the 5^{th} cohort is estimated to be around 0. In the west zone however, there is a higher number of individuals, and the number of individuals does not reach 0.

The fishing mortality (Figure 29) is, consequently to the very low estimation of the number of lobsters, very high for the youngest animals in the catches in the east. Fishing mortality for the

3rd and 4th cohort found in the catches reaches 0.6 $year^{-1}$ at the east zone. Compared to the fishing mortality rates estimated in the west zone, which do not go pass 0.2 $year^{-1}$, it seems that the exploitation of the east fishing zone is higher, and focused on smaller individuals. Indeed, computation of exploitation rates show that the east zone is more exploited. The exploitation rates calculated following the Canadian stock assessment method showed that the exploitation of lobsters in the east zone is higher than the exploitation of lobsters in the Magdalen islands (Table 8). Even though the landings in the Magdalen islands are rising, such high exploitation rates should alert scientists on the stock status. Exploitation rates on the west zone is also high, at 60%

Yield per recruit computations (Figures 30 & 31) confirm that the exploitation of lobsters at the east zone is higher than that of the west zone. In these figures, the actual mortality rate, calculated in the pseudo-cohort model, is set to 1. The maximization effort, F_{max}, corresponding to the maximum yield per recruit is often considered as an estimate of the F_{MSY} (Horbowy 2012). In that case, for the global stock, the F_{max} is reached at 1.7 times the actual rate. Globally, it seems that the stock is fished at a lower rate that the F_{MSY}. However, when the yield per recruit diagnosis is separated by zones, there is a different diagnosis and different conclusions made for both zones.
First, in the west zone, the yield per recruit diagnosis concludes that this part of the stock is underexploited, and the fishing effort can be increased without putting at risk the stock. Fmax is reached for twice the actual fishing mortality rate, mE = 2.
The east zone however appears to be overexploited. F_{max} is lower than the actual fishing mortality rate (mE = 1). The fishing mortality rate should be lowered by 30% in order to exploit the stock at a sustainable level. Indeed, F_{max} is reached for 0.7 times the actual fishing mortality rate. If the continues to be exploited at this rate, the mean size of catches will decrease. The proportion of small and discarded lobsters, already important, will continue to increase.

Even though the east zone seems overexploited, and contains mostly small lobsters, there is a possibility that the fishing pressure on the east zone might not be reduced. Lobsters ranging from 87 to 100 mm are easier to sell, both locally and at the sea-food wholesaler, because there is strongest demand on this size range. There is then a trade-off to be determined between the biological optimum exploitation rate, and the average catch size of lobsters.
Moreover, small female lobsters produce less eggs and of poorer quality (Butler et al. 2015; Haarr et al. 2017). If only small females are left at the east zone, this part of the stock could be less resilient facing changing climatic conditions or climatic event. However, it is also possible that newly hatched larvae spawned at the west of Miquelon-Langlade would be carried to the east zone by sea currents.

2 types of exploitation rates were calculated (Table 8). When using the (Government of Canada 2016c) methodology, the total stock is less exploited than the LFA 22 lobster stock. The exploitation rate in the Magdalen islands is around 64% whereas the total exploitation rate is 37% in total at SPM. However, the exploitation rate is much higher in the east zone, where it almost reaches 60%. Such high exploitation rates could threaten the sustainability and resilience of lobsters at the east zone.

Finally, the lack of data regarding the recreational fishery is concerning. Indeed, the east zone is the closest lobster zone from the village of Miquelon, where the recreational lobster fishery is widely practiced. The model clearly lacks information on the recreational lobster fishery, and then misses a great part of the fishing pressure. To improve the computations and calculations of the exploitation rate and the fishing mortality rates, a quantification of the recreational fishery is necessary.

5. Length-based reference point diagnosis of the SPM lobster stock

To complete the pseudo-cohort analysis, a method based on life-history traits was also investigated concerning the lobster stock (ICES 2012). This method could provide a useful tool for local management authorities, as this method is simple to implement and could also provide the same type of results as those previously discussed.

First, this analysis was only conducted on the landed part of the catches. Contrary to other marine species, crustaceans have a great survival rate when discarded (Mesnil 1996; Bergmann and Moore 2001; Harris and Ulmestrand 2004). Then the fishing mortality in the pseudo-cohort model was calculated on the landings only, and this method is based on the same sample. This method could also be implemented on the total catches, but for consistency and for comparison purposes, it was chosen to compute this method on the landings only. This method is based on the estimation of 4 length reference points for marine species.

L_∞ values found in the literature were not consistent with the size structure of the stock, or the stocks studied was not subject to the same environmental conditions than the climatic environment of SPM. Other method to determine the VB growth could also have been used. However, like previously evoked, the VB curves describes a continuous growth. Lobsters grow once a year, when they molt, and their growth is then discontinuous. As it was not possible to find a cohesive estimation on L_∞ and that the VB growth is not well suited to describe discontinuous growths, L_∞ was then set as the last observed size. In addition, since there is no evidence that the 2 zones constitute 2 different stocks, the estimate of L_∞ was considered constant throughout the fishing zones. In addition, L_∞ was sometimes also set to the maximum observed length in the methodology ICES document.

The length at maturity L_{mat} was determined as 90 mm, as it was the size for which 50% of females were carrying eggs. However, this value is not consistent with the literature, which estimates L_{mat} being between 68 and 73 mm. Since there was still an estimate of L_{mat} for the stock, that estimate was set as L_{mat}.

In this method, $L_{(F=M)}$ is an estimate of the mean length that would be achieved in the landings if the stock was sustainably exploited (ICES 2012).
L_{opt} is an estimate of the peak in weight growth. It is also a reference point for which it is assumed that most of the stock is underexploited, and egg production is maximized.

According to these length-based reference points, it appears that the total stock is slightly overexploited (Figure 34). The mean size of the landings is lower than the size that would be achieved if the stock was sustainably fisher.
The west part of the stock (Figure 35) appears, according to this method, sustainably exploited. The mean length of the landings is equal to the $L_{(F=M)}$.
The east part of the stock (Figure 36) also appears to be overexploited, since the mean length of the landings is significantly lower that $L_{(F=M)}$.
However, these conclusions should be cautiously drawn. The reference points are calculated under very constrained hypotheses. For example, the estimate of L_∞ is to be cautiously considered, since there has never been a study on the growth of lobsters. These conclusions on the length-based diagnosis would benefit from a study of the growth of the lobster at SPM.

6. Conclusion

Although the data used in this report are sometimes lacking precision and/or quality, especially the data from the professional logbooks, the field-work allowed for the collection of new data regarding the SPM lobster stock.

The overall diagnosis indicates a general positive trend in the stock status, although some of the reference points could be alarming. These results need however to be handled carefully considering that they are based only on one year of data, and data of variable quality.

The length-based reference points are computed using very containing hypotheses and should be handled with precaution. The general trend of the pseudo-cohort analysis shows a globally well exploited stock. The effort can be slightly increased; however, this increase should be within reasonable limits. In addition, since lobsters are sedentary animals, the diagnosis draws different conclusions when considering the 2 fishing zones fished by the lobster fishers at SPM. While the west part of the stock seems exploited at a sustainable level, the east part of the stock shows signs of overexploitation. This method is simpler to implement and can rapidly inform on the stock status. This is a simple method that can easily be experimented on the lobster fishery, and even in other SPM artisanal fisheries such as the snow crab, … It allows for the monitoring of the lobster stock status with only the size-structure of the catches. However, it can only be implemented if there is a will to monitor the lobster fishery from the fisheries observers whom have never participated at a lobster fishing trip.

The east part of the stock presents reference points such as the mean length of the catches and the exploitation rate that are very similar to the LFA 22, the Magdalen islands. This stock of LFA 22 has a global production, or CPUE, half the average production of SPM. If the effort in the east zone is not reduced, then this part of the stock could reach as low levels of CPUE. This part of the stock is more likely to be less resilient to climatic events or to resist and cope with the global climatic trend. However, the lack of resilience could partly be improved by newly hatched larvae from the west zone carried by sea currents to the east zone, since the 2 zones show no evidence that they should be considered as 2 different stocks.

Adult lobsters are sedentary animals that probably needs to be considered, in the case of SPM, as 2 subpopulations. Since the environmental conditions and some of their characteristics are different between zones, they probably need to be managed, at least for the short-term, as 2 different units in order to : first, lower the exploitation on the east zone which appears to be overexploited, and second to control the effort on the west zone in order to sustainably exploit this zone. This could be done by implementing a maximum number of traps per zone in order to limit the effort applied to the east part, and control the effort on the other part of the fishing zone.

Finally, there are many points that can be improved regarding the lobster population and fishery at SPM. First, there is a clear lack of data regarding the recreational fishery, that is widely practiced in SPM. The quantification of this fishing pressure could improve the fishery diagnosis, as well as the knowledge on the exploitation of the stock.

The professional fishery's data could also be improved. The logbooks are sometimes very poorly completed, and it renders the computation of simple CPUE very difficult, even though these kind of time series is a first great approach to have an idea of the stock status without any a priori information.

Finally, the stock diagnosis and monitoring could benefit from a scientifically based sampling protocol. There are 2 at-sea fisheries observers, but they have never monitored the lobster fishery. The size structure of the catches every year could be also a great way to monitor the fishery. Although, the length-based reference points method is a very simple method to implement, it can provide a reference for the management of fisheries just using the size structure of the stock.

In addition, scientific surveys of the benthic environment at SPM would improve both the understanding of the lobster populations dynamics. To conclude whether a particular zone is more suitable or the survival and abundance of the lobster, there is a need to map the sea floor and the benthic environments found in the archipelago.

Finally, in order to monitor the lobster population at SPM and to closely study the resilience and future abundances of the population, a study of the SPM lobster recruitment would be beneficial. In addition, this data would also improve the pseudo-cohort model.

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Appendices

Appendix 1 – Base-line for the interviews with SPM fishers

Enquête sur le secteur de la pêche artisanale à Saint-Pierre et Miquelon

Année de l'enquête : 2019

Période de collecte : Mai à Juillet

Lieu de la collecte : Directement sur l'archipel

Méthode de collecte : Entretiens en face à face

Dans le cadre du projet de recherche ATLANTILES, nous essayons de comprendre les stratégies des pêcheurs professionnels de Saint-Pierre et de Miquelon, mais aussi de cerner leurs perceptions et leurs attentes en matière de valorisation des produits de la mer

Cette enquête est commanditée par l'UBO (Université de Bretagne Occidentale) et menée en coopération avec la CACIMA et l'Ifremer. Les enquêteurs sont deux stagiaires employés par l'UBO.

Contacts :

Coordinateur du projet : LE FLOCH Pascal au +33 2 98 64 19 34

Partenaire local : CACIMA au +508 41 05 30

Les informations récoltées resteront confidentielles et seront traitées dans le cadre du projet de recherche ATLANTILES. Elles pourront être exploitées ultérieurement lors de travaux de recherche menés par UBO et Ifremer et portant sur la pêche à Saint Pierre et Miquelon.

Conformément aux dispositions de la loi n° 78-17 du 6 janvier 1978 modifiée, vous disposez d'un droit d'accès, de rectification et d'effacement des données personnelles vous concernant, ainsi que d'un droit à la limitation du traitement. Vous pouvez exercer vos droits auprès du Délégué à la Protection des Données de l'Ifremer : soit par courrier postal : IFREMER - Délégué à la protection des données - ZI de la Pointe du Diable - CS 10070 – 29280 Plouzané soit par courriel : dpo@ifremer.fr

Enquête sur le secteur de la pêche artisanale à Saint-Pierre et Miquelon Année de l'enquête : 2019

Période de collecte : Mai à Juillet
Lieu de la collecte : Directement sur l'archipel
Méthode de collecte : Entretiens en face à face

N° d'immatriculation du navire enquêté : |__|__|__|__|__|__|__|

Nom du navire enquêté : ……………………………………………………………………

Nom de la personne enquêtée : …………………………………………………………

Prénom de la personne enquêtée : …………………………………………………………

Dans le cadre du projet de recherche ATLANTILES, nous essayons de comprendre les stratégies des pêcheurs professionnels de Saint-Pierre et de Miquelon, mais aussi de cerner leurs perceptions et leurs attentes en matière de valorisation des produits de la mer

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Note d'information concernant le droit d'accès aux données (CNIL) remise à L'ENQUÊTé en début d'entretien :

☐ Non ☐ Oui

J'autorise que mes données à caractère personnel soient transmises aux enquêteurs à des fins professionnelles

☐ Non ☐ Oui

Informations générales :

1. Nom de la personne : ______________________________

2. Depuis quand pratiquez-vous la profession de marin-pêcheur ? ________

3. Quelles sont vos raisons d'entrer dans la profession ?

De père en fils / Attrait de la mer / Attrait du métier de la pêche / Emploi pour rester dans la région

Rémunération / Autres

4. Etes-vous armateur de votre bateau ? ______________________

5. Date d'achat du navire ? ______________________

5. Combien d'hommes embarqués sur ce navire, vous compris ? ________

6. Etes-vous adhérent à l'OPAP ? ______________________

Remarques autres :

Calendrier d'activité :

Objectif : On veut ici retracer votre activité de pêche pour l'année 2018. Savoir quels sont les métiers que vous pratiquez ? Quelles sont vos zones d'exploitations ? Comprendre aussi comment évoluent vos différentes stratégies au cours de l'année ?

Comprendre aussi la pêcherie de Homard dans le cadre du stage sur la pêcherie. On pré-remplit le calendrier pour gagner du temps.

Navire	Port	Longueur (m)	Puissance Kw	Année de construction

Année de référence : 2018

Mois	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Aout	Septembre	Octobre	Novembre	Décembre
Actif ?												
Nb de jour en mer												
Nb de jour de pêche												
Nb de personnes à bord												
Métier												
Espèces												
Zones												
Métier												
Espèces												
Zones												
Métier												
Espèces												
Zones												

7. Quel métier vous rapporte le plus ? (Reprendre déjà les métiers pratiqués dans la base) :

	Métier 1	Métier 2	Métier 3	Métier 4
Code métier				
Importance				

8. Nombre de sorties dans l'année ? (Montrer le chiffre calculé depuis la base) :

Homard :

19. Avez-vous pêché du homard sur les 5 dernières années (2013-2018) → on a la réponse dans la base

20. Avez-vous augmenté votre effort pendant les dernières années (2013-2018) (nombre de casier, type de casier, nombre de jours de pêche) → peut être la réponse dans la base

21. Pêchez vous du homard cette année (2019), ou seriez-vous intéressé à entrer dans la pêcherie, et sous quelles conditions ?

22. Votre sentiment sur l'évolution du stock ces dernières années ?

Rétrospective

Objectif : Dans cette partie, nous voulons comprendre l'évolution de vos activités de pêche, et quelles ont été les raisons pour lesquelles votre activité a changé au cours des 15 dernières années ?

9. Est-ce que vous ciblez les mêmes espèces depuis 15 ans ? (regarder aussi sur la base DTAM)

10. Quelles sont les raisons qui vous poussent à cibler une espèce plutôt qu'une autre ?

Vos stratégies de valorisation à l'heure actuelle

11. Quels sont les lieux actuels de vos débarquements ? Différences par espèces ? Quels sont les avantages ? Pré-remplir aussi.

Espèces (pré-remplir)	Lieux de débarquement (pré-remplir)	Mode de commercialisation	Avantages ?	Ordre de grandeur

12. Si vous vendez à Terre-Neuve, comment avez-vous trouvé vos contacts avec les intermédiaires canadiens ? Depuis combien de temps travaillez-vous ensemble ? Est-ce toujours les mêmes ?

14. Comment sont fixés les prix au Canada ? Prix moyen de vente sur l'année 2018 ?

13. Pour la vente directe, plutôt pratiquée au ponton ou par téléphone ? Vous arrivent-ils de sortir uniquement quand vous avez un carnet de commandes plein ?

15. Comment fixez-vous les prix pour la vente directe ?

16. Comment les prix ont-ils évolués lors de ces dernières années ? Distinguer vente aux usines et vente directe.

17. Pourquoi ne pratiquez-vous pas (plus) la vente directe ?

17.b. Pourquoi ne pas vendre directement à l'usine de Miquelon ?

18. Pensez-vous à des changements dans vos modes de vente ? Si oui, lesquels ?

Le futur de votre entreprise : Les contraintes, les opportunités, perspectives :

Objectif : Mieux comprendre et cerner les attentes des pêcheurs pour les années à venir en ce qui concerne leur activité de pêche.

19. Quelles sont les difficultés que vous rencontrez ? Qu'est-ce qui vous manque selon vous pour que les choses aillent mieux ? Conflits avec autres activités ?

20. Quelles sont les évolutions que vous envisagez dans l'année à venir ? Les années à venir ? Des changements majeurs sont-ils à prévoir ?

21. Êtes-vous plutôt optimiste ou pessimiste pour le futur de la pêche à SPM ? Pour le futur de votre entreprise ?

21. Êtes-vous plutôt optimiste ou pessimiste pour le futur de la pêche à SPM ? Pour le futur de votre entreprise ?

Appendix 2 – Number of traps and number of fishing trip per boat between 2012 and 2018

annee	bateau	nb casier	nb jour de mer
2019	3	300	70
2018	3	300	24
2017	3	300	52
2016	3	300	45
2015	3	300	37
2014	3	300	40
2013	3	0	0
2012	3	100	4
2011	3	100	4
2019	2	150	30
2018	2	80	12
2017	2	275	44
2016	2	275	48
2015	2	275	24
2014	2	275	12
2013	2	0	0
2012	2	0	0
2011	2	0	0
2019	4	250	40
2018	4	200	43
2017	4	200	49
2016	4	200	41
2015	4	200	25
2014	4	200	18
2013	4	120	22
2012	4	120	25
2011	4	120	25
2019	5	200	30
2018	5	200	46
2017	5	200	32
2016	5	0	0
2015	5	0	0
2014	5	0	0
2013	5	0	0
2012	5	0	0
2011	5	0	0
2019	6	250	60
2018	6	200	58
2017	6	200	61
2016	6	200	61
2015	6	200	69
2014	6	200	50
2013	6	200	42
2012	6	200	61
2011	6	200	61
2019	9	120	70
2018	9	120	76
2017	9	120	63
2016	9	120	70
2015	9	120	87
2014	9	120	80
2013	9	120	73
2012	9	120	81
2011	9	120	81
2019	7	0	0
2018	7	41	30
2017	7	87	34
2016	7	0	0
2015	7	0	0
2014	7	0	0
2013	7	0	0
2012	7	0	0
2011	7	0	0
2019	8	0	0
2018	8	50	15
2017	8	50	38
2016	8	50	19
2015	8	50	29
2014	8	50	5
2013	8	0	0
2012	8	0	0
2011	8	0	0
2019	10	0	0
2018	10	0	0
2017	10	0	0
2016	10	0	0
2015	10	0	0
2014	10	30	2
2013	10	0	0

2012	10	0	0
2011	10	0	0
2019	1	0	0
2018	1	0	0
2017	1	0	0
2016	1	68	34
2015	1	0	0
2014	1	0	0
2013	1	0	0
2012	1	0	0
2011	1	0	0
2019	11	0	0
2018	11	0	0
2017	11	0	0
2016	11	0	0
2015	11	0	0
2014	11	0	0
2013	11	50	9
2012	11	50	2
2011	11	0	2

Appendix 3 - At-sea sampling schedule

DATE	BOAT N°	ZONE	NB IND SAMPLED
24/05/2019	4	MIQUELON – EAST	265 (144 landed + 121 discarded)
25/05/2019	9	MIQUELON – WEST	99 (54 landed + 45 discarded)
06/06/2019	3	MIQUELON – EAST	32 (15 landed + 17 discarded)
11/06/2019	2	MIQUELON – WEST	153 (103 landed + 50 discarded)
02/07/2019	3	MIQUELON -WEST	66 (39 landed + 27 discarded)

Appendix 4 – (LEFT) Photography of an American lobster (“kisspng.com” 2019) (the blue line represents the carapace length) and (RIGHT) photography of a male (left) and female (right) lobster

Appendix 5 – Head of the size structure data-base, on-field sampling

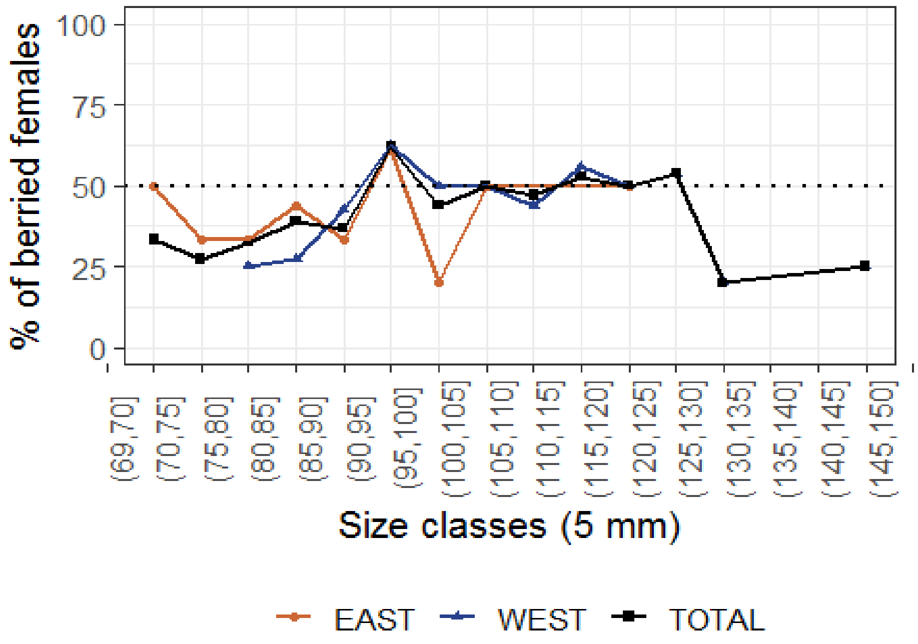
jour	DATE	BATEAU	SEX	TAILLE	BERRIED	DISCARDED	ZONE	NB_CASIER	V_NOTCHED	BAIT
24/05/2019	2019	4	M	103		0	EST	150		HARENG
24/05/2019	2019	4	F	104		0	EST	150		HARENG
24/05/2019	2019	4	M	95		0	EST	150		HARENG
24/05/2019	2019	4	M	101		0	EST	150		HARENG
24/05/2019	2019	4	M	100		0	EST	150		HARENG
24/05/2019	2019	4	F	85		0	EST	150		HARENG
24/05/2019	2019	4	M	94		0	EST	150		HARENG
24/05/2019	2019	4	F	84		0	EST	150		HARENG
24/05/2019	2019	4	F	100	1	1	EST	150		HARENG

Appendix 6 – Photography of the v-notched tail of a berried American lobster female (“V-Notching Remains Critical to the Sustainability of Maine ‘s Lobster Stocks” 2018)

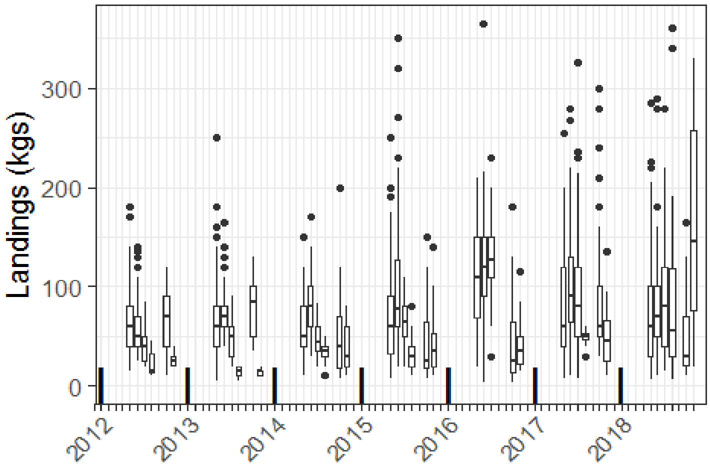
Appendix 7 – List of the packages used (R version 3.6)

'vegan', 'tidyverse', 'here', 'RODBC', 'sf', 'DBI', 'RODBC', 'odbc', 'maps', 'stringr', 'dplyr', 'ggplot2', 'mapdata', 'maptools', 'classInt', 'RColorBrewer', 'sqldf', 'mapview', 'lubridate', 'lwgeom', 'scales', 'lessR', 'verification', 'rgeos', 'RGeostats', 'sp', 'rgdal', 'akima', 'broom', 'TropFishR', 'gdata', 'mixdist', 'dLagM', 'mixtools', 'nor1mix', 'data.table', 'FSA', 'scatterplot3d', 'lattice', 'verification', 'modEvA'

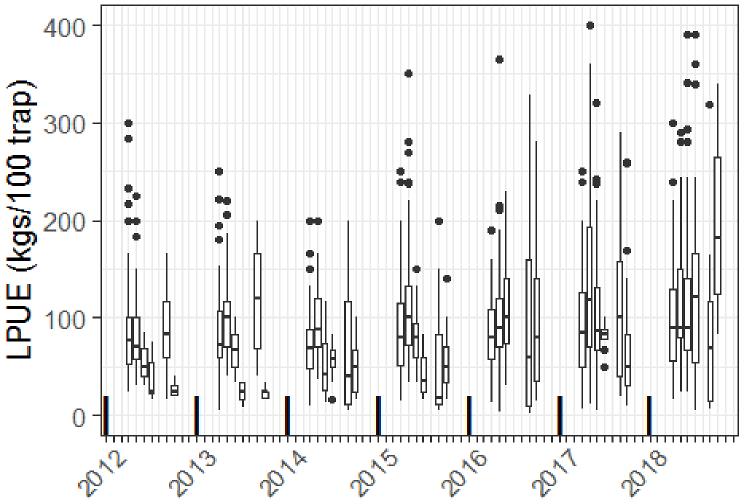
Appendix 8 – Berried females proportion in 5 mm size classes



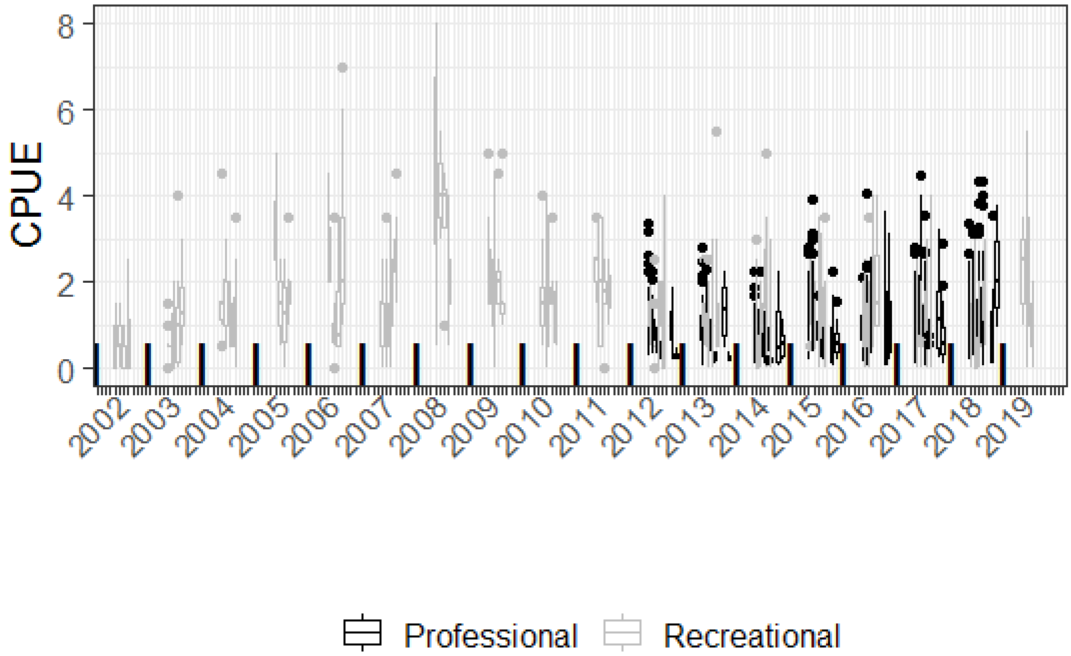
Appendix 9 – Monthly professional lobster landings at SPM



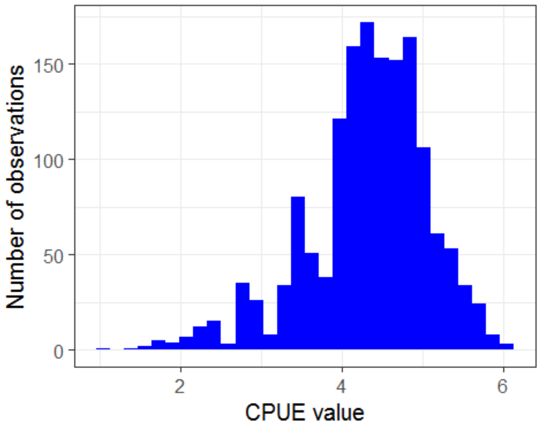
Appendix 10 – Monthly professional lobster CPUE at SPM

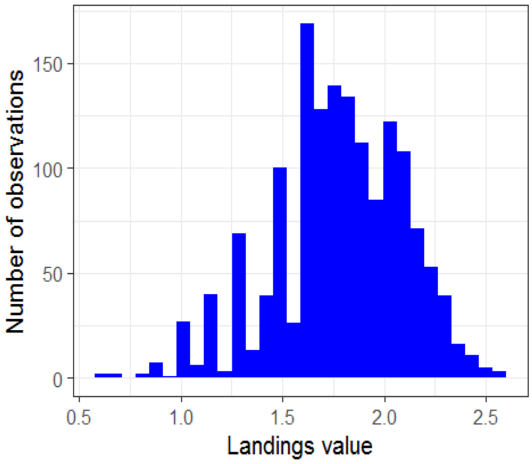


Appendix 11 – Monthly professional and recreational CPUE at SPM

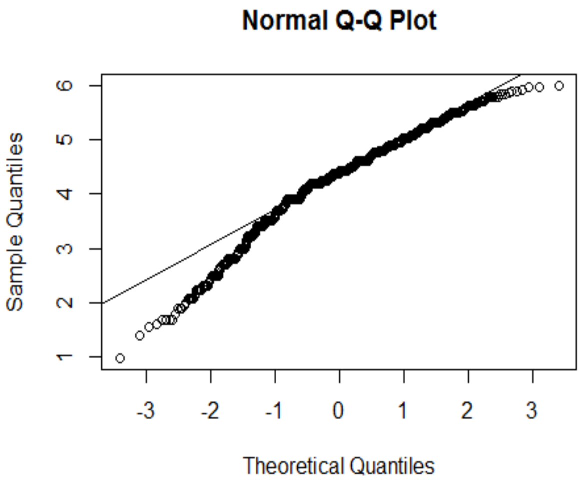


Appendix 12 – Distribution of the log(CPUE) and log(landings) of the professional data

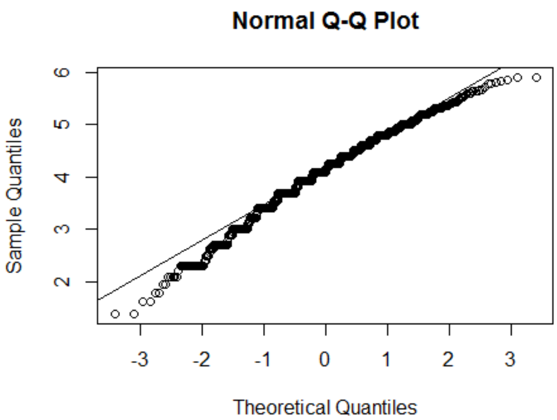




Appendix 13 – Normal qq plots of the log distribution of the CPUE and landings from the professional lobster fishery data

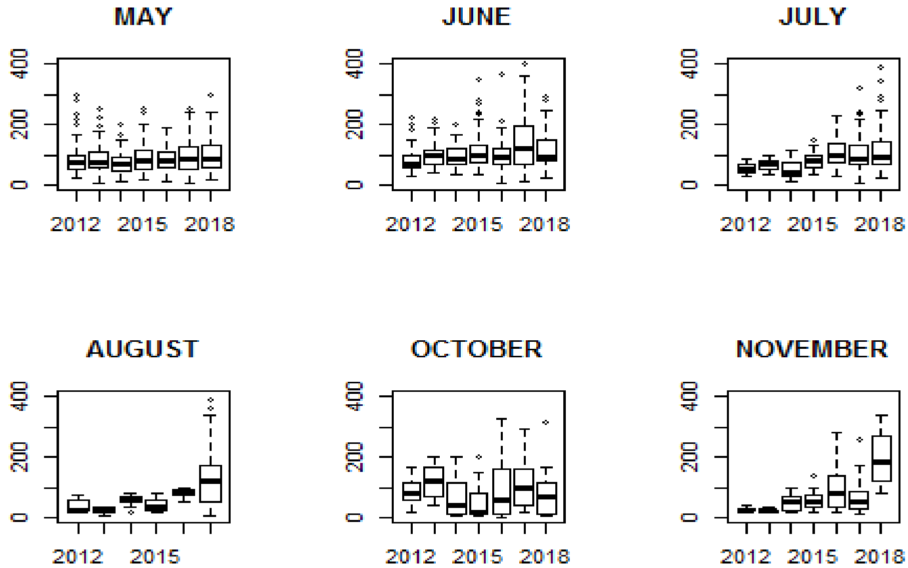


CPUE

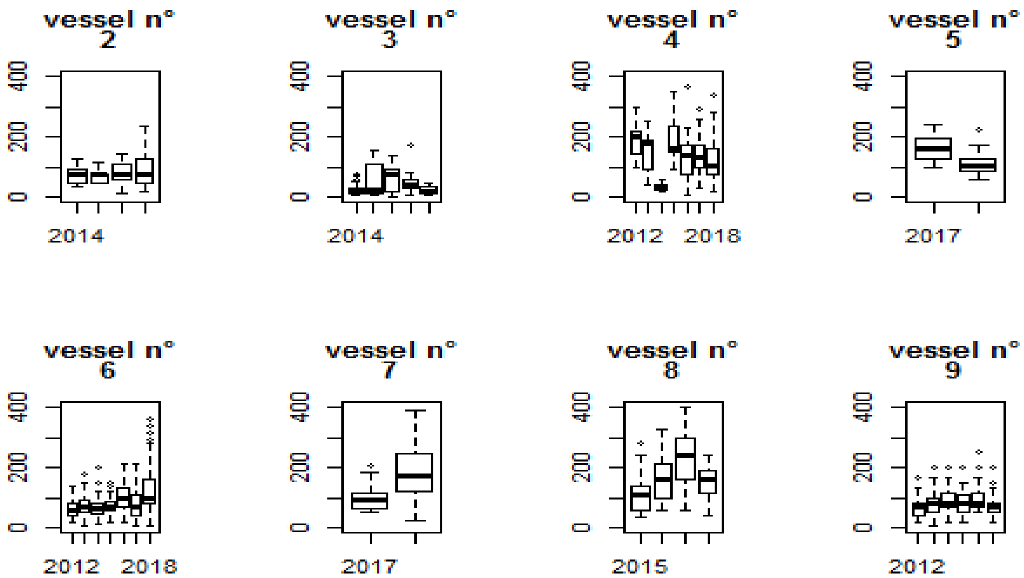


Landings

Appendix 14 – Data Mining of the recreational fishery CPUE (individual per trap) for the standardization glm model



MONTH	MAY	JUNE	JULY	AUGUST	OCTOBER	NOVEMBER
NUMBER OF OBSERVATIONS	415	408	340	79	191	99

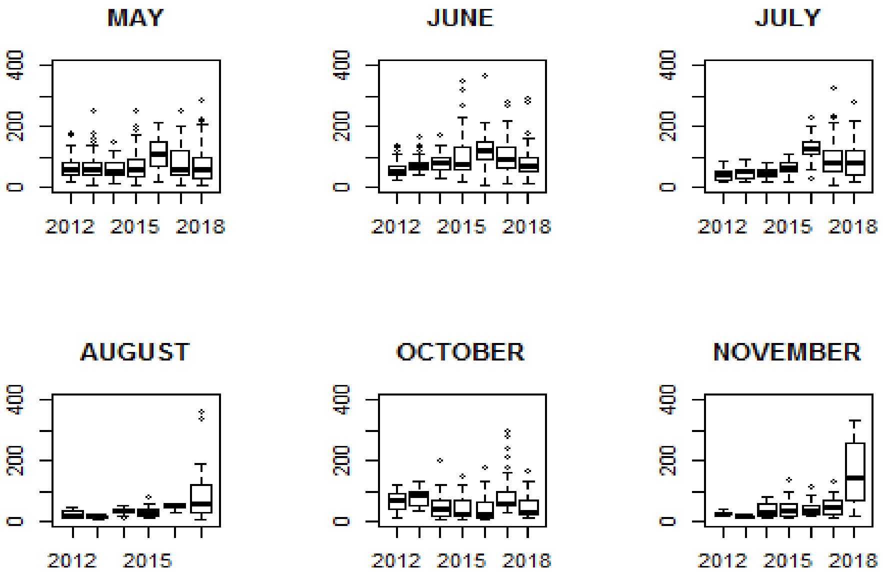


# VESSEL	2	3	4	5	6	7	8	9
NUMBER OF OBSERVATIONS	112	187	170	68	401	57	97	440

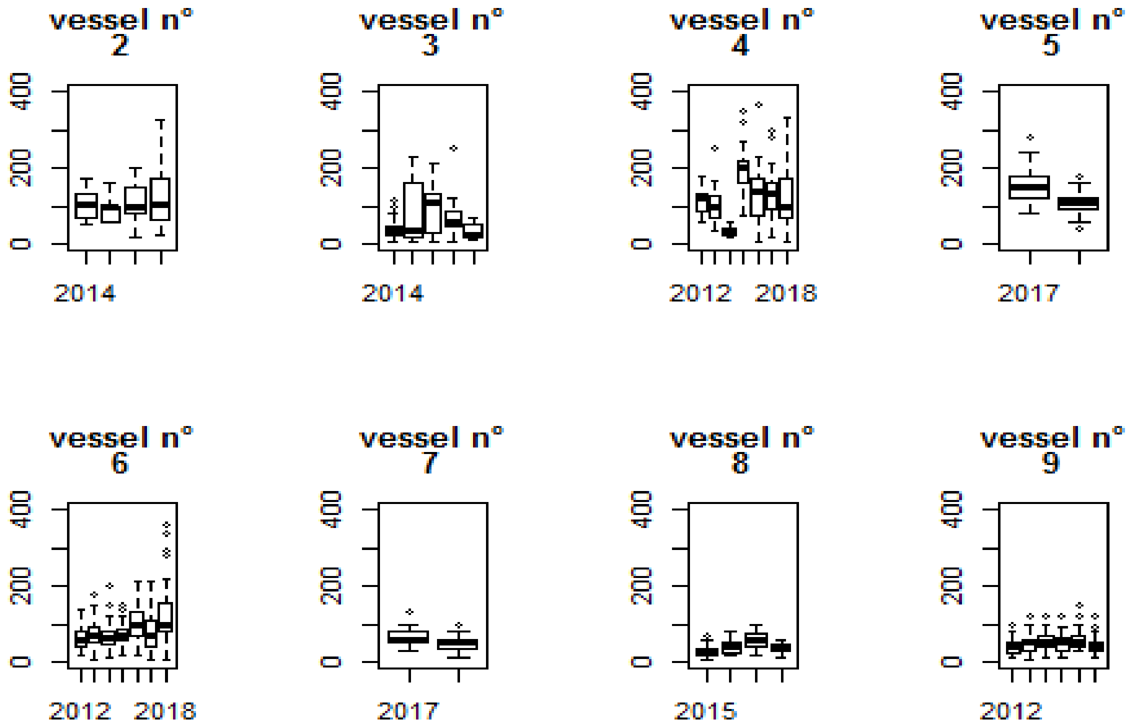
Appendix 15 – GLM model coefficients for the CPUE glm model

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3,53640429	0,07083583	49,9239494	3,55727265005698e-322
ANNEE2013	0,12110149	0,06720581	1,80194969	0,0717523
ANNEE2014	0,06442428	0,06365701	1,01205319	0,31167444
ANNEE2015	0,15081745	0,05939103	2,53939808	0,01120373
ANNEE2016	0,39860772	0,06662735	5,98264386	2,74E-09
ANNEE2017	0,28553889	0,05846907	4,88358921	1,15E-06
ANNEE2018	0,30513532	0,06134581	4,97402101	7,31E-07
MOIS6	0,22277215	0,03987802	5,58633987	2,75E-08
MOIS7	0,01366623	0,04234003	0,32277317	0,74691163
MOIS8	-0,16871027	0,07184262	-2,34833133	0,01898588
MOIS10	-0,08265082	0,05077395	-1,62781942	0,10377139
MOIS11	-0,37466248	0,06423986	-5,83224261	6,68E-09
NAV2	0,45739488	0,06930318	6,59991215	5,68E-11
NAV7	1,10596862	0,08967438	12,3331615	2,27E-33
NAV4	1,1677765	0,06249942	18,6845963	2,90E-70
NAV5	1,01723256	0,08530281	11,9249604	2,13E-31
NAV8	1,31534697	0,07286455	18,0519456	3,99E-66
NAV6	0,65688091	0,05252584	12,505861	3,20E-34
NAV9	0,69338881	0,05444818	12,7348382	2,31E-35

Appendix 16 – Data mining for the landings model



MONTH	MAY	JUNE	JULY	AUGUST	OCTOBER	NOVEMBER
NUMBER OF OBSERVATIONS	415	408	340	79	191	99

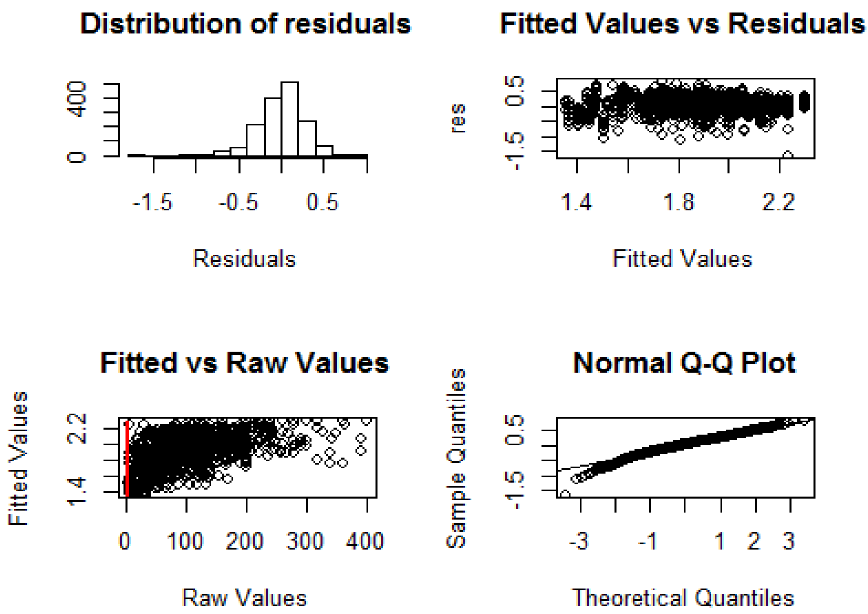


# VESSEL	2	3	4	5	6	7	8	9
NUMBER OF OBSERVATIONS	112	187	170	68	401	57	97	440

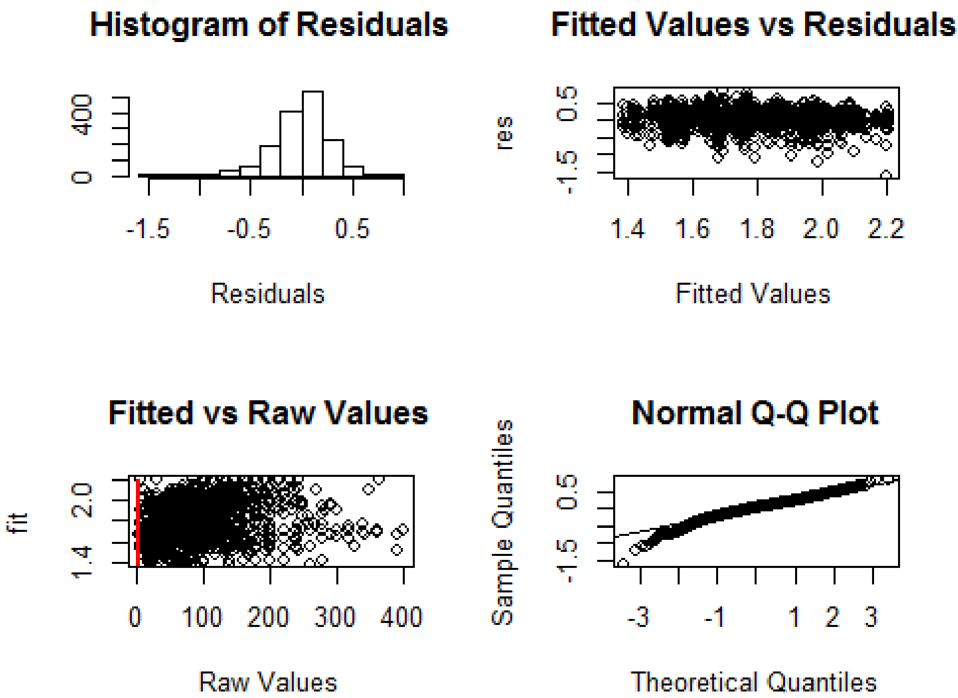
Appendix 17 – GLM model coefficient for the landings based standardization model

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	4,21409144	0,07846783	53,7047023	0
ANNEE2013	0,13423231	0,06645796	2,01980778	0,04357931
ANNEE2014	0,13199514	0,06294865	2,09687002	0,03617074
ANNEE2015	0,23539103	0,05873014	4,00801087	6,42E-05
ANNEE2016	0,49881492	0,06588594	7,5708856	6,41E-14
ANNEE2017	0,40158322	0,05781844	6,94559124	5,58E-12
ANNEE2018	0,32436497	0,06066317	5,34698403	1,03E-07
MOIS6	0,2225671	0,03943426	5,64400307	1,98E-08
MOIS7	0,00700954	0,04186888	0,16741637	0,86706482
MOIS8	-0,2367217	0,07104317	-3,33208229	0,00088278
MOIS10	-0,12482153	0,05020895	-2,48604155	0,01302452
MOIS11	-0,43674167	0,06352502	-6,87511276	9,03E-12
NAV3	-0,35655641	0,06853199	-5,20277346	2,23E-07
NAV4	0,32114402	0,07044912	4,55852448	5,57E-06
NAV5	0,23325161	0,09116327	2,55861405	0,01060565
NAV6	-0,07205452	0,0627139	-1,14894016	0,25076226
NAV7	-0,5717975	0,09542161	-5,99232689	2,58E-09
NAV8	-0,8284698	0,07912442	-10,4704695	8,13E-25
NAV9	-0,52938249	0,06489192	-8,15791023	7,09E-16

Appendix 18 – Distribution of the residuals for the glm standardization model of the CPUE and landings

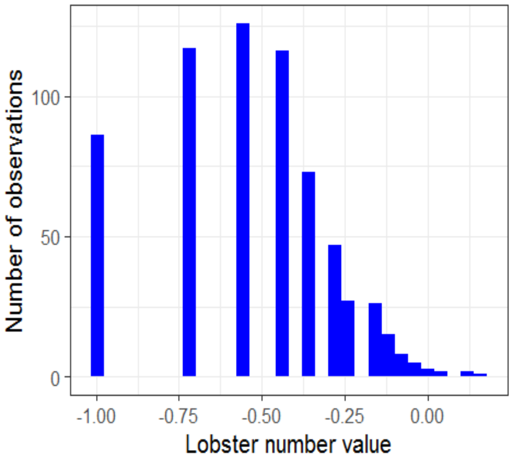


CPUE

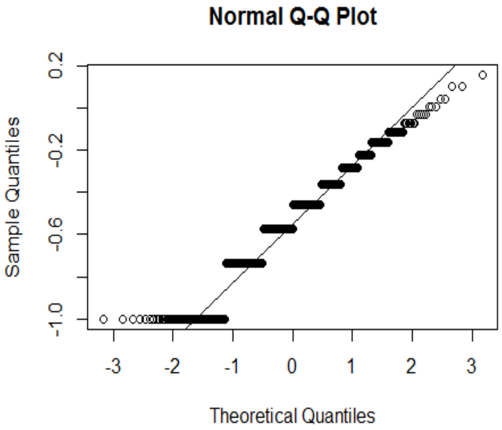


landings

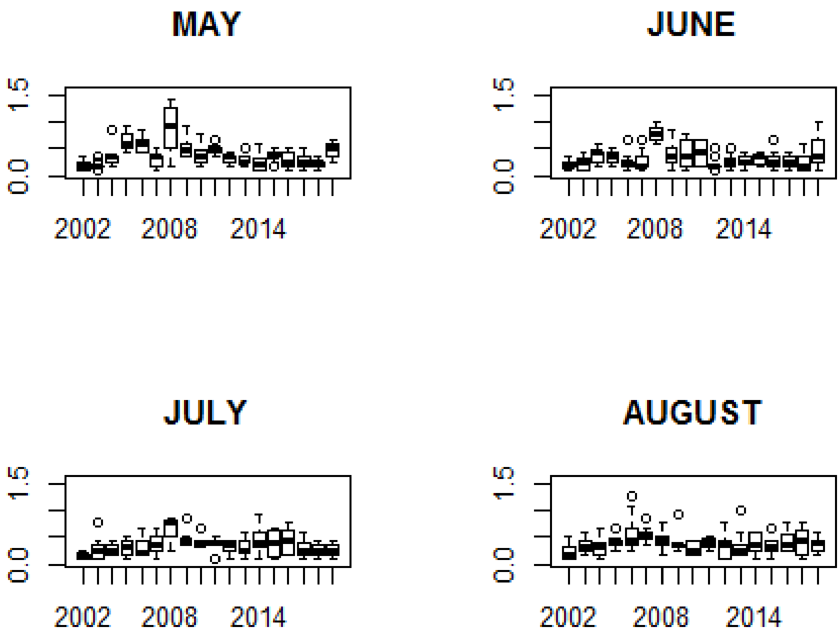
Appendix 19 – Distribution of the log(CPUE) of the recreational fishery of lobster



Appendix 20 – Normal qq plot diagnosis for the recreational fishery standardization model



Appendix 21 – Data mining of the data for the recreational fishery of mobsters at SPM

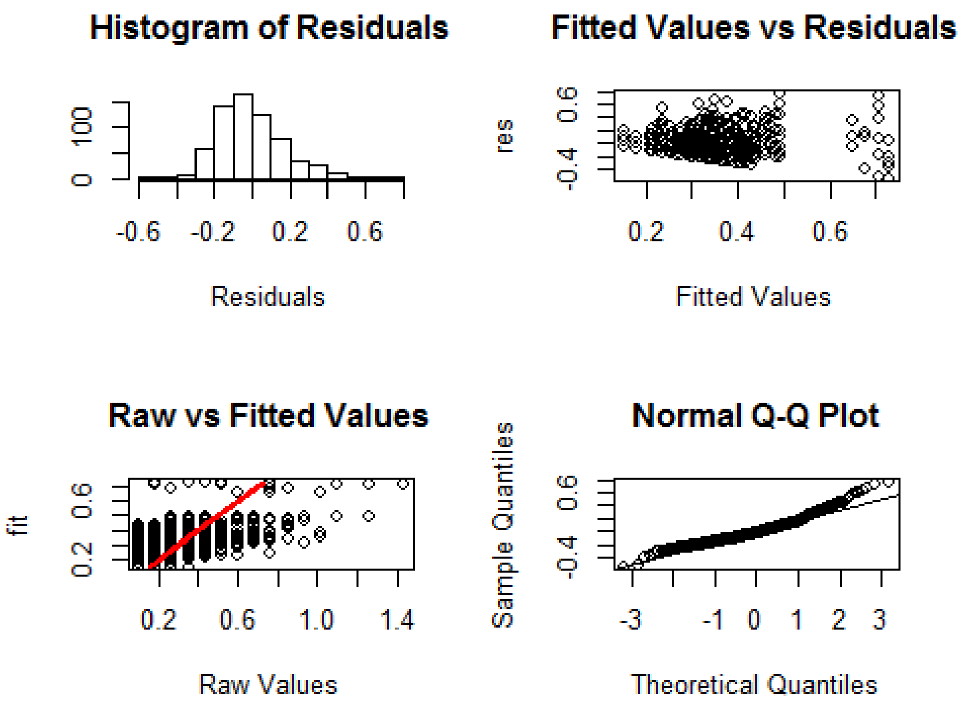


MONTH	MAY	JUNE	JULY	AUGUST
NUMBER OF OBSERVATIONS	164	170	156	164

Appendix 22 – GLM model indices for the standardization of the recreational fisheries data

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-1,63312303	0,07502099	-21,7688822	7,42E-79
ANNEE2003	0,26481777	0,09652933	2,74339166	0,00625301
ANNEE2004	0,53857752	0,10934697	4,92539963	1,08E-06
ANNEE2005	0,83303403	0,11159727	7,46464552	2,77E-13
ANNEE2006	0,83228998	0,10658627	7,80860446	2,41E-14
ANNEE2007	0,66150687	0,1047346	6,31603027	5,06E-10
ANNEE2008	1,28845255	0,1369301	9,409564	9,05E-20
ANNEE2009	0,84380322	0,11266706	7,48935174	2,33E-13
ANNEE2010	0,68722708	0,12127252	5,66679959	2,21E-08
ANNEE2011	0,79393083	0,13147338	6,03871933	2,65E-09
ANNEE2012	0,41059615	0,10649841	3,8554205	0,00012733
ANNEE2013	0,48293389	0,10103991	4,77963513	2,19E-06
ANNEE2014	0,54087719	0,10326686	5,23766498	2,22E-07
ANNEE2015	0,5997404	0,10830884	5,53731726	4,51E-08
ANNEE2016	0,62515523	0,1083364	5,77050022	1,24E-08
ANNEE2017	0,48801641	0,10104791	4,82955473	1,72E-06
ANNEE2018	0,34934873	0,10321277	3,38474319	0,00075648
ANNEE2019	0,79276268	0,1158376	6,84374233	1,83E-11
MOIS6	-0,12419585	0,05584131	-2,22408567	0,02649468
MOIS7	-0,04814944	0,0571465	-0,84256156	0,39979193
MOIS8	0,11463496	0,05674902	2,02003434	0,04380058

Appendix 23 – Distribution of the residuals of the glm standardization model of the recreational fisheries data



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Parcours : Sciences Biologiques Marines
Spécialisation / option : Ressources et Ecosystèmes Aquatiques
Enseignant référent : Didier Gascuel</td></tr>
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Date de naissance* : 16/03/1995</td><td rowspan="3">Organisme d'accueil : AMURE - IUEM
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<tr><td colspan="2">Nb pages : 35 Annexe(s) : 23</td></tr>
<tr><td colspan="2">Année de soutenance : 2019</td></tr>
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Titre français : Evaluation du stock de homard américain (*Homarus americanus*) de l'archipel français de Saint-Pierre et Miquelon.

Titre anglais : Stock assessment of the American lobster (*Homarus americanus*) in the French archipelago of Saint-Pierre & Miquelon

Résumé (1600 caractères) : Le homard américain (*Homarus americanus*) est une des espèces les plus ciblées sur la côte nord est américaine. Au Canada, chaque année sont débarqués 90 000 tonnes de homard. Sur l'archipel de Saint-Pierre et Miquelon, la pêche du homard a récemment suscité l'intérêt grandissant des pêcheurs artisans, à la suite des baisses de rendement de la pêche au crabe des neiges. Cependant, aucune étude sur la population de homard n'a encore été menée. Il existe un TAC global de 30 tonnes, cependant celui-ci n'est pas basé sur des avis scientifiques, puisque aucune étude scientifique n'a encore été menée sur ce stock. Premièrement, des sondes de relevés environnementaux ont été placés dans les casiers des pêcheurs de l'archipel, qui permettront de mieux connaitre les caractéristiques environnementales des zones de pêche du homard. Ensuite, des concentrateurs relevant la position GPS ont également été installés sur les bateaux de l'archipel. Ces données GPS ont permis de cartographier les différentes zones de pêche, ainsi que de quantifier la pression de pêche qui y est appliquée. Enfin, un travail de relevés sur le terrain ainsi que de collecte de données de différentes sources et format a été réalisé durant ce stage. Ces données terrain ont permis de réaliser deux objectifs. Premièrement, les caractéristiques biologiques de la population de homard ont été étudiées. Ensuite, ces données structurées en taille ont permis d'alimenter un modèle d'évaluation de stock par la méthode des pseudo-cohortes, ce modèle étant corrigé des variations d'abondance et d'effort sur la période d'analyse.

Abstract (1361 caractères) : American lobster (Homarus americanus) is one of the most targeted species on the Northeastern American coast. In Canada, 90,000 tons of lobster are landed each year. On the French archipelago of Saint-Pierre & Miquelon, the lobster fishery has developped in response to the declined the snow crab landings. However, no studies on the lobster population have yet been conducted. There is an overall TAC of 30 tons, not however based on scientific advice, since no scientific study has yet been conducted on this stock. First, environmental survey probes have been placed in the archipelago fishermen's traps, which will provide a better understanding of the environmental characteristics of the lobster fishing areas. Then, concentrators recording the GPS position were also installed on the boats of the archipelago. These GPS data provided a map of the different fishing zones, as well as to quantify the fishing pressure applied to them. Finally, field surveys and data collection from different sources were carried out during this internship. These field data aimed to complete two objectives. First, the biological characteristics of the lobster population have been studied. Then, these size-structured data were used to feed a stock assessment model using the pseudo-cohort method, which was adjusted for abundance and effort over the analysis period.

Mots-clés : pseudo-cohorte, évaluation de stock, Saint-Pierre et Miquelon, homard américain, relevés en mer, données limitées

Key Words: pseudo-cohort, stock assessment, Saint-Pierre & Miquelon, american lobster, at-sea sampling, data-poor

* *Elément qui permet d'enregistrer les notices auteurs dans le catalogue des bibliothèques universitaires*

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