Regular paper

The fisheries of the sea around Saint-Pierre and Miquelon: from cod to sea cucumber

by

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Submitted: 3 Mar. 2022
Accepted: 9 Sep. 2022
Editors: F. Teletchea, D. Pauly

Key words
Catch reconstruction
Stock-status plots
Fishing down
Stock assessments
CMSY
Biomass left

Abstract. – A description of Western North Atlantic fisheries is provided in the form of catch time series covering the years from 1950 to 2019 and two derived indicators: 1) stock status plots; and 2) the mean trophic level of the catch. These are shown at three different geographic scales, all of which exhibit the same patterns of decline. Maps are presented which illustrate the decadal decline in an indicator of aggregate biomass from 1950 to 2019 based on an application of the CMSY stock assessment method to 35 important fish and invertebrate stock exploited by Northwest Atlantic fisheries. These assessments suggest that Saint-Pierre and Miquelon was no exception in the regional trends of overfishing and biomass decline, as confirmed by the scale invariance of the trends presented in this contribution. Some emphasis is given to the Atlantic cod (*Gadus morhua*) of Eastern Canadian waters, whose exploitation by European fishing fleets dates at least to 1508, but whose major biomass collapse began in the 1960s, when distant-water trawler fleets reigned supreme. Some reflections are provided on the implications, for Saint-Pierre and Miquelon having transited from a fishery relying predominantly on cod to a fishery targeting orange-footed sea cucumber (*Cucumaria frondosa*).

Résumé. – Les pêcheries de la mer autour de Saint-Pierre et Miquelon : de la morue au concombre de mer.

Une description des pêcheries de l'Atlantique Nord-Ouest est fournie sous la forme de séries temporelles de captures couvrant les années 1950 à 2019 et de deux indicateurs dérivés, à savoir les diagrammes d'état des stocks et le niveau trophique moyen des captures, à trois échelles géographiques différentes, qui présentent tous les mêmes schémas de déclin. Des cartes sont présentées qui illustrent le déclin décennal d'un indicateur de la biomasse agrégée de 1950 à 2019, basé sur une application de la méthode d'évaluation des stocks CMSY à 35 stocks importants de poissons et d'invertébrés exploités par les pêcheries de l'Atlantique Nord-Ouest. Ces évaluations suggèrent que Saint-Pierre et Miquelon n'est pas une exception dans les tendances régionales de surpêche et de déclin de la biomasse, comme le confirme l'invariance d'échelle des tendances présentées dans cette contribution. Une attention particulière est accordée à la morue de l'Atlantique (*Gadus morhua*) des eaux de l'Est du Canada, dont l'exploitation par la flotte de pêche européenne remonte au moins à 1508, mais dont l'effondrement majeur de la biomasse a commencé dans les années 1960, lorsque la flotte de chalutiers de pêche lointaine régnait en maître. Quelques réflexions sont fournies sur les implications, pour Saint-Pierre et Miquelon ayant transité d'une pêche reposant principalement sur la morue à une pêche ciblant le concombre de mer à pieds orange (*Cucumaria frondosa*).

INTRODUCTION

The world's marine fisheries are monitored and documented by the Food and Agricultural Organization of the United Nations (FAO), which has divided the global ocean into 19 FAO Statistical Areas. Saint-Pierre and Miquelon (SPM) is near the centre of FAO Area 21, the Northwest Atlantic, which ranges from the coast of the U.S. state of North Carolina in the Southwest to Baffin Bay in the North and to the Southern tip of Greenland in the East (Fig. 1).

FAO area 21 experienced a massive decline of the biomass of exploited fish starting in the 1980s and continuing to the present (Pauly *et al*., 1998; Christensen *et al*., 2003). As shown below, this decline also affected the fisheries based in Saint-Pierre and Miquelon, whose economy was strongly altered by the closure of the Canadian commercial fisheries in 1992.

In this contribution, we present:

1. Actual fisheries catch at different spatial scales of the Northwest Atlantic region from 1950 to 2018, which complement the official catches reported by the FAO;
2. Catch-derived indicators of the status of the fisheries in the Northwest Atlantic region from 1950 to 2018;
3. The decadal trend of relative biomass of exploitable fish left in FAO Area 21 by the fisheries since 1950;
4. The biomass of Atlantic cod (*Gadus morhua*) in the part of FAO Area 21 that now corresponds to the Canadian Province of Newfoundland and Labrador, from 1508 to 2019, with emphasis on the period since 1950.

These data provide a context for the catastrophic closure, in 1992 of most of the fisheries' activity, *i.e*., fish catching and processing, upon which the economy of Saint-Pierre and Miquelon was based, and for the present emphasis on high-value, but sensitive species such as lobster (*Homarus*

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Figure 1. – FAO Statistical Area 21, ranging approximately from 35 to 77.5 ^{0}N, and from 42 to 77.5 ^{0}E (6,293,000 km^2), and encompassing the Newfoundland-Labrador Shelf Large Marine Ecosystem (LME; dark grey; 664,700 km^2) and the Southern Grand Banks-South Newfoundland Marine Ecoregion (light grey; 55,400 km^2), slightly modified to fit inside the LME. The insert in the lower right corner shows the Exclusive Economic Zone of St Pierre and Miquelon (12,400 km^2).

americanus) and especially the orange-footed sea cucumber (*Cucumaria frondosa*), which are currently the mainstay of the archipelago's fishery.

MATERIAL AND METHODS

The catch data used for this contribution are mainly based on the data assembled annually and disseminated by FAO from its member countries (Garibaldi, 2012). These data were complemented by data on discards (Zeller *et al*., 2018) and other catches from fisheries not comprehensively covered or missing entirely in FAO statistics, *i.e*., artisanal, subsistence, and recreational fisheries. These data are the result of a process known as "catch reconstruction" (Pauly, 1998; Pauly and Zeller, 2016a, b; Zeller *et al*., 2018; Palomares *et al*., 2020). For SPM, this process is documented in Bultel and Zylich (2015, 2016) and Page *et al*. (2020), whose results will continue to be revised and expanded, as also done with other territories and countries.

Following the reconstruction of national catches – *i.e*., by a country or territory – in areas corresponding to its current Exclusive Economic Zone (EEZ), the catches are spatially allocated to ½ latitude and longitude degree cells following the rules described in Palomares *et al*. (2016) and Lam *et al*. (2016). Then, we added to the appropriate ½ degree cells the catch of distant-water fleets that was previously allocated by FAO to their Area 21 or the smaller statistical areas of the Northwest Atlantic Fisheries Organization (NAFO), and other past and current Regional Fisheries Management Organizations (RFMO; see, *e.g*., Coulter *et al*., 2019).

These procedures generate a more realistic and more extended time series of catches than the official statistics, particularly when the catch by ½ degree cells is aggregated into larger areas, such as EEZs, or areas perceived as 'ecosystems, *i.e*., Large Marine Ecosystems (LME; Sherman and Duda, 1999) or as the 'Marine Ecoregions' (Spalding *et al*., 2012), which allowed exploring the possibility that the dominant trend of catches in FAO Area 21 are reproduced at smaller spatial scales.

We interpreted these reconstructed catch time series using stock-status plots, which are defined by the attribution, for every year, for each stock, a status based on its level and timing relative to its historic peak. Stock-status categories were defined as follows: 'Developing' (= catches ≤ 50% of peak and year is pre-peak, or year of peak is the last year of the catch time series); 'Exploited' (= catches ≥ 50% of peak catches); 'Over-exploited' (catches between 50% and 10% of peak and year is post-peak); 'Collapsed' (catches < 10% of peak and year is post-peak); and 'Rebuilding' (catches between 10% and 50% of peak and year is after post-peak minimum) (see Kleisner *et al*., 2013). Note that the number of 'stocks' is defined as a time series of a species, genus or family for which the first and last reported landings are at least 10 years apart, for which there are at least 5 years of consecutive catches and for which the catch in a given area is at least 1000 tonnes (see also www.seaaroundus.org).

We also interpreted the reconstructed catch time series using the 'fishing down' concept (Pauly *et al*., 1998), *i.e*., by plotting the mean trophic level of the fish and invertebrates included in these times series, and trophic level estimates in FishBase (www.fisbase.org) for the former, and SeaLifeBase (www.sealifebase.org) for the latter. Time series of mean trophic levels were then computed from:

$$\overline{TL}_j = \frac{\sum_{i=1}^{m} Y_{ij} \cdot TL_i}{\sum_{i=1}^{m} Y_{ij}} \qquad (1)$$

where Y_{ij} is the catch of taxon i in year j, and TLi is its trophic level (see also Pauly *et al*., 2001).

Finally, we used the catches by species and marine ecoregions to apply the CMSY stock evaluation approach (Froese *et al*., 2017) to 35 important and representative FAO

Table I. – Basic information on 35 CMSY++ stock assessments of important exploited fish and invertebrate species exploited around the EEZ of St Pierre and Miquelon, including the regions and years covered, the priors used and the key results, *i.e.*, *r* and *k* (and their 95% confidence intervals, C.I.) and the biomass left, *i.e.*, B_{end}/k.

Number, common name (scientific name)[a)]	Region[b)]	Start year[c)]	Res.[d)]	r prior	B_{start}	B_{int}	B_{end}	Other priors	r (C.I.)	k (C.I.)	B_{end}/k (C.I.)
1, Wahoo (*Acanthocybium solandri*)	1	1950	3	0.37-0.85	0.6-1	0.5-0.9 (1987)	0.1-0.5	CPUE: Luckhurst and Trott (2000)	0.57 (0.39-0.84)	94 (67-140)	0.36 (0.23-0.79)
2, Alewife (*Alosa pseudoharengus*)	2, 3	1960	3	–	–	–	–	–	0.21 (0.14-0.27)	51 (40-75)	0.18 (0.07-0.38)
3, Frigate tuna (*Auxis thazard)*	1	1950	3	0.37-0.85	–	–	0.44-0.84	B_{end}: Pons *et al*. (2019)	0.5 (0.36-0.62)	184 (152-255)	0.66 (0.47-0.92)
4, Tusk (*Brosme brosme*)	2, 3, 4	1950	3	0.3-0.68	–	–	0.01-0.4	CPUE: RLSADB (2018); B_{end}: Harris *et al*. (2018)	0.31 (0.22-0.43)	31 (23-42)	0.22 (0.07-0.47)
5, Atlantic rock crab (*Cancer irroratus*)	2, 3, 5, 6	1980	3	–-	–	0.5-0.9 (2005)	0.3-0.7	B_{end} and CPUE: DFO (2013; 2016a)	0.33 (0.18-0.57)	67 (40-123)	0.66 (0.38-1.25)
6, Snow crab (*Chionoecetes opilio*)	2, 3	1968	3	0.38-0.87	–	0.5-0.9 (2002)	0.3-0.7	CPUE: RLSADB (2018)	0.53 (0.37-0.77)	329 (229-477)	0.69 (0.47-1.04)
7, Iceland scallop (*Chlamys islandica*)	2, 3, 7, 8	1992	3	–	–	–	–	CPUE: DFO (2009)	0.17 (0.1-0.28)	30 (17-55)	0.22 (0.08-0.48)
8, Atlantic herring (*Clupea harengus*)	2, 3	1950	3	0.3-0.68	0.6-1	0.1-0.4 (2005)	–	CPUE: Surette *et al*. (2015)	0.29 (0.22-0.39)	1424 (1125-1869)	0.14 (0.06-0.30)
9, Common dolphinfish (*Coryphaena hippurus*)	1	1950	4	0.72-1.64	0.6-0.8	–	–	–	1.01 (0.73-1.21)	132 (110-179)	0.57 (0.34-0.85)
10, Roundnose grenadier (*Coryphaenoides rupestris*)	2 - 9	1965	2	0.23-0.53	–	0.01-0.2 (2000)	–	CPUE: Simpson *et al*. (2011)	0.24 (0.17-0.34)	1539 (935-2869)	0.04 (0.01-0.13)
11, Little tunny (*Euthynnus alletteratus*)	10	1979	3	0.37-0.85	0.6-1	0.4-0.6 (2000)	0.4-0.6	B_{end}: Pons *et al*. (2019)	0.49 (0.34-0.6)	57 (46-79)	0.58 (0.41-0.81)
12, Atlantic cod (*Gadus morhua*)	2, 3	1950	3	0.34-0.78	–	0.01-0.4 (1974)	0.01-0.2	CPUE: RLSADB (2018); B_{end}: Brassard *et al*. (2020)	0.31 (0.23-0.42)	2563 (1760-3947)	0.09 (0.03-0.24)
13, Witch flounder (*Glyptocephalus cynoglossus*)	2, 3	1950	3	0.32-0.73	0.6-1	–	0.01-0.4	CPUE: RLSADB (2018); B_{end}: DFO (2018a)	0.27 (0.2-0.37)	98 (73-141)	0.03 (0.01-0.10)
14, American plaice (*Hippoglossoides platessoides*)	2, 3	1950	2	–	–	–	0.01-0.2	B_{end}: Ricard and CSAS (2016)	0.08 (0.04-0.11)	4116 (2934-7252)	0.10 (0.03-0.24)
15, American lobster (*Homarus americanus*)	2, 3	1950	3	0.37-0.85	–	0.4-0.8 (2012)	–	B_{int}: Wahle *et al*. (2013)	0.48 (0.32-0.62)	438 (316-762)	0.56 (0.26-1.02)
16, Blue marlin (*Makaira nigricans*)	1	1960	3	0.35-0.8	0.6-1	0.2-0.6 (1971)	0.1-0.4	CPUE: ICCAT (2019a)	0.33 (0.24-0.44)	68 (49-100)	0.21 (0.11-0.37)
17, Capelin (*Mallotus villosus*)	2, 3	1950	3	0.27-0.62	–	–	–	CPUE: DFO (2011)	0.32 (0.22-0.44)	148 (110-204)	0.14 (0.05-0.32)
18, Haddock (*Melanogrammus aeglefinus*)	2, 3	1950	3	0.33-0.74	–	0.2-0.6 (1970)	–	CPUE: Hurley (2009)	0.26 (0.19-0.36)	436 (275-749)	0.13 (0.05-0.32)

Table I. – Continued.

Number, common name (scientific name)[a)]	Region[b)]	Start year[c)]	Res.[d)]	r prior	B_{start}	B_{int}	B_{end}	Other priors	r (C.I.)	k (C.I.)	B_{end}/k (C.I.)
19, Silver hake (*Merluccius bilinearis*)	2, 3, 5-8	1952	3	0.25-0.56	–	–	0.6-1	CPUE: DFO (2016b); B_{end}: Rubidge *et al.* (2020)	0.27 (0.19-0.39)	5143 (3612-8669)	0.57 (0.32-1.10)
20, Striped bass (*Morone saxatilis*)	2, 3	1950	2	0.18-0.43	–	–	–	CPUE: DFO (2019a)	0.27 (0.18-0.4)	13 (8-20)	0.29 (0.14-0.54)
21, Bow smelt (*Osmerus mordax mordax*)	2, 3	1950	3	–	–	–	0.1-0.3	B_{end}: J. Hutchings (Dalhousie Univ. pers. com.)	0.2 (0.13-0.26)	15 (11-23)	0.19 (0.09-0.38)
22, Northern prawn (*Pandalus borealis*)	2, 3	1979	3	0.38-0.87	–	–	–	–	0.5 (0.35-0.63)	191 (160-254)	0.25 (0.10-0.46)
23. American sea scallop (*Placopecten magellanicus*)	2, 3	1950	3	0.37-0.84	–	–	–	–-	0.36 (0.26-0.47)	144 (105-243)	0.27 (0.12-0.53)
24, Saithe (*Pollachius virens*)	2, 3	1950	3	0.33-0.76	0.6-1	0.4-0.8 (1985)	–	–	0.4 (0.27-0.5)	105 (86-142)	0.08 (0.02-0.20)
25, Blue shark (*Prionace glauca*)	11	1960	2	0.04-0.1	0.8-1	0.2-0.6 (2006)	0.01-0.5	CPUE: ICCAT (2015); B_{end}: Froese *et al.* (2018), ICCAT (2015)	0.05 (0.04-0.08)	6376 (3136-12349)	0.46 (0.19-0.97)
26, Winter flounder (*Pseudopleuronectes americanus*)	2, 3	1950	3	–	–	–	0.01-0.4	CPUE: DFO (2017); B_{end}: Surette and Rolland (2019)	0.15 (0.1-0.26)	75 (40-140)	0.05 (0.02-0.09)
27, Greenland halibut (*Reinhardtius hippoglossoides*)	2, 3, 5, 6, 7, 8, 12	1950	2	0.17-0.38	–	0.2-0.6 (2001)	0.01-0.4	CPUE: NAFO (2016); B_{end}: DFO (2019b)	0.26 (0.18-0.38)	762 (540-1143)	0.38 (0.18-0.71)
28, Atlantic mackerel (*Scomber scombrus*)	13	1950	3	0.31-0.75	–	0.01-0.4 (2002)	0.01-0.4	CPUE: RLSADB (2018)	0.49 (0.37-0.63)	1643 (1348-2040)	0.01 (0.01-0.04)
29, Smooth hammerhead (*Sphyrna zygaena*)	1	1990	2	0.16-0.49	0.8-1	–	–	CPUE: Lynch *et al.* (2018)	0.28 (0.17-0.48)	201 (121-387)	0.59 (0.30-1.24)
30, Atlantic surf clam (*Spisula solidissima*)	2, 3	1988	3	0.31-0.7	–	–	–	–	0.41 (0.28-0.51)	5 (4-7)	0.49 (0.26-0.88)
31, Picked dogfish (*Squalus acanthias*)	2 - 8	1965	1	0.04-0.12	0.4-0.8	–	0.4-0.8	CPUE: DFO (2007); B_{end}: DFO (2016c, 2018a, b); other priors: DFO (2014)	0.06 (0.04-0.11)	586 (278-1130)	0.54 (0.29-0.96)
32, Green sea urchin (*Strongylocentrotrus droebachiensis*)	2, 3	1950	3	–	–	–	0.4-0.8	CPUE: DFO (2015)	0.27 (0.17-0.41)	11 (7-17)	0.57 (0.40-0.87)
33, Yellowfin tuna (*Thunnus albacares*)	1	1950	3	0.37-0.85	0.8-1	0.2-0.4 (1997)	0.4-0.8	CPUE: ICCAT (2016); B_{end}: ICCAT (2019b, c), Popi (2018)	0.57 (0.41-0.8)	1087 (774-1495)	0.58 (0.38-0.84)
33, 34, Bigeye tuna (*Thunnus obesus*)	1	1950	3	0.43-0.98	0.8-1	0.4-0.6 (1994)	0.01-0.4	CPUE: ICCAT (2019d); B_{end}: Popi (2018)	0.6 (0.43-0.83)	575 (424-782)	0.27 (0.17-0.43)

Table I. – Continued.

Number, common name (scientific name)[a]	Region[b]	Start year[c]	Res.[d]	r prior	B_{start}	B_{int}	B_{end}	Other priors	r (C.I.)	k (C.I.)	B_{end}/k (C.I.)
35, White hake (*Urophycis tenuis*)	2 - 8	1950	2	0.35-0.81	–	0.3-0.7 (1983)	0.01-0.4	CPUE: RLSADB (2018) and Simpson *et al*., (2013); B_{end}: DFO (2016d); other priors: DFO (2002)	0.29 (0.21-0.4)	829 (556-1323)	0.39 (0.20-0.68)

a) 1 = Atlantic Ocean; 2 = Gulf of St Lawrence; 3 = Eastern Scotian Shelf; 4 = Scotian Shelf; 5 = Southern Grand Banks; 6 = South Newfoundland; 7 = Northern Grand Banks; 8 = Southern Labrador; 9 = Northern Labrador; 10 = Northwest & Western Central Atlantic; 11 = North Atlantic and Mediterranean; 12 = Hudson Bay Complex, Baffin Bay and West Greenland Shelf; 13 = Northwest Atlantic.
b) The end year of the catch time series was 2016, except for # 7, 22 and 30 (2017), and # 27 and 28 (2016).
c) Resilience: very low = 1; low = 2; medium = 3 and high = 4.

Area 21 stocks (Tab. I). The CMSY approach, summarized in Fig. 2, uses stock-specific series of catch data and various constraints to identify the estimates of *r*, the intrinsic rate of population growth, and *k*, the carrying capacity of that stock, to generate a time series of biomass compatible with the catch time-series and their constraints (Froese *et al*., 2017).

In practice, the CMSY approach consists of tracing, for any given exploited population, multiple trajectories of its likely biomass time series and identifying those trajectories that remain viable while accommodating the catches taken from this population over this time period and the constraints mentioned above (or 'priors' in Bayesian terminology), *i.e*., i) assumed biomass reductions caused by fishing; ii) a range for the carrying capacity (*k*) for the species under study in the region in question; and iii) a range of likely values of *r*, which is the species' maximum intrinsic rate of population growth (Fig. 2A). Qualitative measures of *r*, *i.e*., resilience as defined in Musick *et al*. (2000), are available for fishes from FishBase and from SeaLifeBase for invertebrates. For most exploited species, FishBase also provides *r* priors from a range of biological parameters, derived from estimates of their natural mortality, the von Bertalanffy growth parameter, generation time, maximum age, and fecundity.

Once a catch time series and priors are available (Fig. 2B), the software that implements the CMSY produces a multitude of potential biomass trajectories, given a catch time series and a large range of paired growth rate-carrying capacity (*r* and *k*) estimates (see cloud of grey points in Fig. 2C). Equation (2) describes how *r* and *k* are used, jointly with the catches in a given year (C_t) and the population biomass in the same year (B_t) to calculate the biomass (*B*) in the subsequent year ($t+1$):

$$B_{t+1} = B_t + \left(1 - \frac{B_t}{k}\right) B_t - C_t \quad (2)$$

To account for reduced productivity at low biomass level ('Allee effect', or 'depensation'; Perälä and Kuparinen, 2017; Neuenhoff *et al*., 2019), Equation (2) is replaced when $B < k/4$, by

$$B_{t+1} = B_t + \left(\frac{4\,r\,B_t}{k}\right)\left(1 - \frac{B_t}{k}\right) B_t - C_t \quad (3)$$

The method then identifies the mean of the *r* and *k* value pairs (see crosses in Fig. 2C) that produce 'viable' biomass trajectories, *i.e*., which exclude population collapses and also comply with constraints on the relative decline of the terminal exploited population biomass (Froese *et al*., 2017). These constraints may also include the likely reduction of population biomass that fishing imposed to the carrying capacity (in % relative to *k*) at the start of the time series, here usually 1950 (Tab. I; Fig. 4).

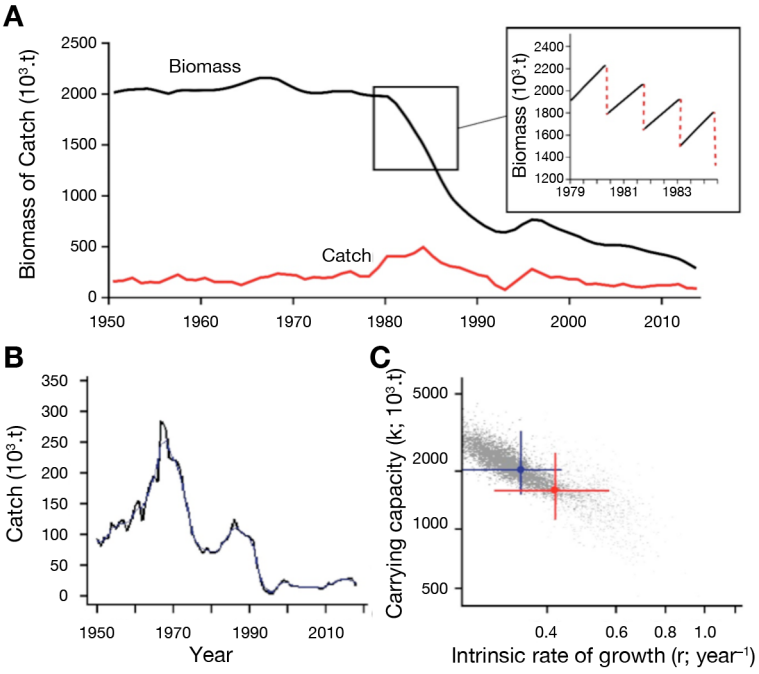

Figure 2. – Principles of CMSY assessments. **A**: Schematic representation of a biomass trajectory, showing at first the limited effect of modest catches on a large biomass, then a large decline due to high, unsustainable catches (see dotted red vertical lines in insert), not compensated any more by biomass growth, and which declines further after the catch is reduced to a lower level than previously, because the low biomass is now insufficient to sustain even such low catch levels. **B**: Catch of cod (*Gadus morhua*) from the Southern Grand Banks – Southern Newfoundland Marine Ecoregion from 1950 to 2019 used from a CMSY assessment (see # 12 in Tab. I). **C:** Showing the values (dark grey) of *r* and *k*, which lead to viable biomass trajectories. The blue cross (upper left) identifies the 'best' *r* & *k* pair without considering ancillary data, while the red cross (lower right) identifies the best pair when such data (CPUE data in this case) were also considered (see Table I and text).

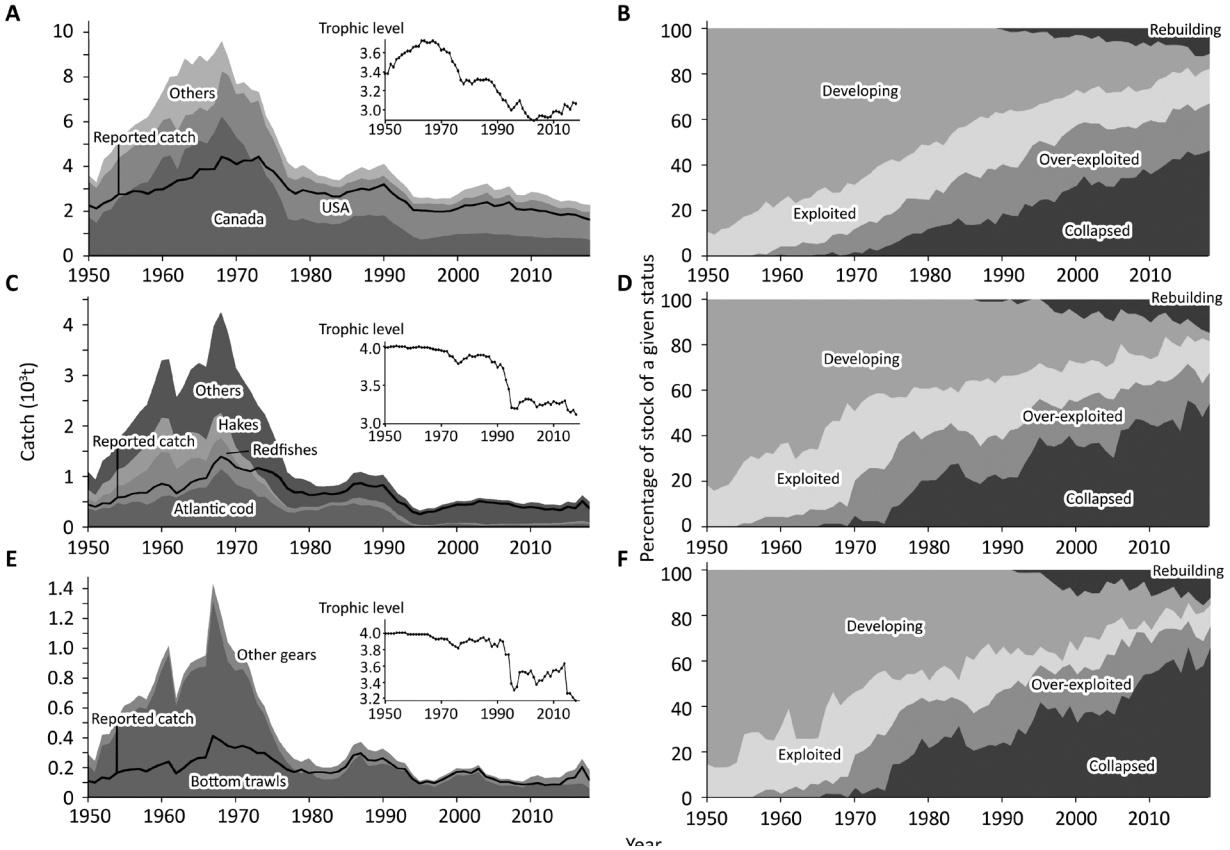

Figure 3. – Reconstructed catch and derived information of the fisheries of the Northwest Atlantic at 3 different geographic scales. **A**: Catch by countries in FAO Area 21, with insert showing the decline in the mean trophic level of the catch. **B**: Stock-status plot illustrating the changing status of 197 stocks. **C** and **D**: Same information, but for the Newfoundland -Labrador Shelf Ecosystem, with 95 stocks. **E** and **F**: Same information, but for the Southern Grand Banks – South Newfoundland Marine Ecoregion, with 79 stocks. Note the same patterns at all 3 scales.

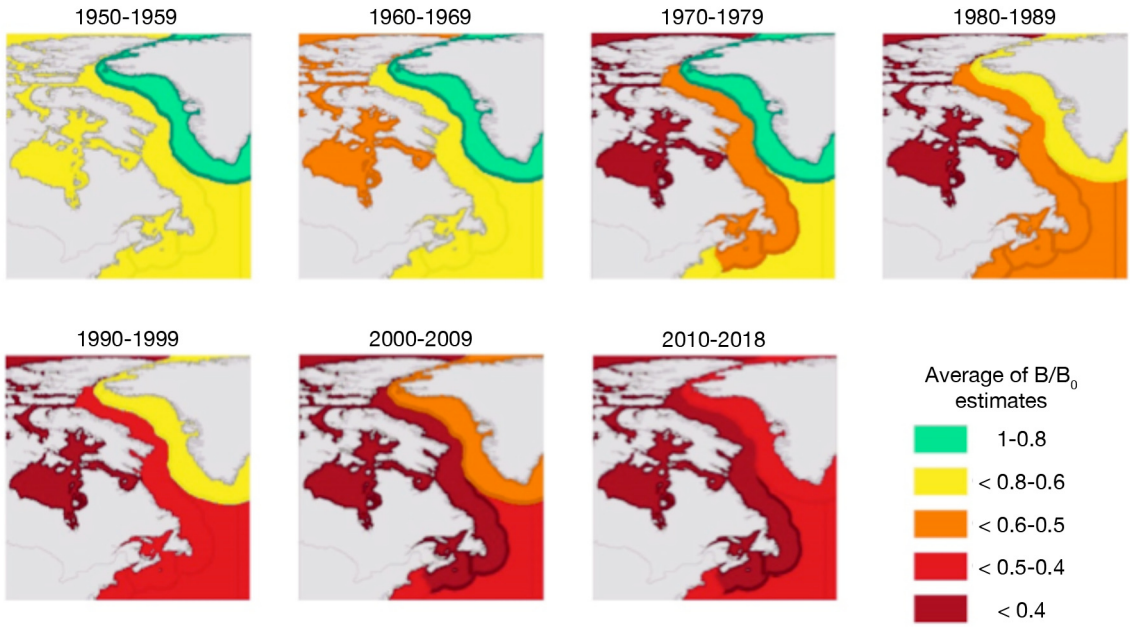

Figure 4. – Showing mean B/B_0, *i.e.*, the mean fraction of carrying capacity (≈ unfished biomass) of the exploited fish 'left' in FAO Area 21, by decade. Fishing in the early 1950s was mainly artisanal and involved mainly passive gear (trammel nets, traps, hooks and lines, etc.). Large bottom trawlers (mainly from Europe) began to operate in the region in the late 1950s and early 1960s.

Finally, we contrast our CMSY results for cod, starting only in 1950, with the results of an earlier analysis by Schijns *et al*. (2021) that covered Canadian cod stocks from 1508 to the present.

RESULTS

Figure 3, which is based on reconstructed catches rather than only official catches, shows the catches that fisheries extracted from the Northwest Atlantic from 1950 to 2018, along with stock status indicators. These reconstructed catches are higher than official catches, notably because the latter omit discarded fish and thus convey a biased impression of the impact of fisheries on ecosystems. The reconstructed catches show similar trends at three different scales, that is, for:

A. The large FAO Area 21;

B. The less extensive LME of Newfoundland-Labrador;

C. The smaller ME of Southern Grand Banks – South Newfoundland.

For even smaller areas such as NAFO's Subdivision 3Ps and the EEZ of SPM near its center, this suggests that they will also follow these general trends. The inserts in Fig. 3A, C, E show the trends in mean trophic level of the catch, which illustrate "fishing down" (Pauly *et al*., 1998) as documented earlier for the waters of Eastern Canada by Pauly *et al*. (2001). The stock-status plots in Fig. 3B, D, F, which are similar to stock status plots also published by FAO (Grainger and Garcia 1996; FAO, 2020), confirm the overfishing – as the fraction of underexploited stocks at the three scales – dwindled to almost nothing, while the number of the collapsed stocks increased.

DISCUSSION

The CMSY stock assessments confirm the problematic catch-derived stock status. We used these data to produce maps of the "biomass left" in the Northwest Atlantic after the largely uncontrolled bottom trawling rush that lasted from the 1960s to 1992. These maps thus illustrate the devastating impact of trawling, whose widespread use is now increasingly questioned (Steadman *et al*., 2021). Figure 5 illustrates this point with the Atlantic cod, which was sustainably exploited, with catches ranging from 100,000 to 200,000 $t \cdot year^{-1}$ for over 450 years, from 1508 to the mid-20th century, when bottom trawlers from Western and Eastern Europe drove the catch up to 800,000 t in 1968. This led to a biomass collapse that was completed by the Canadian Government, once it had declared an Exclusive Fishing Zone in 1979, when it subsidized the construction of a national trawler fleet to replace the foreign fleets (Verma, 2019).

These fraught decisions also devastated SPM's fisheries. Thus, as the fraction of the small total allowable catch (TAC) of cod within Subdivision 3Ps that is currently allocated to SPM is minuscule (DFO, 2021), the fisheries based in SPM now target a number of less abundant, high-value species,

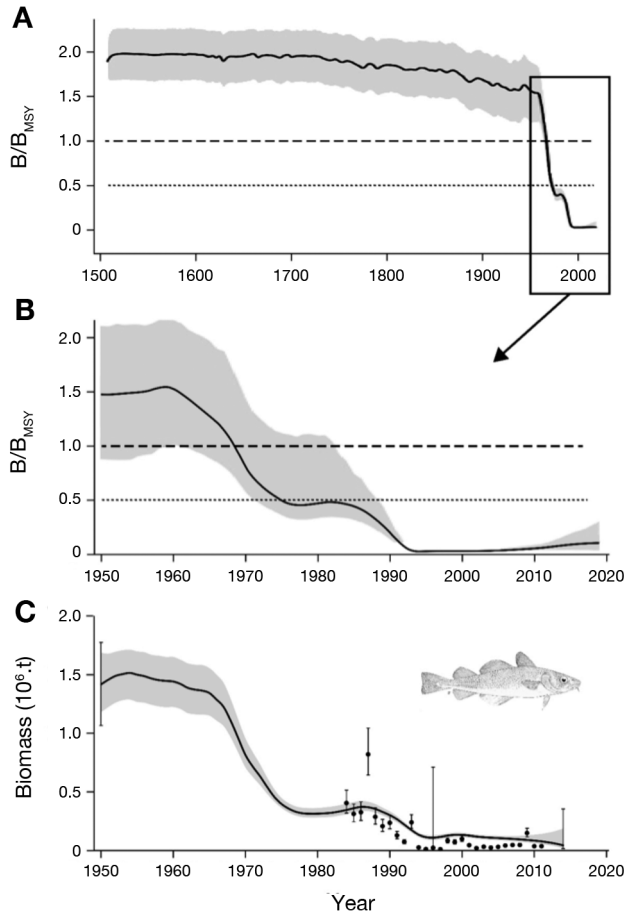

Figure 5. – Biomass trend of cod off the Canadian coast and around St Pierre and Miquelon, 1508 to 2019. **A**: 1508 to 2019, based on a CMSY assessment by Schijns *et al*. (2021); **B**: the same data, for 1950 to 2019, and emphasizing the trawler-induced collapse if cod biomass in the entire eastern Canadian region; **C**: biomass trend in an independent CMSY assessment of cod from the Southern Grand Banks-Southern Newfoundland (see Fig. 3B, C), validated by CPUE data (black dots with corresponding confidence intervals) documented for # 12 in Table I.

notably lobster (*Homarus americanus*) and especially sea cucumbers (Fig. 6). Large Atlantic cod are predators with trophic levels ranging from 3.5 to 4.5. Sea cucumbers feed on detritus with a nominal trophic level of 1; hence, sea cucumbers have a trophic level of 2. Thus, SPM fisheries now target a resource that is at the very bottom of the marine food web and which, additionally, has been shown, in a wide variety of countries throughout the world, to collapse after a few years of exploitation (Reitz, 2004; Jaureguizar and Milessi, 2008; Mumby *et al*., 2012; Pestle, 2013; Palomares and Pauly, 2014; Kc *et al*., 2017; see also www.fishingdown.org).

The future of the fisheries of St Pierre and Miquelon should not depend on a species as vulnerable to overexploitation as *Cucumaria frondosa* is likely to be. Rather, if fishing around the archipelago is to be sustained in the future, it

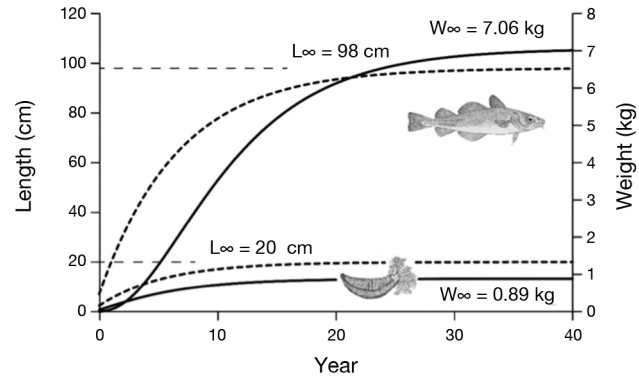

Figure 6. – Contrasting the growth of Atlantic cod (*Gadus morhua*) with that of orange-footed sea cucumber (*Cucumaria frondosa*) as representative of two, radically different fisheries in St Pierre and Miquelon. The growth parameters of *G. morhua* (L_∞ = 98 cm total length, K = 0.15 year^{-1} and t_0 = –0.5 year) are from May *et al*. (1966), with W = 0.0075·L^3 (g; cm) from Mello and Rose (2005) used for the conversion to growth in weight. Those for *C. frondosa* (L_∞ = 20 cm mouth-to-vent, K = 0.18 year^{-1} and t_0 = –0.7 year) were computed by the authors based on data in figure 7 of Hamel and Mercier (1996), with W = 16·L$^{1.34}$ (g; cm, caliper length) from Harper *et al*. (2020) used for growth in weight.

will be in the form of revived artisanal fisheries exploiting a wide range of fish species, whose stocks will have to be rebuilt, through efforts that would include close cooperation with Canada, which now has a fisheries legislation that emphasizes the rebuilding of depleted fish stocks.

Acknowledgments. – We thank Ms Elaine Chu for drafting our figures, Ms Vina Angela Parducho and Mr Martin Nevado for their assistance in extracting the stock assessment data for FAO area 21 from the *Sea Around Us* database. We also thank Dr Nicolas Bailly for editing the French translation of our abstract. The *Sea Around Us* is a research initiative supported by the David and Lucille Packard Foundation, Marisla Foundation, MAVA Foundation, Minderoo Foundation, Oak Foundation, OCEANA, Paul M. Angell Family Foundation, Pew Charitable Trusts, and the Bloomberg and Rockefeller Foundations through RARE. The authors thank two anonymous reviewers for their useful comments.

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