Polar Biology
https://doi.org/10.1007/s00300-022-03102-8

BRIEF REPORT

Jan Mayen—a new spawning and fishing area for Atlantic cod *Gadus morhua*

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Received: 12 July 2022 / Revised: 17 November 2022 / Accepted: 22 November 2022

Abstract

In 2018, commercially exploitable concentrations of Atlantic cod *Gadus morhua* were found on the shelf around the Arctic island Jan Mayen (7 1°N, 8–9 °W) and in 2019–2021 an exploratory cod fishery with longline was carried out in the area. The total catch in the period 2018–2021 was 1737 tonnes. The first records of cod fishery in the Jan Mayen area are from the early 1930s but catches before 2018 were minimal. In 2019–2020 cod spawning was documented in this area for the first time. Catches in 2019 and 2020 were dominated by cod between 70 and 100 cm, while in 2021 the main part of the catches was cod between 60 and 100 cm. Catch rates were highest in autumn. We summarize the history of cod observations and the experience from the recent exploratory fishery in this shelf area where there has been no regular monitoring of demersal fish abundance. Further, we consider possible links with cod stocks in other Arctic and sub-Arctic areas and discuss the occurrence of cod in the Jan Mayen area in relation to the biology and recent development of other cod stocks.

Keywords History · Exploratory fishery · Catch rates · Stock identity

Introduction

Atlantic cod (*Gadus morhua* L.) is widely distributed in the North Atlantic (e.g., Garrod and Schumacher 1994) and due to its large abundance and great importance for fisheries, it is very well studied throughout its distribution area. It was thus a surprise when a Norwegian fishing vessel in 2018 reported fishable concentrations of cod in the Jan Mayen area, where only very low densities of cod had been observed before, and small catches had been taken only occasionally. To follow up this discovery, Norway launched an exploratory fishery on cod in this area in 2019 and the following years.

Jan Mayen is a volcanic island in the Atlantic, north of Iceland and east of Greenland, located between 8° and 9° W at latitude 71° N (Fig. 1). The shelf area around the island is fairly small and mainly stretches southward of the island, and the shelf is very narrow on the northern side (Fig. 2). The island has been a part of the Kingdom of Norway since 1930. In 1980 Norway claimed an exclusive economic zone (EEZ) of 200 nm around the island. For a description of the marine environment and ecosystem around Jan Mayen we refer to Fossum et al. (2012). The fish fauna in the area is well described by Wienerroiter et al. (2011).

The first fisheries investigations for demersal fish in the area were carried out by Johan Hjort in 1900, but he found 'no fish usable for food' (Iversen 1936). Exploratory fisheries with longline and handline were carried out in August in 1930 and 1931 (Iversen 1936). Catch rates were moderate (62 fishes per 1000 hooks in 1930 and 46 fishes per 1000 hooks in 1931). Total catches amounted to 2112 specimen (about 5500 kg salted fish) in 1930 and 1462 specimen (about 4000 kg salted fish) in 1931. The catch mainly consisted of large cod, and the mean length in 1930 was 86 cm. An exploratory fishery in June 1930 was, however, not successful (total of 3 specimens of cod on 3000 hooks). In 1933, people who wintered at Jan Mayen reported that cod was caught on handline close to the shore in late autumn (Iversen 1936; Barr 1991, pp. 81–82).

In 1950, a longline was set east of the island on 31 July during a herring survey, and 27 large cod were caught on 1000 hooks (Devold 1950). The next exploratory fishery for cod in the area took place in August 1955 (Rokstad 1955). The fishery reported was by longline using frozen herring as bait, as no catches were taken in attempts by handline. Cod was caught at depths between 100 and 200 m. Catch

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Published online: 06 December 2022

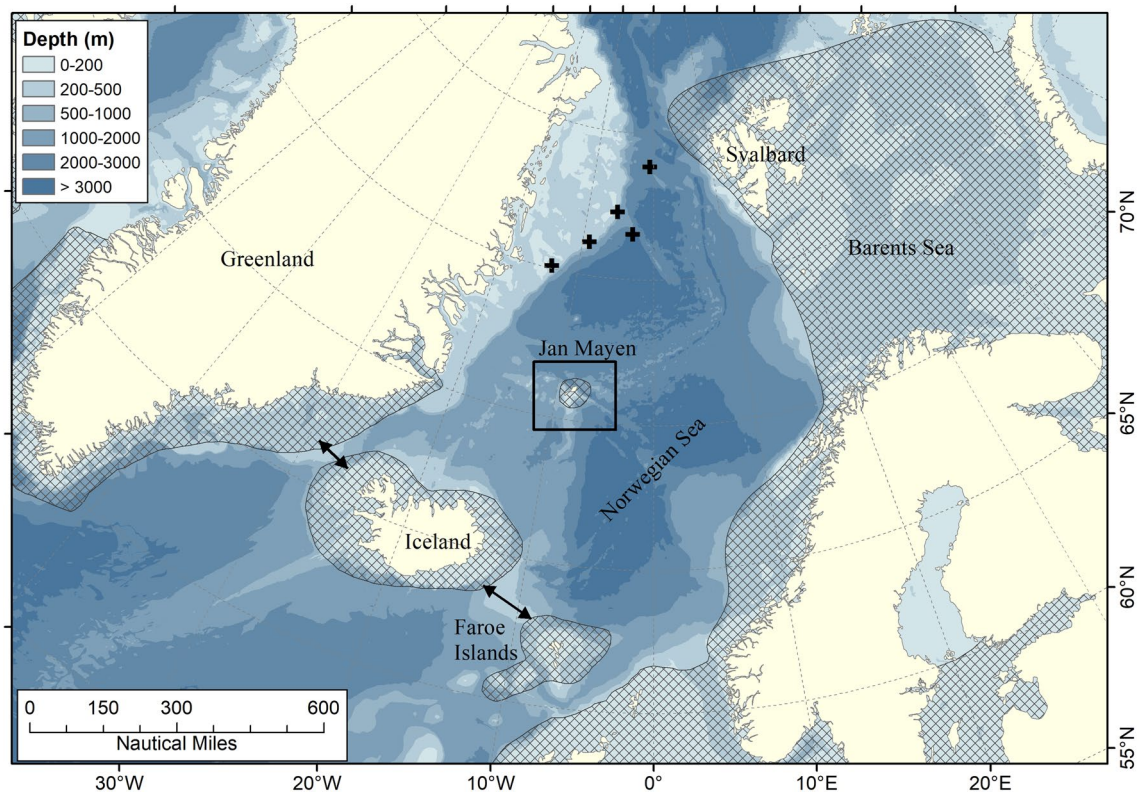

Fig. 1 Distribution of cod stocks in the Northeast Atlantic (hatched areas). Known connections between stocks are shown by arrows. Positions of cod catches off Northeast Greenland in 2007–2017 (Andrews et al. 2019) are marked by crosses

rates were generally low (in total about 400 specimens of cod on 30,000 hooks). The fish was very large (mainly 120–135 cm), but in poor condition, skinny and frequently with open wounds—'a cemetery for cod' as the author put it.

There was renewed interest in demersal fisheries in the area when a commercial shrimp (*Pandalus borealis*) fishery started there in 1974, and small numbers of cod were caught during exploratory shrimp fisheries carried out by commercial vessels. Ponomarenko (1989) describes investigations in November 1974–March 1975 and September–November 1978 (or 1979, the paper quotes both years). Cod was caught by shrimp trawl 'individually, rarely by tens' in October–January at depths of 160–500 m, with the largest catches in November. The length and age range of the fish were 24–65 cm and 2–6 years. The length distribution may be affected by the selectivity of the shrimp trawl which probably has lower selectivity for large cod. In shrimp trawl surveys in 1979–1981, occasional by-catches of cod were reported, but most stations had no cod in the catches. No cod by-catches were reported from shrimp surveys in 1994–1995 (Aschan et al. 1996).

In 1982, 1993, 1995, and 2004, 149 specimens were reported from nine stations close to the island and in the eastern part of the fishery zone around Jan Mayen Island (IMR database). Cod was also reported to be among the species caught there in June–July 2008 (Christiansen 2012). The October 2011 trawl survey in the area (Fossum et al. 2012) caught a total of 19 cod (79 kg) with mean length around 75 cm on 2 stations (both < 200 m), while on the other 7 stations deeper than 500 m no cod was caught. In July 2017, the cruise ship FRAM delivered 350 kg fresh cod to the station at Jan Mayen. (http://jan.mayen.no/nyheter/besok-av-ms-fram-og-350-kg-torsk/).

Data on Norwegian catches of cod reported in this area (defined as Norwegian statistical areas 35, 36, and 38) were available from 1977 onward (Online Resource 1). Some of these catches are likely by-catches in Greenland halibut (*Reinhardtius hippoglossoides*) fishery, while some of the other catches reported before 2008 may well be misreported by area (J. I. Maråk, Norwegian Federation of Fishing Vessel Owners, pers. comm.) The catch of 2.4 tonnes in 2010 is known to be correctly reported by area, as samples were obtained from this catch. Before 2019, there were no quota regulations for cod fishery in the Jan Mayen EEZ, and the fishery for Greenland halibut is still unregulated.

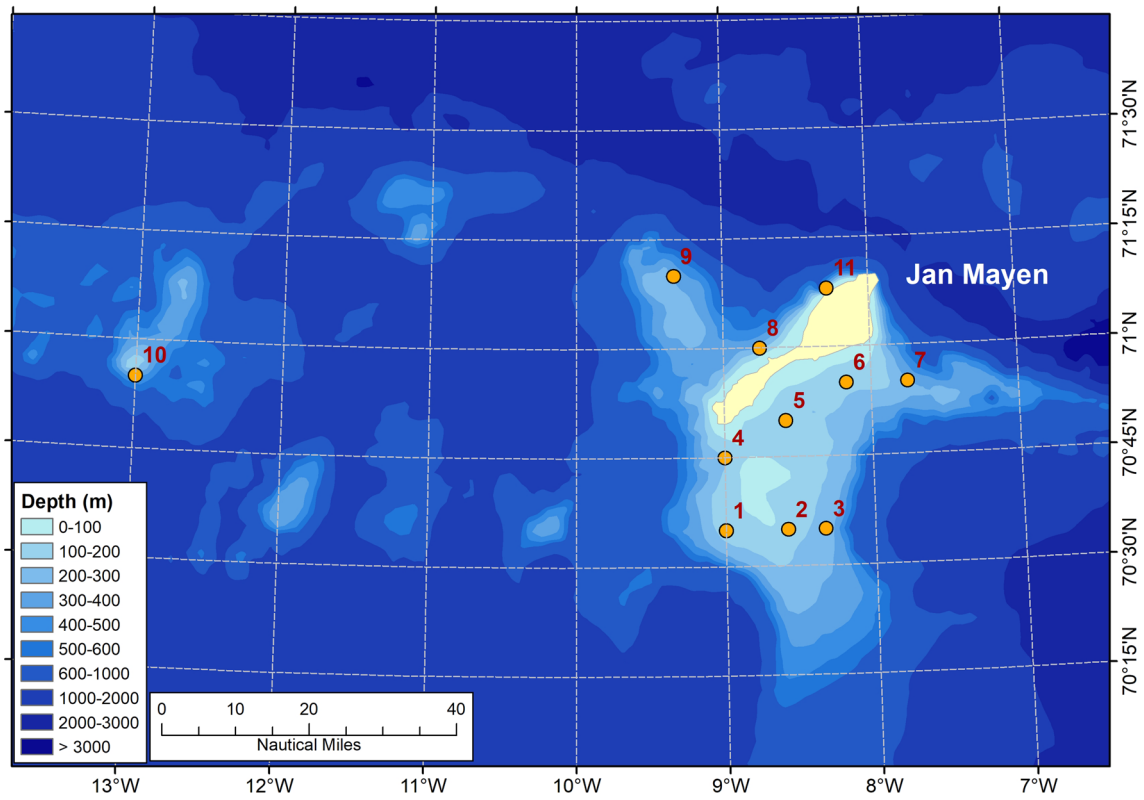

Fig. 2 Obligatory research stations used in the exploratory cod fishery in the Jan Mayen area in 2019–2020

Material and methods

The Norwegian fishing vessel "Loran" went fishing for Greenland halibut in the Jan Mayen area in July 2018 and as by-catch they caught some cod. Following this, they made two more expeditions to the area, one in September and one in October–November, and the total cod catch from these three expeditions amounted to 441 tonnes. Almost all of this was caught by longline but also some by gillnet, which is the preferred gear for Greenland halibut fishing in this area. Catch rates improved during autumn but leveled off and decreased somewhat toward the end of the last trip (9 November). The highest daily catch was 35.6 tonnes, which is very high for such a fishery. The catches consisted of large fish with normal condition factor (i.e., normal length–weight relationship), and almost exclusively of cod. Catches were taken on the south side of Jan Mayen, in the area spanned by stations 1–8 on Fig. 2, but also with some catches between stations 8 and 9 and east of station 7. Catches close to station 9 were minimal.

Following the successful fishery by "Loran" in autumn 2018, the Norwegian authorities decided to carry out a quota-regulated exploratory fishery with longline in 2019, and this was continued in 2020–2022. Norwegian longliners could apply for participation, and then a lottery was held to select two vessels each year to do two trips each. The vessels were required to fish at 10 obligatory research stations spread out over the shelf (Fig. 2), and the gear and bait was standardized, but the vessels could otherwise fish freely as they wanted. Observers from IMR were present on most trips. As there was quota remaining after four trips in both years, a fifth trip with no requirement of fishing at the research stations was made in both years. In 2019 stations 1–10 were covered. Station 10 was dropped after the first two trips in 2019, as no cod was caught there. In 2020 station 11 was added, and station 9 was dropped after two trips in 2020 as cod catches there were minimal. In 2021–2022, the vessels were not obliged to fish at the research stations.

Sampling routines were different at the research stations and during the commercial fishery elsewhere in the area. At the research stations all fish caught on a 5000-hook section of the longline was counted, and length measured (maximum 100 length measurements per species). A stratified sample (1 fish for each 5-cm length group) was taken where in addition to length, age, sex, maturity, and stomach content was recorded. Age reading was done by readers with long experience in age reading of Northeast Arctic cod. Maturity stage was determined according to the standard scale used at IMR (immature, mature, spawning, spent). Stomachs were frozen onboard the vessel and analyzed in the laboratory at

IMR where the prey were weighed, identified to species level or lowest taxonomic level possible, and prey length was, where possible, recorded. During the regular commercial fishery, a representative length sample (20 specimens) from the catch was taken from a 5000-hook section, and every week one stratified sample was taken as described above.

The cod collected for the genetic analysis was analyzed by pan1 and a selection of Single-nucleotide polymorphic (SNP) markers according to Johansen et al. (2018). The assignment of the cod into coastal cod, Northeast Arctic cod, and Icelandic frontal or coastal cod was combined with reference samples from these stock components.

Results and discussion

Catches consisted almost exclusively of cod, catches of other species were minimal (around 1% of total catch when directed Greenland halibut fishery is excluded). In addition to Greenland halibut, catches of some other commercial species were also recorded: Atlantic halibut (*Hippoglossus hippoglossus*), spotted wolffish (*Anarchias minor*), northern wolffish (*Anarchias denticulatus*), and roughhead grenadier (*Macrourus berglax)*. Catch rates were highest in autumn, somewhat lower in spring and generally low (but variable) in summer. In autumn, catch rates of 7–10 tonnes per day could be maintained for a 4-week trip, but exceptional daily catches like "Loran" obtained in 2018 were not observed, the highest observed catch on 1 day was 19 tonnes. Catch rates in 2019 and 2020 were similar and in 2021 they were somewhat lower. Total cod catches in 2019 were 628 tonnes, while the catch in 2020 was 522 tonnes, in 2021 146 tonnes and in 2022 276 tonnes. An overview of fishing trips, quotas, cod catches, and catch rates for each trip is given in Table 1. The drop in catches from 2020 to 2021 was mainly related to fewer fishing days and less interest in the fishery. This was related to a very high cod quota in 2021 in the Barents Sea, where the relevant vessels have their main fishery.

Table 1 Summary of fishing trips, cod catches, and quotas 2018–2022 in the Jan Mayen area

Year	Period (dd mm–dd mm)	Cod catch (kg)	Catch rate (kg day^{-1})
2018	30.06–12.07	19 261	1482*
2018	09.09–01.10	111 054	4442*
2018	11.10–09.11	311 066	10,726*
2019	28.04–20.05	180 637	7854
2019	28.06–01.07	2 754	689
2019	02.08–29.08	217 485	7767
2019	26.09–16.10	160 459	8023
2019	10.12–17.12	65 992	8249
2019	28.05–21.06	955	119*
2020	15.03–02.04	47 095	2479
2020	21.06–25.06	4 151	830
2020	24.07–27.07	1 209	302
2020	23.10–22.11	280 308	9042
2020	06.12–31.12	188 645	7256
2020	05.08–18.08	196	14*
2021	26.09–30.09	17 044	3409
2021	28.11–13.12	127 500	8500
2021	18.05–27.05	1 467	147*
2022	12.10–08.11	276 274	9209**
Year	Quota (kg)	Catch (kg)	
2018	–	441 381	
2019	800 000	628 282	
2020	800 000	521 604	
2021	600 000	146 011	
2022	347 000	276 274**	

All catches are given in kg round weight

*Trips by «Loran» which fished both for cod and Greenland halibut in 2018 and only for Greenland halibut in 2019–2021

**Preliminary numbers

Most of the cod caught was between 70 and 100 cm (60–100 cm in 2021) and with normal condition factor. The length range was 38.5–127 cm and the age range was 3–19 years. The 2007 year class dominated the catches in 2019 and 2020, while in 2021 also recruitment of younger fish (mainly 2016 year class) was observed. Length and age distributions for August–December for the years 2019–2021 are given in Online Resource 2. Those months were selected because they had relatively stable catch rates, and length distributions from different trips in the period were thus aggregated without weighting them by catch rates. Age distributions were calculated by combining the length distributions with age–length keys from the stratified age samples.

Spawning cod was observed in spring both in 2019 (trip from 28 April to 20 May) and in 2020 (trip from 15 March to 2 April). In 2019 most of the fish had already spawned and in 2020 most of the fish had not yet started spawning. Thus, the peak time for spawning is likely around 15 April. The age and length distributions were similar to that in autumn for both 2019 and 2020, the smallest mature fish was 58 cm and the youngest 5 years. Spawning cod has not been observed in this area earlier, but as far as we know there have been no fishery investigations in the area at this time of year, due to weather and ice conditions. Genetic analysis found that the Jan Mayen cod was of both Icelandic and Barents Sea origin, but significantly different from both stocks (Johansen et al. in prep.). The otolith typing indicated that some of the cod was of Barents Sea type, while others were of type unknown, which could support that these cod had grown up around Jan Mayen. Also a few cod were of a coastal cod type both based on otoliths and genetic analyses.

Themisto spp. and other invertebrates dominated in the cod diet (in total 350 stomachs analyzed from 2019 to 2020), with fish prey making up around 20% of the stomach content in the samples. This is different from most other cod stocks, where the diet of cod of this size is dominated by fish prey (Link et al. 2009), but similar to the diet of cod on the Greenland shelf (Werner et al. 2019). Temperature was recorded on some expeditions by a sensor attached to the long line and was mostly between 0 and 1 °C.

Based on the oceanographic current pattern around Jan Mayen (Mork et al. 2019) larval drift from other stocks (distribution areas shown in Fig. 1) to Jan Mayen seems unlikely. Migration of cod between the Jan Mayen area and Iceland has earlier been confirmed by tagging studies. Iversen (1936) reports that of 113 cod tagged at Jan Mayen in August 1930, 5 were recaptured in waters around Iceland in 1931–1932, four of these five were recaptured during spawning time (March–April). Also some cod specimens caught at Iceland in 1930–1931 had angles in their body which clearly were of a type only used at Iceland. For management purposes, exchange between the northernmost Atlantic cod stocks (Barents Sea, Faroes, Iceland, Greenland, Newfoundland (2J3KL or northern cod)) has been considered to be negligible, except for migrations between Iceland and Greenland. However, Tåning (1934) showed that cod tagged at the southwest coast of Iceland were recaptured in all of these areas. Out of 4939 tagged cod in 1924–1925 443 were recaptured at Iceland, 17 at West Greenland, 2 at the Faroes, 2 off Northern Norway, 1 at Newfoundland, and 1 in the Danish Strait. Knowledge of migration of cod in the North Atlantic was summarized by Neuenfeldt et al. (2013). It is possible that the cod now found in the Jan Mayen area has migrated there from other cod stocks such as Iceland, Northeast Arctic, and possibly also southeast Greenland.

The distribution of cod expanded northward in other areas in the northernmost part of the Atlantic Ocean in the 2000s, related both to increased temperature and increased stock size (which are linked to each other). This occurred both in the Newfoundland/Labrador area (Rowe and Rose 2015), in the Barents Sea (Kjesbu et al. 2014) and at Greenland (ICES 2021b). Thus, the recent occurrence of cod in Jan Mayen waters seems in line with this northward expansion of distribution of other stocks in the northernmost part of the Atlantic. Note that Icelandic cod has quite limited possibility to extend its distribution northward as it already occupies almost the entire shelf area around Iceland. Some of the variations in cod abundance in the Jan Mayen area through time are likely related to oceanographic conditions, such as bottom temperature and ice coverage, particularly since bottom temperatures in the area are low and close to the lower temperature limit for cod. Cod can be found in temperatures down to − 1.5 °C although the proportion of cod found in waters below 0 °C is low (Righton et al. 2010). The ice coverage in April in Nordic Seas (Vinje 2001) has decreased considerably from the end of the nineteenth century to present, with low values found, e.g., in the 1930s when cod concentrations first were reported from the Jan Mayen area. In cold periods the area around Jan Mayen has been partially covered by ice. This may have affected the spawning conditions for cod in the area negatively. For a recent review of changes in oceanographic conditions in the Nordic Seas, see Smedsrud et al. (2022).

Off East Greenland potential spawning areas are identified up to 66° N along the coast (Storr-Poulsen et al. 2004). Andrews et al. (2019) found a total of 10 juvenile cod (all specimens < 1 kg) on the shelf off NE Greenland and in the Fram Strait between 74° and 79° N in August–October in the period 2007–2017 and genetic analyses showed this to be cod from the Barents Sea. These observations are much farther north than previous occurrences of cod off East Greenland. Probably these specimens have as 0-group drifted northward along the west coast of Svalbard and then entered a branch of the oceanographic currents which goes westward

toward NE Greenland. These observations are in line with the study by Strand et al. (2017) who identified the Northeast Greenland Shelf as a potential habitat for Northeast Arctic cod. Also 27 adult cod were caught in pelagic hauls over deep waters in the Fram Strait in 2014–2015 (Ingvaldsen et al. 2017).

It is likely that there have been small quantities of cod in the Jan Mayen area since the 1930s and that an increase in stock abundance occurred sometime in the 2000s, most likely after 2007 since that year class is abundant in the catches. This increase may be due to immigration of cod from other areas as well as successful spawning at Jan Mayen. However, the 2007 year class was average for Icelandic and West and East Greenland cod (ICES 2021b) and weak for Northeast Arctic cod (ICES 2021a), so there is no evidence that the oceanographic conditions in this part of the ocean were particularly favorable for cod recruitment in 2007. If immigration is the main reason for the increase, cod from that year class likely would have to be at least 3–4 years before having the swimming capability to migrate that far irrespective of where it came from.

Since spawning in the area has now been confirmed, egg and larval drift routes for cod spawning at Jan Mayen should be investigated using oceanographic models, as done for other cod stocks, e.g., Northeast Arctic cod (Vikebø et al. 2005). Also trawling for egg and larvae in the surface layers as well as bottom trawling with small-meshed trawl should be carried out to verify whether all age and size groups of cod are found in the area.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00300-022-03102-8.

Acknowledgements I would like to thank Tom Williams, Institute of Marine Research, for invaluable assistance in the organization and administration of the exploratory fishery for cod in the Jan Mayen area in 2019–2022. Also thanks to Torild Johansen, IMR, and two anonymous referees who helped improve the manuscript, to Kjell Bakkeplass for making Fig. 1 and 2, to the crew of all vessels for good cooperation and to IMR personnel for participation on fishing trips and laboratory analyses.

Author contributions As a single author I have written the manuscript myself. Those who provided assistance are thanked in the Acknowledgements.

Funding Open Access funding provided by Institute Of Marine Research. The participation of IMR personnel on the fishing trips to Jan Mayen as well as the laboratory analysis of the data collected was funded from the Norwegian fee for fisheries research and surveillance (Fiskeriforskningsavgiften).

Declarations

Conflict of interest The author has no competing interests to declare that are relevant to the content of this article.

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