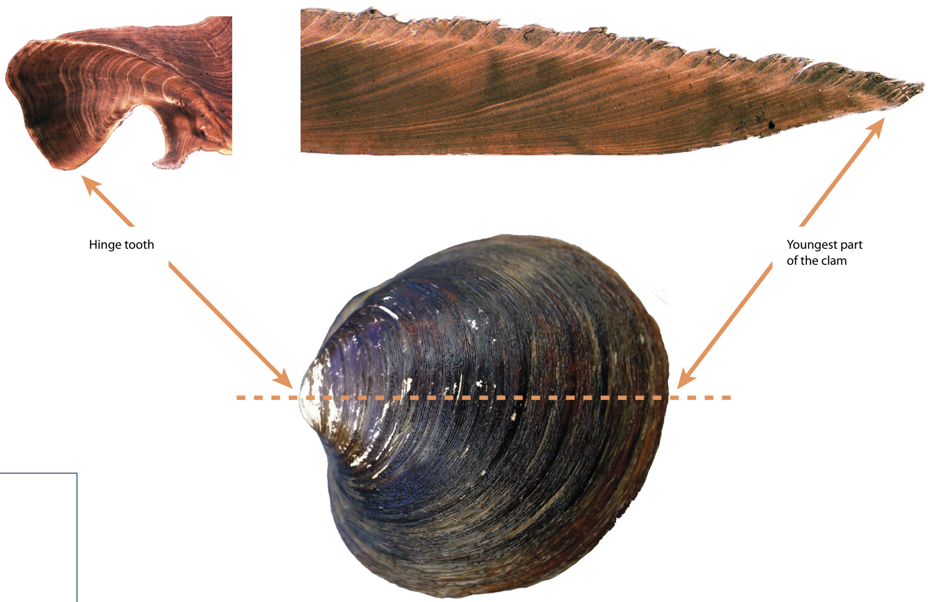
Nøgd av makreli undir Føroyum í eina øld

Mackerel during a century, on the Faroe Shelf

A study based on the growth of Arctica islandica

Tórshavn · May 2014



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Summary

This research funded by Fiskivinnugransking, Statoil and Havstovan was carried out at Havstovan during the period May 2013 to March 2014. Collaboration has been with Felagið Nótaskip (Faroese Pelagic Organisation). The *Arctica islandica* specimens were sampled in the long-line fishery by M/B Bjørgvin and dredged by M/B Norðheim.

The aim of the research was to sample ocean quahog *Arctica islandica* from seabeds away from the impact of fresh water runoff from land and at depths of about 100 meters.

This work is based on the authors' earlier work of *Arctica islandica* on the Faroe Shelf. Measurements of Arctica specimens from former work are included in the calculations in this report.

The procedure used for age determination was the "Acetate peel method". The new equipment, saw, polishing machine and microscope, funded by Fiskivinnugransking, made it possible to carry out the work at Havstovan, successfully.

The material is composed by Arctica specimens from Vestmanna, Sandvíkum and Oyndarfjørður on depths below 30 metres and from depths of 100 meters in an area north of the Islands (Kallurin) and from the queen scallop area east of the Islands.

The growth of 102 Arctica shells have been analyzed. The growth of *Arctica islandica* from the deeper areas has been compared to the previous collected specimens from depths in the shallower areas.

The main factors influencing the Arctica growth is food availability and temperature. The result of the growth increment analyzes reveal differences in the environmental conditions of the shells at the individual level as well as at the regional level.

Faroese Arctica specimens reach high ages. The oldest specimen so far was more than 400 years old and origin east of the Islands. A substantial proportion of the sample reached high ages from about 100 to 200 years.

The main result is an inversely relation between Arctica growth and the biomass of zooplankton. From this correlation an index of mackerel on the Faroe Shelf is reconstructed.

Acknowledgements

Thanks to Kristin Vilhelmsen for his enthusiasm in being the link between Havstovan and the long-liner fishermen. Thanks to Jákup Páll Joensen on the M/B Bjørgvin and to the crew of M/B Norðheim as well as divers, who without payment has collected and delivered specimens of *Arctica islandica* to this research. Thanks to PhD Dánjal Petur Højgaard for commenting earlier versions of this report and for his encouragement in this research.

The aim

To reconstruct the amount of plankton 100 years back in time based on the growth of *Arctica islandica* from depths below 100 meters. To recreate the amount of mackerel for the 20' century based on a correlation between the reconstructed plankton and observed amount of mackerel on Faroe Shelf.

Introduction

The ocean quahog *Arctica islandica* is a bivalve mollusk and is an infaunal sedentary filter-feeder. *A. islandica* is a North Atlantic species and is distributed on the continental shelf on both sides of the ocean in temperate and boreal waters. Ocean quahogs occupy sea beds of muddy to coarse sediment from low intertidal zone down to about 300 meters. Ocean quahogs are characterized by its longevity. Specimens' origin in the Faroe Islands reaches high ages. The oldest specimen sampled in the northern area (Kallurin) was 177 years old and the oldest specimen of the eastern area is more than 400 years old. A substantial proportion of the sampled specimens reached high ages of about 100 to 200 years.

Ocean quahogs mature very slowly. The mean age of sexual maturity is around 13 years (Rowell et al. 1990; Thorarinsdottir et al. 2000). The recruitment of ocean quahogs is via planktonic larvae and the spawning season is prolonged and may last for several months.

Results of experimentally cultured ocean quahogs show maximum growth rate during the warmest period (Lutz et al. 1983). The growth season for *A.*

islandica is from February to September in the North Sea (Schöne et al. 2005). For clams in Faroese areas the growth season is unknown and might cause some troubles when dating the clams. The warmest months of the Faroe Shelf water is in the late summer period from July to September, and may be considered as the growth season of ocean quahogs. According to the results of this work, the Arctica growth coincides with the late summer primary production.

Although a commercially important bivalve in USA, Canada and a few years ago in Iceland (Dahlgren et al. 2000), the knowledge of the ocean quahog in Faroese water is limited. Besides a small fishery in fjords of ocean quahog for bait, there have been no commercial fisheries for ocean quahog in Faroese waters. The distribution and abundance of the species is unknown. Besides information from the Biofar project and from fishermen who have had a limited Arctica fishery in fjords, the established cooperation with the long-line fishermen have revealed some new information of the distribution of the clams in deeper areas.

Arctica islandica is renowned by its longevity and has been referred to as the tree of the sea. The marked growth banding in the shell of *Arctica islandica* is caused by the strong seasonal variation in temperature and production, and has an annual pattern (Ropes et al. 1984, Ramon & Richardson 1992, Witbaard et al. 1994). Like the ring in trees show past environment growth conditions on land back in time, the growth increment incorporated in the shell of ocean quahogs reflects the environmental conditions in the sea.

The sea water on the Faroese Shelf is well mixed down to a depth of about 100 meters and the temperature of the water column is the same at the sea surface and at the seabed. The yearly average sea temperature in the Faroe Islands is about 8 degrees Celsius, with relatively small seasonal variations, summer temperature of 10 °C and winter temperature of 6 °C (Fig. 6). The growth of ocean quahogs is depending mostly on temperature and food supply. As the main food source of this clam is phytoplankton and the difference between the summer and winter temperature of the sea surrounding the Faroe Islands is small, the growth increments of the ocean quahogs mostly reflects available food supply of phytoplankton.

One of the most popular and serious issues today is climate change. This concerns most human, politicians as well as scientists. By dendrochronology it has been possible to elucidate environmental conditions on land thousands of years back in time. In the marine environment in the North Atlantic Ocean, *Arctica islandica* has proved to be the key species in revealing conditions in the past. Climate change is affecting us all and the understanding of the impact on the marine environment is highly important, especially for the Faroese people which overall relies on marine fishery. The fisheries and aquaculture are vital to the Faroese economy and scientific advice is critical to secure the future of our food industries. Today we experience a change in the distribution of fish stocks which most likely is caused by the climate change. These changes will have some significant challenges for policy-makers, fisheries managers and for the fishing industry itself. Therefore the present research should be of huge interest for the Faroese nation and further research should be seen as a very important issue for the understanding of climate change in the sea surrounding the Faroe Islands.

In order to understand the changes in the environment it is crucial to know about the past and how things have behaved. This study is an important contribution and can reveal past primary production, which is known to be fundamental for the marine life.

Material and Method

Specimens of *Arctica islandica* are sampled in three fjords, Vestmanna, Oyndarfjørður and Sandvíkum, on depths approximately 20-25 metres and in two areas on 100 meters depth, one north of the Islands and one east of the Islands (Fig. 1).

As *Arctica islandica* is not a commercially exploited species in the Faroe Islands, it was a challenge to get specimens below depth of 30 meters, which is the safe diving depth. During an research and contact with fishermen we experienced that *Arctica islandica* is caught as bycatch on the long-line occasionally. Thus we established a co-operation with some long-liner fishermen. Live clams fished by long liners were delivered frozen at the Faroe Marine Research Institute. Additionally, specimens of *Arctica islandica* were collected in an area east of the Islands in the queen scallop fishery. These specimens were dead when collected, but as the valves still were paired (articulated) and clean (without any epizoa), we accepted the shells as recently dead.

Until now 102 specimens from the Faroe Shelf have been analyzed (Table 1).

Samples were kept frozen and later thawed to determine the biometric characteristics of the individuals. Shell length (longest anterior-posterior dimension), height (deepest dorsoventral dimension) and width (widest lateral dimension) were measured with vernier callipers to the nearest 0.1 mm, and the wet meat weight was determined to the nearest 0.1 g. Shell weight was measured to the nearest 0.1 g.

The procedure used for age determination is the "Acetate Peel Method" developed by Ropes J.W. 1987.

Examination of the acetate peel were viewed under a light stereomicroscope *Leica M80* and digitized with a *Q Imaging Retiga 2000R, FAST 1394* camera. Analyses of the annual growth increment were measured with the software *Image-Pro Plus, version 7.0 from Media Cybernetics – From Image to Answers*.

Mackerel data

Unfortunately it turned out to be problematic to get hold of catch statistics for mackerel on the Faroe Shelf. Mackerel data for the Faroe Shelf is merged into data for a larger area. Data that is used in this report originates from Magnus Heinason surveys, and is from 100 stations in March and 200 stations in August. This data is the best offer available at present moment to calculate Mackerel on the Faroe Shelf.

CPR-data from SAHFOS

The time series is from 1958 to 2010 and origin within these positions:

N	W
62°40	8°30
62°40	5°30
61°00	8°30
61°00	5°30

Table 1. Arctica islandica collected on the Faroe Shelf.

Year	Area	Number	Depth (m)
2010	Vestmanna	13	20-25
2010	Oyndarfjørður	8	20-25
2010	Sandvíkum	6	20-25
2011	Northern area	45	100
2012	Eastern area	30	100

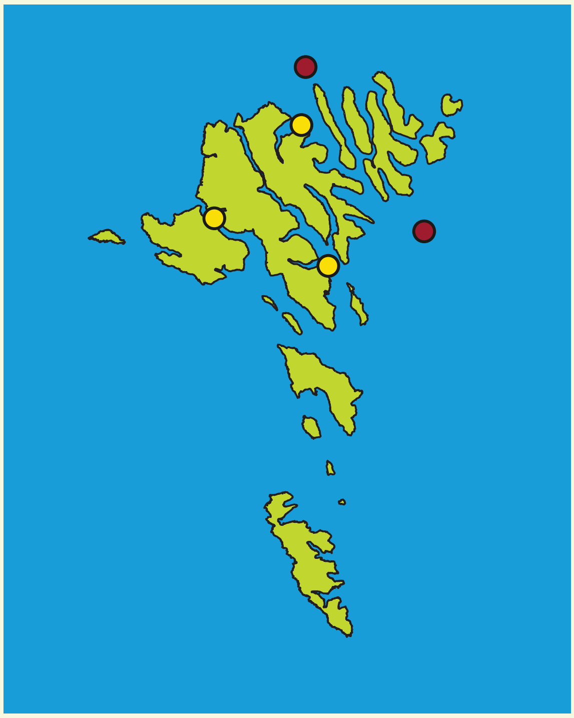

Figure 1. Map of the Faroe Islands. Red spot indicate sampling areas on 100 m depths (K and Ey) and yellow spots indicate shallow areas of less than 30 m (VOS).

Other data

Other data used in this report is from the database at Havstovan.

Chronology construction

- Cofecha

To analyze and reexamine the increment growth data for possible errors, we used the program COFECHA. This software is a quality-control program used to check the cross dating and the quality of tree-rings chronology, but is widely used in the work of *Arctica islandica*.

The verification of the dating of the clams COFECHA results in shift of 11 clams +/- one or two years.

- Arstan

Arstan was used to make the final chronology. To maximize the signal and remove noise, the final chronology was constructed using the regional curve standardization (RCS) in the program Arstan. Using the RCS the low-frequency variability in the chronology is maintained, which is useful to determine long-term trends in past climate.

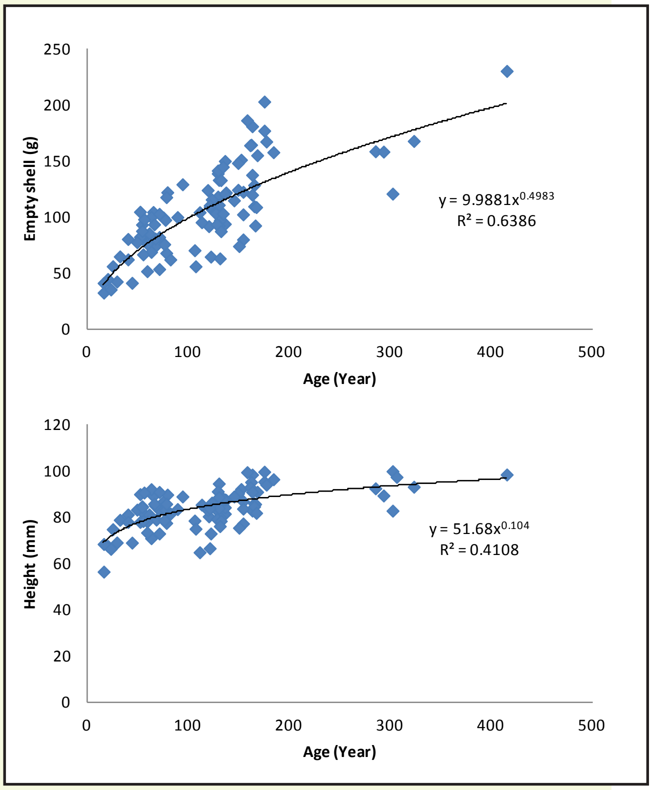

Figure 2. Age-weight of empty shell and age-height relationship of A. islandica from five sampled sites around Faroe Islands.

Results

So far 102 specimens of ocean quahog have been analyzed (Tab. 1). The biometrics of the specimens has been measured, including: height (measured along the line of maximum growth from the umbo to the ventral margin), breadth, and thickness of the clam and weight of whole animal, shell, left and right valve as well as wet weight of soft tissue.

Biometrics

The biometric data, height-age and weight-age relationship (Fig. 2), indicate a positive relationship of shells older than about 50 years. The material does not give the opportunity to see the growth structure of the whole population, as young specimens are lacking.

Comparing the age-total weight relationship of *Arctica islandica* from different areas, indicate a difference of specimens from the four areas. Ocean quahog from Sandvíkum (S) and Kallurin (K) show a similar growth pattern though specimens from

Sandvíkum are heavier. Specimens from Vestmanna (V) seem to have a different growth pattern. Specimens sampled in Oyndarfjørður (O) are of similar age and therefore it is not possible to say much about the age-total weight relationship. As for specimens origin in Kallurin it is obvious from figure 3 that only knowing the total weight of the animal may not reveal the age of the clam. The growth of ocean quahog may vary considerably. A specimen from Kallurin which is 120 year old has a weight of 130 grams and another specimen from the same location weighs 96.3 grams at the age of 122 years.

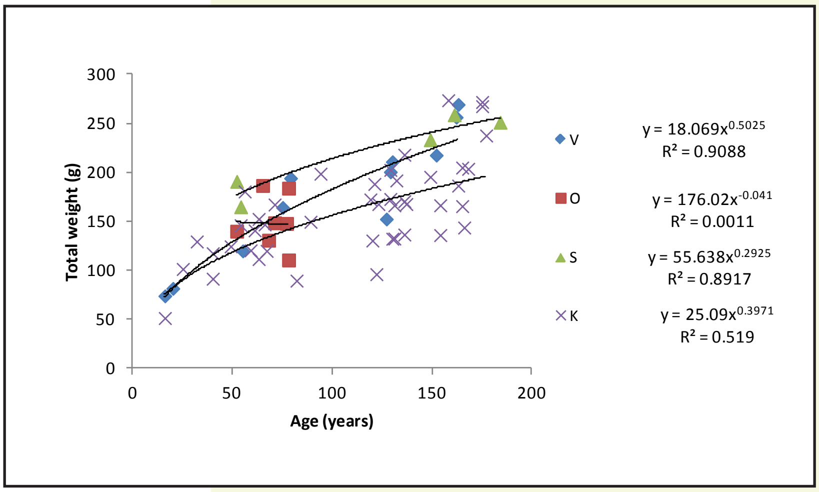

Figure 3. Age – Total weight of A. islandica in four sampled sites around the Faroe Islands. V: Vestmanna, O: Oyndarfjørður, S: Sandvíkum and K: Kallurin.

The results from figure 4 indicate that it is necessary to have a suitable sample size. As for the area Oyndarfjørður there are far too few clams to reveal any tendency. The clams are growing throughout life and as the increment growth becomes very small there is a clearer increase in shell weight. This is because the growth of the animal occurs not only at the edge of the shell, but there will be added a new layer on the inside of the entire shell.

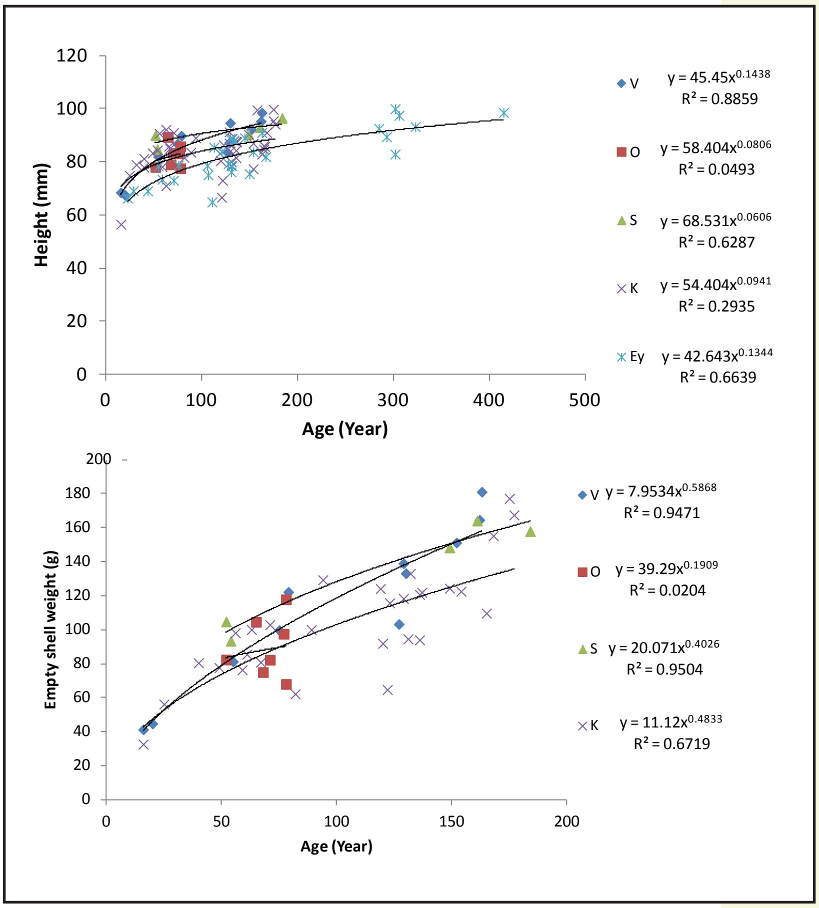

Figure 4. Height – age and empty shell weight –age relationships of A. islandica in four sampled sites around the Faroe Islands.

The Growth of *Arctica islandica*

From the former project it was obvious that the growth conditions of *Arctica islandica* in the three sampled areas was different. The difference might be attributed to differences in food supply and how exposed the area is, as well as fresh water run-off from land. Numbers of specimens were small and might affect the outcome of the growth rate. Clams from areas farther away from the Islands and in deeper waters may give a clearer signal of the available food supply of the Shelf.

The growth of *Arctica islandica* from the different sampling sites on the Faroe Shelf reveals that the growth conditions are different but that the signal from each area is similar (Fig. 5).

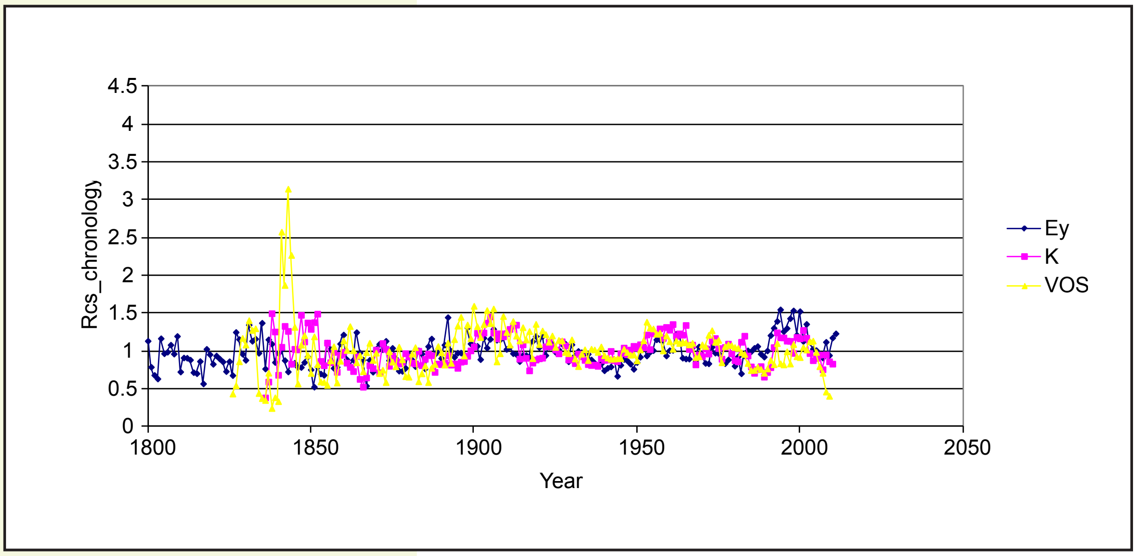

Figure 5. Mean yearly growth of Arctica islandica on the Faroe Shelf. The northern area (K), the eastern area (Ey) and in three fjords (VOS).

The spring bloom on the Faroe Shelf starts in April and peaks in May-June, after which a much lower amount of phytoplankton extends until August-September, the timing of highest temperatures on the Faroe Shelf (Fig. 6).

The Arctica growth was positively correlated with an index of primary production 1990-2011, although not significantly (Table 2). It was more closely correlated with Chlorophyll A concentration from 15. June to 31. August, although still not significantly.

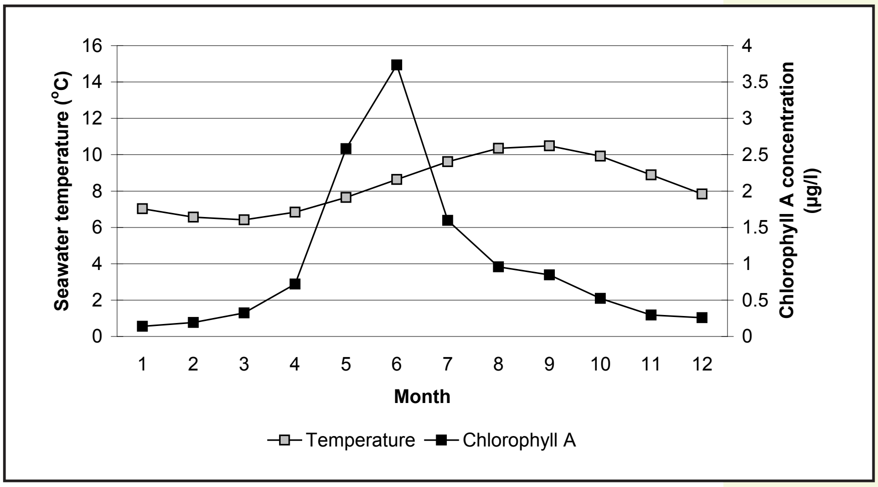

Figure 6. Mean monthly seawater temperature and chlorophyll A concentration on the Faroe Shelf.

Table 2. Correlation coefficients between Arctica growth and varying time periods of Chlorophyll A measurements on the Faroe Shelf. For example, from 4.5 to 9 denotes from 15 June to 31 August. "NA": Not available.

	From (month)					
To (month)	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**
6	0.29			NA	NA	NA
6.5	0.41	0.40			NA	NA
7	0.43	0.42	0.50			NA
9	0.52	0.54	0.61	0.61	0.65	0.31

The annual growth of Arctica islandica is compared to the measured values of plankton on the Shelf. The annual growth rate of Arctica islandica specimens is negatively correlated to the concentration of zooplankton on the Faroe Shelf (Fig. 7). Measurements of zooplankton on the Faroe Shelf have been carried out since the year 1991 at Havstovan. From the Arctica growth it is possible to model the zooplankton concentration back in time (Fig. 8). This might shed light on changes of the main food source that have been available as zooplankton is the main link to higher trophic levels.

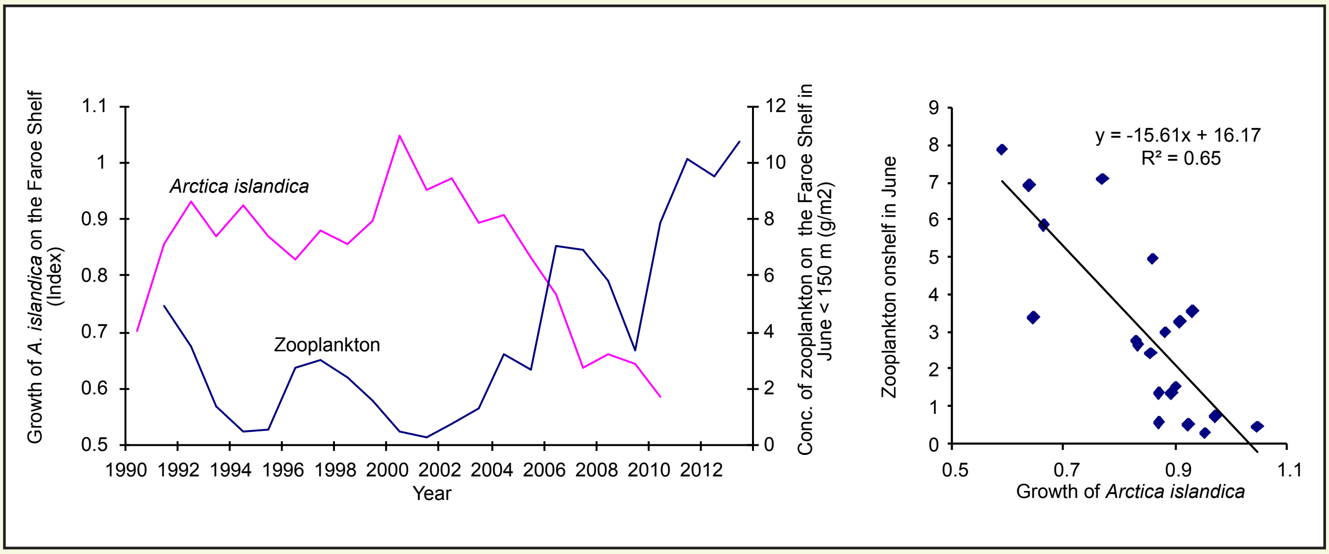

Figure 7. Annual shell growth of Arctica islandica and measured concentration of Zooplankton in June on the Faroe Shelf.

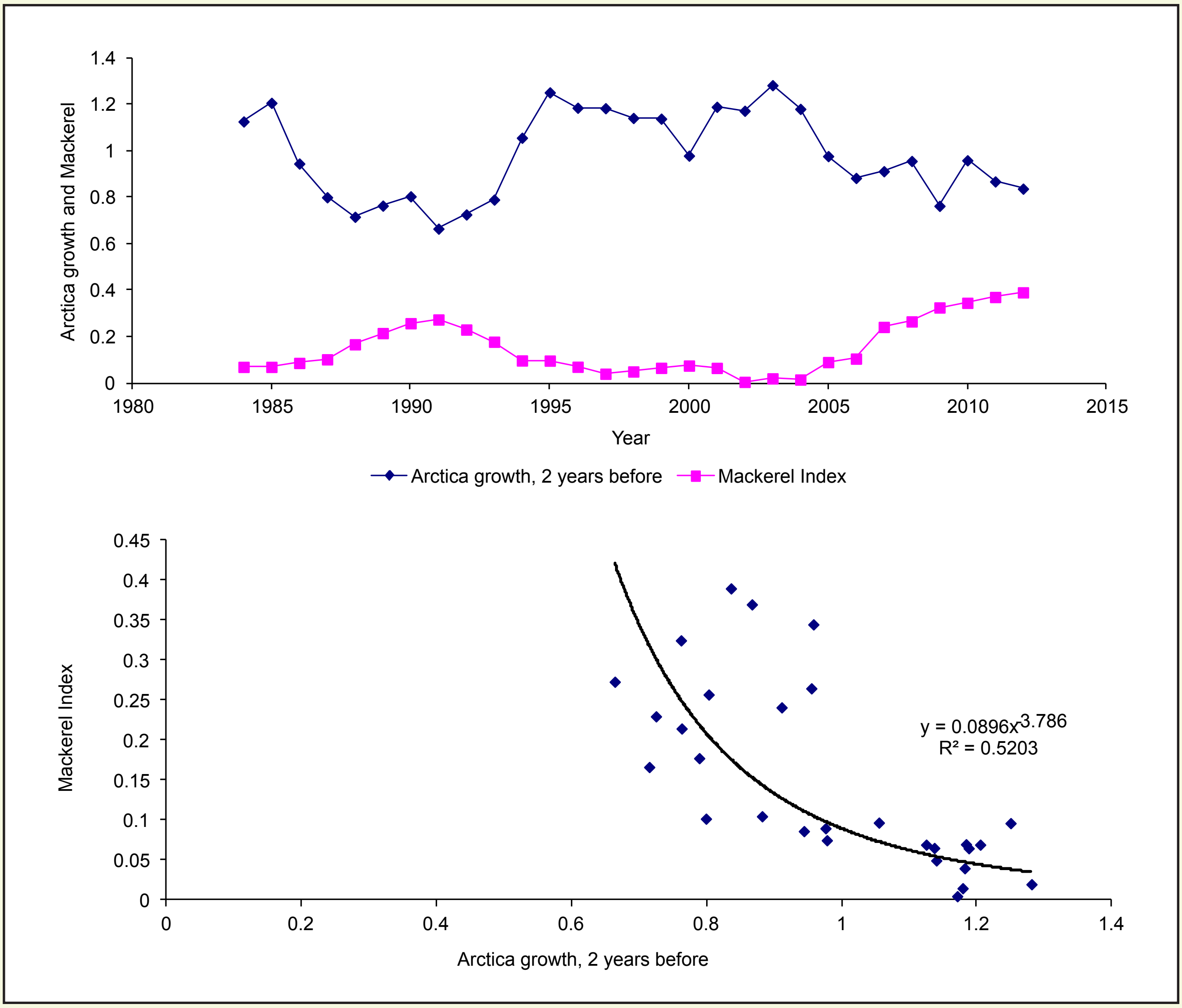

Figure 8. Arctica growth shifted 2 years back in time and Mackerel Index indicate an inverse relationship.

Pelagic fishes

The food source of pelagic fish species is dominated by large zooplankton such as Calanus and krill. *Calanus finmarchicus* constitutes the majority of zooplankton on the Faroe Shelf. The main food resource of mackerel and herring is Calanus (Misund et al. 1996; Nottestad et al. 1999; Gislason and Astthorsson 2002). Hence, the amount of zooplankton reveals the available food supply for pelagic species as herring. Calanus and krill feed on phytoplankton and are in the same trophic layer in the ecology system.

Mackerel

The mackerel data analyzed in this report is from the Magnus Heinason survey. An inverse relationship is seen between Arctica growth and mackerel two years delayed (Fig. 9). The Mackerel Index is low two years after a period of high Arctica growth and vice versa.

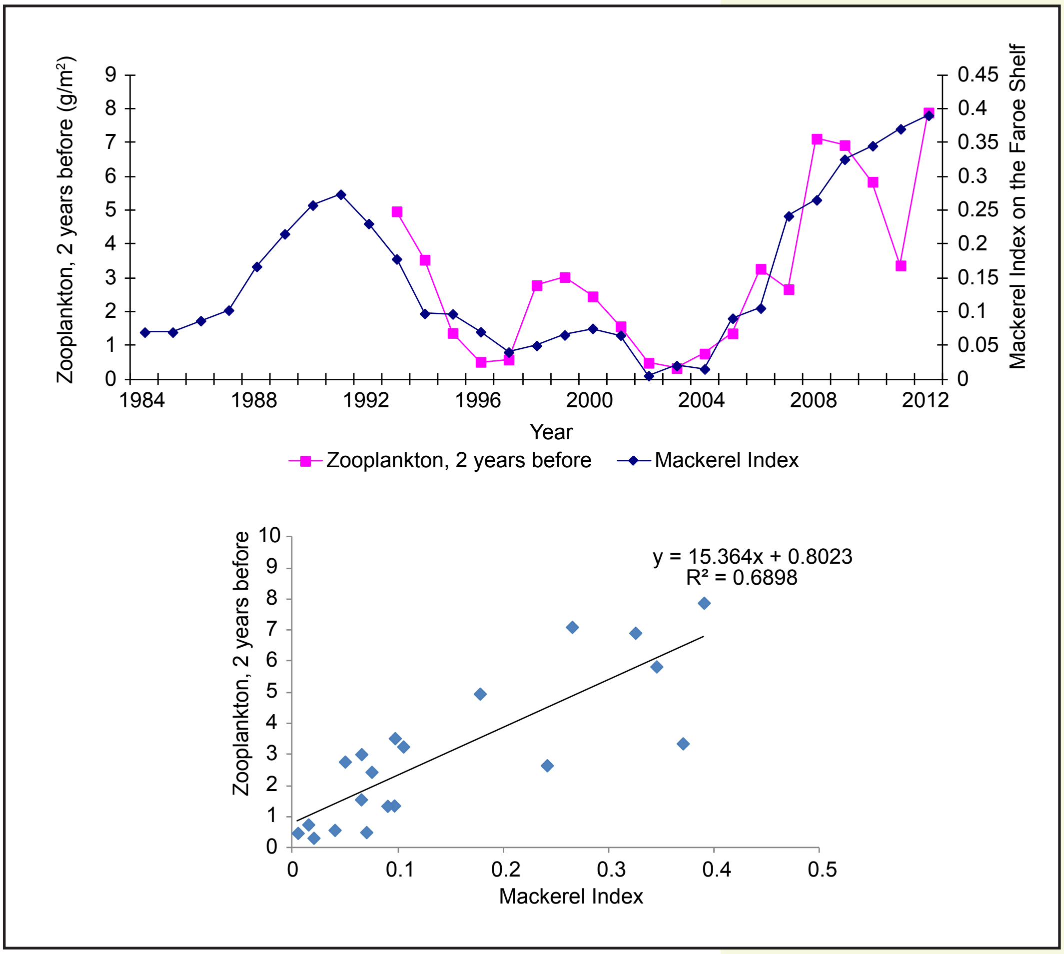

Figure 9. Relationship between Zooplankton 2 years before and Mackerel Index.

When comparing Mackerel Index to the concentration of zooplankton, a clear correlation is seen when the zooplankton is shifted two years back in time.

The strong correlation between Zooplankton and Mackerel Index makes it possible to give an estimation of the Mackerel on the Faroe Shelf back in time (Fig. 10), based on the growth of *Arctica islandica*.

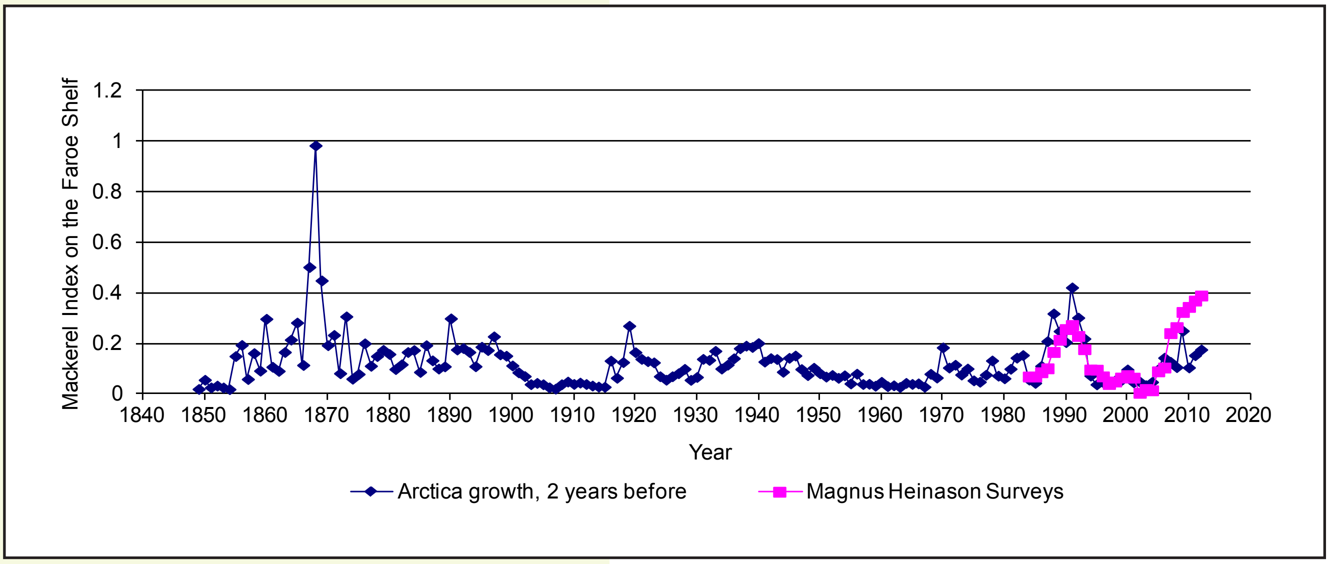

Figure 10. Mackerel on the Faroe Shelf back in time.

The reconstructed Mackerel Index back to around 1880 is based on sufficient shell material. In the period from 1880 to 2011 there have been variations in the amount of mackerel on the Faroe Shelf and the reconstruction indicate that the mackerel amount in 1990 and from 2006 are unusually high (Fig. 10).

Discussion

This work has clearly showed that the growth increment in the shell of *Arctica islandica* reflects informations from the past which can be of great importance of understanding the ecosystem on the Faroe Shelf.

Doing this work, we have established wider evidence concerning the distribution of *Arctica islandica* on the Faroe Shelf. Knowledge of the species' distribution has been limited to areas close to land, in the fjords. A limited knowledge has also been on the species' distribution in deeper water, partly from the Biofar project and partly from long-line fishery. It would be an interesting task to get a better estimate of the distribution of the species on the Faroe Shelf.

Arctica islandica specimens in this project do not resemble the whole population as mostly large or old animals have been caught by the long-line and only large specimens have been picked by scuba-divers. Therefore it is not possible to conclude anything about the population structure on the Faroe Shelf. The biometrics of ocean quahogs include mostly old specimens and the growth shown in figures 3 to 6 therefore is not representative for young mussels as they are too few. The growth is expected to be exponential. Through the first 20 years of life of *Arctica islandica* the distance between each growth line is large. As the mussels gets older the yearly growth of the shell become smaller. Relationship between height/ weight and age (Fig. 2 & 3) proves that the mussel continues to grow throughout life. Additionally there is an individual growth difference as the variation is large, e.g. a specimen 120 years of age from Kallurin may have a shell height of 73 to 86 and a total weight between 96 to 168 g (Fig. 4).

The biometric data reveal a difference in growth conditions of *Arctica islandica* in four sampled areas (Fig. 4). This may be caused by e.g. a local effect from fresh water run-off from land and the differences in exposure (sheltered or exposed areas). Local differences may have an effect on the productivity in the area. The area north of Kallurin stand out, however, from the other three areas as the depth and the location is quite different. Specimens from Kallurin origin at a depth of about 100 meters and is situated in open ocean area, whereas the three other areas are located in fjords in a depth of about 25 meters. The results indicate that the number of specimens examined is too few to give reliable results about growth differences between sites. The differences may however indicate that the productivity in enclosed bays and fjords is different from off shore locations.

The growth of Faroese ocean quahogs (*Arctica islandica*) is consistent to other studies e.g. in Iceland (Thorarinsdottir et al. 2000). Ocean quahogs are fast growing during the first 20 to 30 years of its lifespan. Then there is a sudden stop in the growth but it continues to grow steadily throughout life. The size of the increment varies through the years. A large increment of ocean quahog indicates that the environment in the growth period has been favorable. The food source of ocean quahog is phytoplankton. Therefore growth of ocean quahogs reflects the primary production available at the seabed.

In the theory the main growing period of ocean quahog in Faroese sea water should coincide with the spring bloom in early spring and continue during the summer and cease in autumn. Smetacek 1984 and Christensen and Kanneworff 1985 have shown that the main growing season for benthic filter feeders is in early spring. This is when the spring bloom occurs and the copepod grazers have not yet developed. Therefore a considerably amount of decaying phytoplankton will sink to the bottom and be available food source to the filter feeders at the sea bed. The phytoplankton on the Faroe Shelf is characterized by a spring bloom topping in May-June and a second smaller bloom in August-September which coincide with the highest sea surface temperature (Fig. 6). Witbaard et al. 2003 found that the main growth period of ocean quahogs is in autumn in the Fladen Ground. They found the best relation between autumn phytoplankton color and the shell growth of *Arctica islandica*. This might as well be true for Faroese *Arctica islandica* which means that a growth increment is from autumn to autumn. This is supported by the correlation in Table 1, as the best correlation between measurement of Chlorophyll A and Arctica growth is in autumn, when the sea surface temperature is highest.

A correlation was found between the annual growth rate and concentration of phytoplankton in the summer, but the strongest correlation was found between Arctica growth and zooplankton. This is an inverse relationship. When the concentration of zooplankton is high Arctica growth is small, and vice versa. An explanation is that *Arctica islandica* and zooplankton forage on the same food source, phytoplankton. However, the habitat is not the same for these two grazers. Zooplankton is living in the upper zone of the water column together with the phytoplankton. Contrary, *Arctica islandica* which is a sedentary species living borrowed in the seabed, will have to wait for phytoplankton to settle. Another explanation is that when the concentration of zooplankton is high, the production of feces is high. These particles may form part of the food source for filter feeders on the bottom. However, some of these particles are too large and are discarded as food for mussels (Witbaard et al. 2003). Filter feeders living on the seabed need to spend energy to sort out the larger particles. Additionally, feces particles of the right size to be eaten, does not contain as much energy as pure phytoplankton. Thereby the condition for filter feeders on the seabed becomes poor.

This apparent correlation between Arctica growth and zooplankton is the cardinal result of this study and makes it possible to recover the amount of zooplankton hundreds of years back in time.

Zooplankton has a crucial importance for fish stocks (Steingrund and Gaard 2005). The present results also provide an opportunity to restore fish stocks back in time. This allows for a broader and deeper understanding of the ecology on the Faroe Shelf and e.g. the interaction of the different fish stocks.

Mackerel

A correlation (R^2=0.689) is found between the recovered zooplankton and quantity of mackerel from trawling survey of the Faroese research ship Magnus Heinason. The pattern of the size of the mackerel stock follows the pattern of zooplankton approximately two years delayed.

Despite no available mackerel data for the Faroe Shelf, the data from Magnus Heinason surveys have proved to be sufficient for making a reconstruction of the Mackerel Index on the Faroe Shelf back in time.

Based on the growth of *Arctica islandica* it has been possible to reconstruct the Mackerel Index back in time (Fig. 10). There is a strong correlation between Arctica growth and Mackerel Index 2 years delayed. Mackerel Index follows the zooplankton concentration 2 years delayed. Large amount of zooplankton gives rise to a success recruitment seen as an increase of the stock two years delayed. Figure 10 reveal that the mackerel stock has been very large around 1990 and since 2006. This appears to be an unusual situation, and may reflect changes in the ecological species composition on the Shelf due to climatic changes.

Conclusion

This research has made it possible to study important interaction in the marine ecosystem on the Faroe Shelf during a century. The high correlation between the growth of *Arctica islandica* and the concentration of zooplankton has made it possible to extend the plankton series hundreds of years back in time. This result has made it possible to clarify some mechanisms that control long-term changes in the Faroese marine ecosystem. Thus a long-term interaction is shown between zooplankton and the fish stock of mackerel.

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