SWORDFISH TOWARDS THE ARCTIC ATLANTIC IN CLIMATE CHANGE

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SUMMARY

The remarkable increase in abundance of swordfishes (Xiphias gladius) along the Norwegian coast is coinciding with the recent temperature increase in the North Atlantic Ocean since the cold period during the 1960s and 1970s. This increase is mainly due to the large-scale natural climate oscillation of the Atlantic Multidecadal Oscillation (AMO). The major part of the swordfishes occurred during late summer, particularly in August when sea temperature is at maximum. The swordfishes along the Norwegian coast seem to be solitary juvenile visitors and have all been within a limited size group from 1.5 to 2.65 m in length and from 20 to 40 kg in weight most probably corresponding to ages of 3-4 years. Younger fish would probably be too small for these long excursions to the north, but it is not clear why older and larger individuals stay away from the northern fringes of the distribution area. This is a different behavior from the bluefin tuna (Thunnus thynnus) in earlier periods, particularly in the 1950's and 60's.

RÉSUMÉ

*L'augmentation remarquable de l'abondance de l'espadon (*Xiphias gladius*) le long du littoral norvégien coïncide avec la hausse récente des températures dans l'océan Atlantique Nord depuis la période froide des années 60 et 70. Cette augmentation est principalement due à l'oscillation climatique naturelle à grande échelle de l'oscillation atlantique multidécennale (AMO). La majorité des espadons sont apparus à la fin de l'été, notamment en août lorsque la température de la mer est au maximum. Les espadons rencontrés le long de la côte norvégienne semblent être des juvéniles solitaires et s'inscrivent tous dans un groupe de tailles limité, allant de 1,5 à 2,65 m de longueur et pesant entre 20 et 40 kg, ce qui correspond selon toute probabilité aux âges 3-4 ans. Des poissons plus jeunes seraient probablement trop petits pour ces longues excursions vers le Nord, mais on ne sait pas pourquoi des spécimens plus âgés et plus grands restent éloignés des limites septentrionales de la zone de distribution. Il s'agit d'un comportement différent de celui du thon rouge (*Thunnus thynnus*) au cours de périodes antérieures, notamment dans les années 50 et 60.*

RESUMEN

*El marcado incremento en la abundancia de pez espada (*Xiphias gladius*) a lo largo de la costa de Noruega coincide con el reciente incremento de las temperaturas registrado en el océano Atlántico norte después el periodo de frío de los años 60 y 70. Este incremento se debe sobre todo a la oscilación climática natural de gran escala de la Oscilación Multidecadal Atlántica (AMO). La presencia de la mayor parte de los peces espada se detectó durante la última parte del verano, sobre todo en agosto, cuando la temperatura del mar alcanza su máximo. Los peces espada presentes a lo largo de la costa de Noruega parecen ser visitantes juveniles solitarios y todos se inscriben en un grupo de talla limitado de 1,5 a 2,65 m de talla y de 20 a 40 kg de peso, que probablemente se correspondan con las edades 3-4 años. Probablemente los ejemplares más jóvenes serán demasiado pequeños para estas largas excursiones al Norte, pero no está claro por qué los ejemplares más mayores y grandes se mantienen fuera de los extremos septentrionales de su zona de distribución. Se trata de una conducta diferente a la del atún rojo (*Thunnus thynnus*) en periodos anteriores, sobre todo en los cincuenta y sesenta.*

KEYWORDS

Swordfish, Norwegian coast, climate change, AMO

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1. Introduction

Atlantic swordfish (*Xiphias gladius*) is distributed from Argentina to the banks south of New Foundland in the western Atlantic (Stillwell and Kohler 1985), and from South Africa to the entrance of the Nordic Seas in the eastern Atlantic. However, there have been occasional reports of solitary individuals observed or caught along the Norwegian coast all the way north to the entrance of the Barents Sea over the last 200 years. From the coastal waters of southern Norway Wollebæk (1924) reported that swordfish occurred annually. However, subsequently it has occurred less regularly (Gjøsæter 1992). From the coastal water of northern Norway Hognestad and Vader (1979) reported 13 individual swordfishes during the ~150-year period from 1828 to 1975.

2. Material

Since 1967 the Institute of Marine Research has kept an archive over observations and catches of swordfishes in Norwegian waters. The archive is obtained from newspaper articles and by direct reports from fishermen to Institute of Marine Research. During the 44-year period 1967-2011 altogether 25 individuals have been recorded (**Table 1**). Differently from the earlier observations (Wollebæk 1925; Hognestad and Vader 1979) the abundance along the northern Norway coast is not lower than along the southern Norway coast. In fact, 13 of the 25 swordfishes were even observed to the north of the Arctic Circle, and the most frequent region for the observations is in the three neighboring fjord systems Skjærstadfjord, Folla and Tysfjord to the east of the Lofoten Archipelago where 8 of the observations have been taken (**Figures 1** and **2**). The other remarkable feature is the large increase in observations during the second half of the observation period of 44 (**Figures 1** and **2**). During the first half of the period (**Figure 1**) 24% of the swordfishes was observed, while remaining fraction (76 %) occurred after 1992 (**Figure 2**). The swordfishes have become particularly abundant after year 2000 when 56% the observations during the 44-year period occurred. The peak abundance occurred in 2006 when four swordfishes were caught. The four catches this year were geographically distributed all along the Norwegian coast from the southeastern Kragerø to Gratangen in the Troms County, northern Norway.

In the present paper we have compared the swordfish observations with time series of ocean climate and time series of potential prey organisms, particularly abundance of herring.

3. Results and discussion

The remarkable increase in abundance of swordfishes along the Norwegian coast is coinciding with the recent temperature increase in the North Atlantic Ocean since the cold period during the 1960s and 1970s (**Figure 3**). This increase is mainly due to the large-scale natural climate oscillation of the Atlantic Multidecadal Oscillation (AMO) (Sutton and Hodson 2005), but probably also partially due to the global anthropogenic climate change. The increase in swordfish observations is indeed correlated with the large-scale multidecadal temperature change. **Figure 3** shows the number of swordfish observation in each decade versus the decadal-averaged regional sea temperature. The temperature data are from the Kola sections in the Barents Sea. The recent decade has had the highest average sea temperature since our observations started at the beginning of the 20th century, and at the site near Kragerø, southeastern Norway, were the swordfish was caught on 21 August 2006 the temperature was 20 ^{o}C which was 3 ^{o}C higher than the long-term average sea temperature down to 30 m depth of that region. On the other hand, many of the swordfishes have also been caught at much lower ambient temperatures, partly because temperature in northern Norway is much lower and partly because some of the fishes were caught later in the autumn and even in winter. **Figure 4** shows the approximate ambient temperature where the fishes were observed or caught. The mean catch temperature for all the fishes is 12.5 ^{o}C. One swordfish was caught 27 March 2003 in Oslofjorden when the ambient temperature was as low as 5 ^{o}C.

The major part of the swordfishes occurred during late summer, particularly in August when sea temperature is at maximum (**Figure 5**). The secondmost frequent month was September, and some of the observations were also done later in the autumn. One anomalous observation was done in March 2003 at the lowest temperature of the year. Even though this was an anomalously warm winter the ambient temperature was only 5 ^{o}C. Even though the increasing abundance of swordfish is coinciding with anomalously high temperatures the actual ambient temperature at catch is still low for a swordfish (**Figure 4**). This brings the attention to possible other co-occurring variables of importance to swordfishes. Along with the increasing temperature since the cold 1960s and 1970s an increase in the abundance of the traditional boreal fish species has occurred. This has occurred to the Norwegian spring-spawning herring (Toresen and Østvedt 2000) and to the Atlantic mackerel. Such species might be important prey for swordfish.

In the western North Atlantic, i.e. in the Gulf Stream from Cape Hatteras to south of New Foundland, the main diet of swordfish was squid while fish was the secondmost important food consisting of gadoids, scombrids, butterfish, bluefish and sand lance (Stillwell and Kohler 1985). In the Bay of Biscay squid and fish also comprised the main diet (Chancollon et al. 2006). However, they also pointed out that swordfish showed a large plasticity in the diet depending of local region. The stomach content reported from the swordfish caught along the Norwegian coast and fjords has been herring. However, possibly also other pelagic fishes like mackerel and blue whiting which have become increasingly abundant far north along the Norwegian coast might have been important prey organisms. Norwegian spring-spawning herring which recovered after the stock collapse during 1960s is presently one of the largest fish stocks in the world with the total stock abundance peaked in 2006 of almost 14 million tons, the same year as the swordfish observations peaked. It is assumed that the present strength of the herring stock is due to a combination of low fishes pressure ($F < 0.15$) and high productivity of the boreal ecosystem during the present warm period.

The swordfishes along the Norwegian coast seem to be solitary juvenile visitors and have all been within a limited size group from 1.5 to 2.65 m in length and from 20 to 40 kg in weight most probably corresponding to ages of 3-4 years. Younger fish would probably be too small for these long excursions to the north, but it is not clear why older and larger individuals stay away from the northern fringes of the distribution area. This is a different behavior from the bluefin tuna. Up to the 1980s, before the stock of bluefin tuna in the Northeast Atlantic was depleted, large schools of the biggest fish, up to more than 300 kg in weight, migrated to the Norwegian coast for summer feeding on pelagic fishes. Hence, bluefin tuna is clearly adapted to lower temperatures than the swordfish. With the present abundance of pelagic fishes along the Norwegian coast the blufin tuna would have optimal feeding conditions.

4. References

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Table 1. Observations and catches of swordfish along the Norwegian coast and in the fjords from 58 ^{o}N to 71 ^{o}N for the period 1967 – 2011.

Latitude	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11
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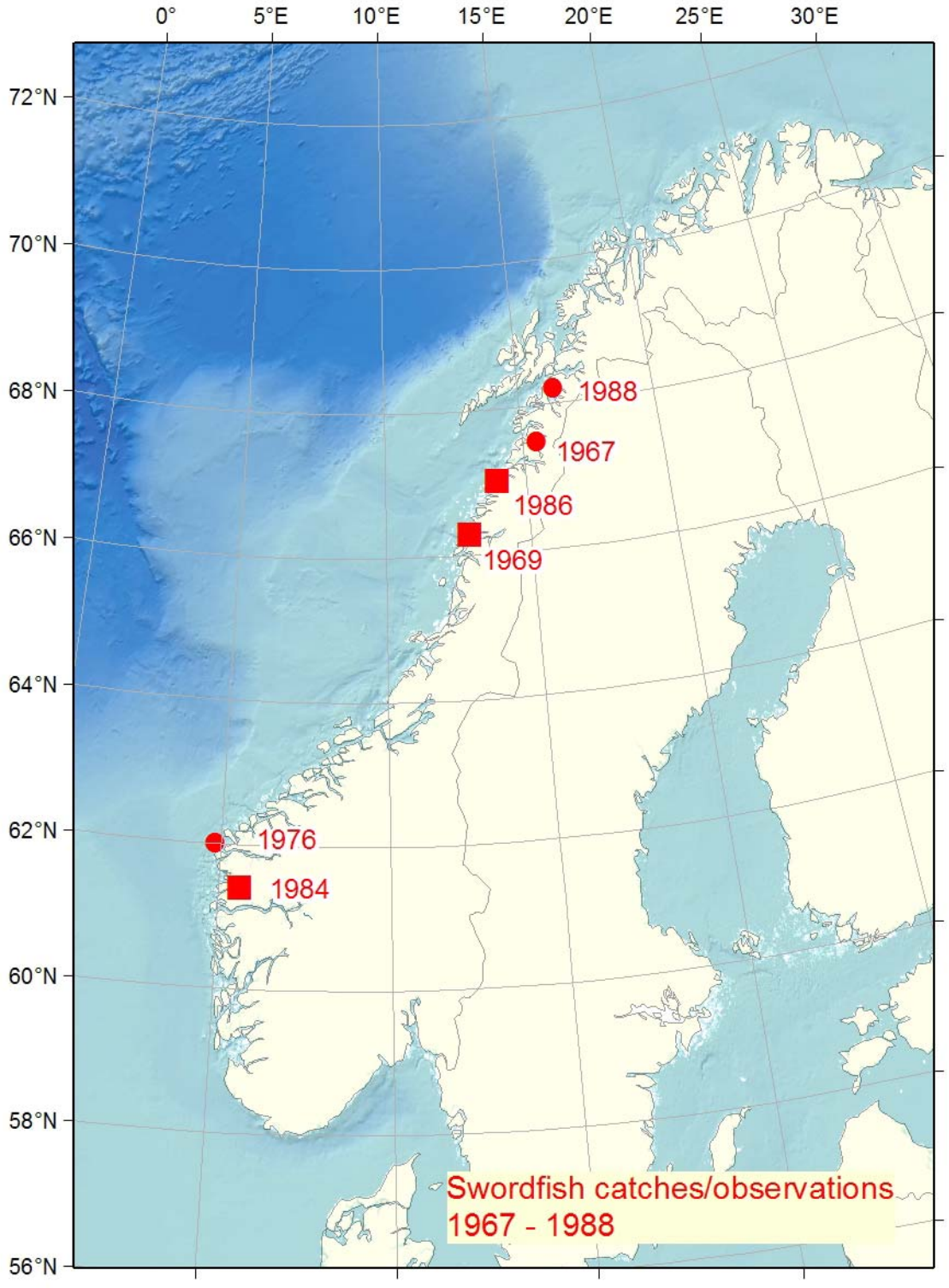

Figure 1. Catches and observations of swordfishes along the Norwegian coast and in the fjords during the period the period 1967-1988. Circles show exact location of the observation. Where exact locations are not known larger squares indicate approximate location.

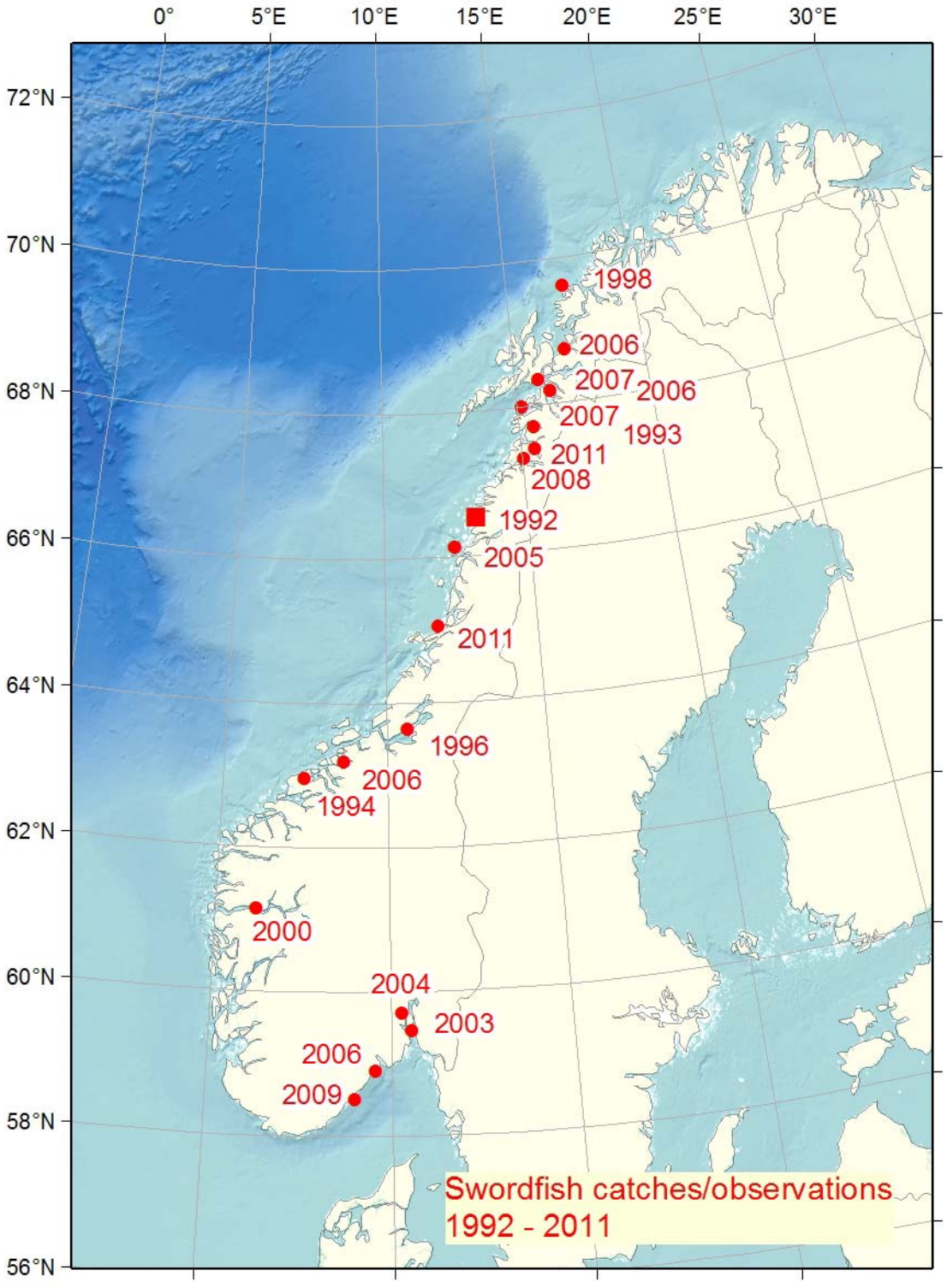

Figure 2. Catches and observations of swordfishes along the Norwegian coast and in the fjords during the period the period 1992-2011. Circles show exact location of the observation. Larger square indicates approximate location where exact location is not known.

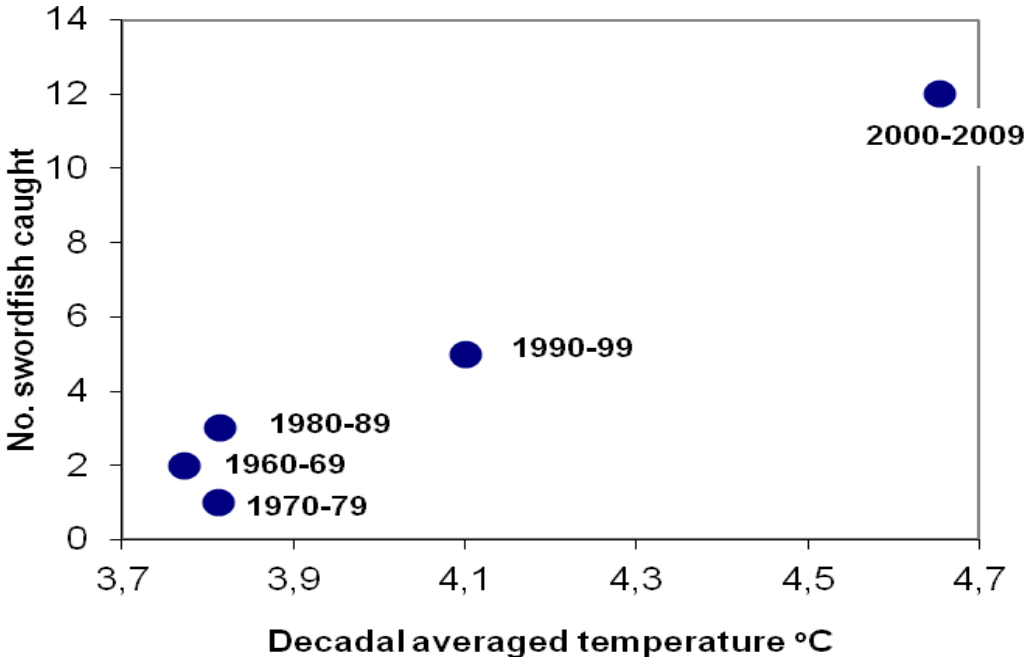

Figure 3. Number of swordfish caught in each decade versus the decadal averaged temperature of the northeastern North Atlantic (Temperature based on the Kola Section time series in the Barents Sea).

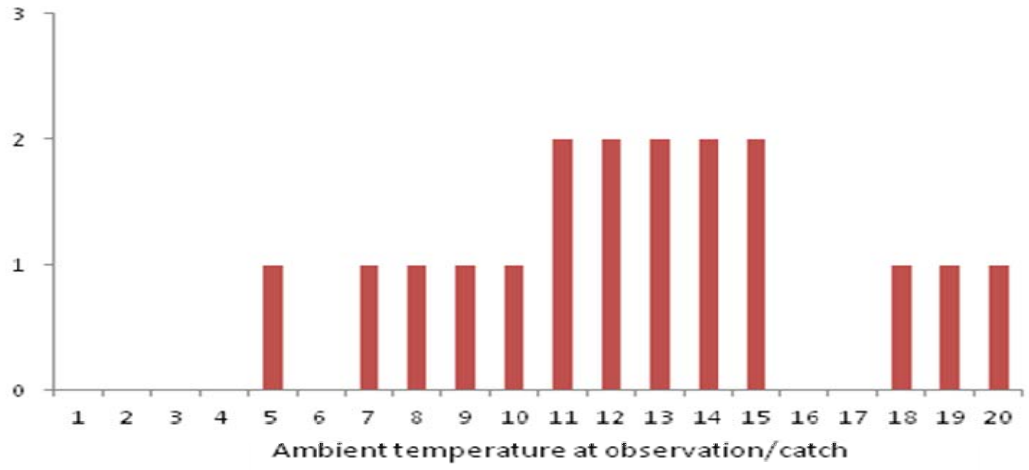

Figure 4. Ambient temperature (^{o}C) of swordfish at observation or catch. The average temperature for all observations is 12.5 ^{o}C. (Temperature based on nearest local c hydrographic station).

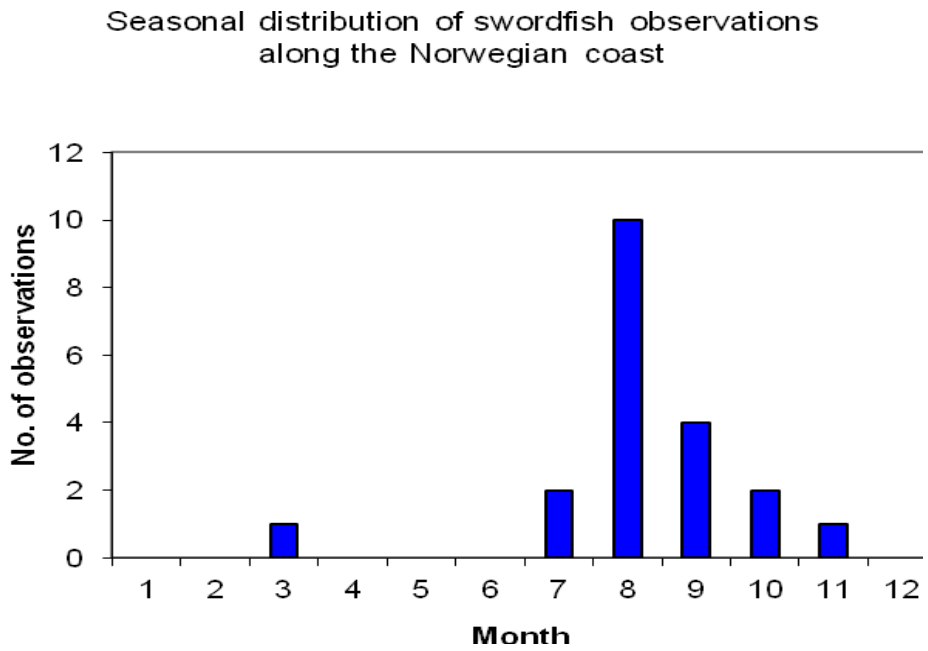

Figure 5. Seasonal distribution of swordfish observations/catches for the period 1967-2011.

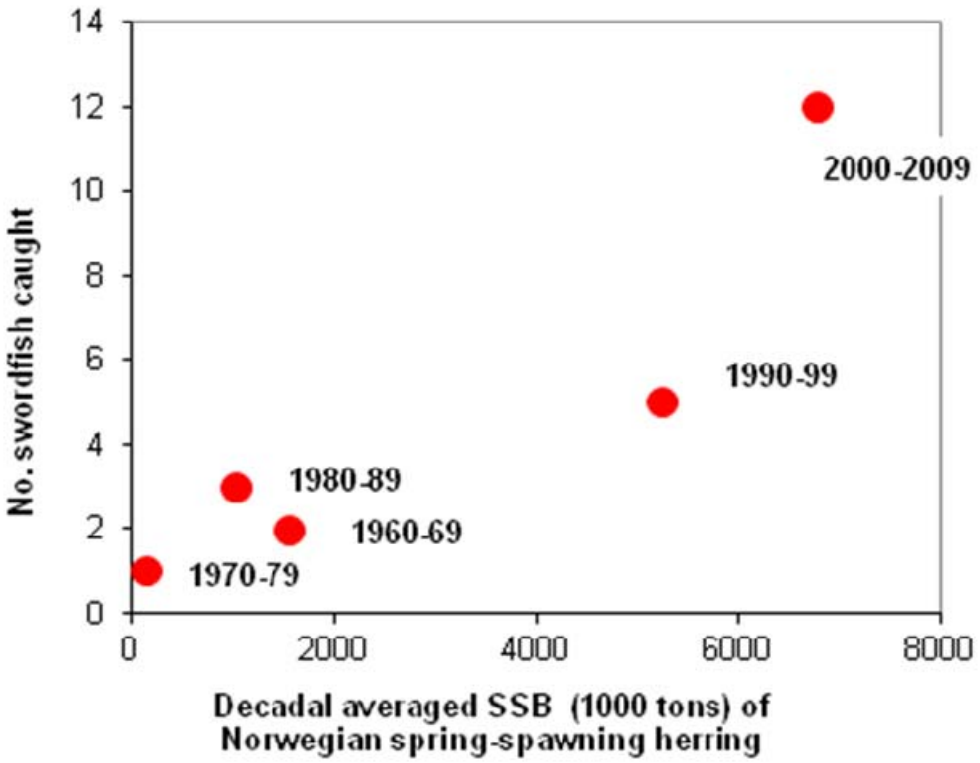

Figure 6. Number of swordfish caught in each decade versus the decadal averaged spawning-stock biomass (in 1000 tons) of Norwegian spring-spawning herring.