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Age structure, growth and size at sexual maturity in ocean quahog, *Arctica islandica* (Mollusca: Bivalvia), off NW-Iceland.

by

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ABSTRACT

Ocean quahogs, *Arctica islandica* (Linnaeus), were collected from a single population in Aðalvík for the study of growth and age, and from several locations in the Vestfirðir area, NW-Iceland for estimation of size at sexual maturity.

Ocean quahogs from Aðalvík ranged from 31 to 100 mm in shell height and from 7 to 202 years of age. The growth was relatively fast for the first twenty years, the shell height reaching 63 mm at the age of twenty, but gradually declining after that. Maximum asymptotic height, 81 mm, was reached at the age of sixty. The age distribution had three modes at approximately twenty years interval which possibly indicates occasional reqruitment to the Aðalvík population.

Male ocean quahogs were growing significantly faster than females and females attained a bigger infinit shell height. The oldest individuals were all females. Sexual maturity of *Arctica islandica* from Vestfirðir showed good relationship with size and both males and females attained full maturity at the the same size (approximately 55 mm in shell height) but at different age.

Introduction

Studies on ocean quahog, *Arctica islandica*, have revealed it to be extremely slow growing and long living bivalve. With the exception of one abyssal species, the growth rate of *A. islandica* is slower than in any other bivalve for which this has been measured (Turekian et al. 1975; Thompson et al. 1980a). Quahogs commonly grow to the age of 100 years and its longevity is believed to be at

least 225 years (Ropes 1985). Ageing of large ocean quahog is not possible by using external growth checks on the surface of the valve but recent studies make use of microscopic techniques to examine internal growth bands of the shell (acetate peel method; Ropes 1985). Reports of animals of such a high age have raised questions on the reliability of the ageing methods used. However, evidence supporting the hypothesis that the internal growth bands are in fact formed annually (Thompson et al. 1980a) have derived from studies using radiometric techniques (Turekian et al. 1982; Bennett et al. 1982), mark-recapture techniques (Murawski et al. 1982; Ropes et al. 1984a) and from studies measuring oxygen and carbon isotopes in the shell material (Witbaard et al. 1994).

Intensive fishery for ocean quahog has been practiced off the Atlantic coast of the United States for a number of years. This has made extensive research on the population dynamics of the ocean quahog very important. Size-frequency distributions of *A. islandica* are normally dominated by large individuals but small shells are rare (Fogarty 1981; Murawski et al. 1982; Thórarinsdóttir and Einarsson 1994) which can to some extent be explained by the selectivity of the sampling gears. Good recruitment events are rare and some reports indicate recruitment failure for extended period of time (20 to 30 years, Anon. 1993). Studies on the gametogenic cycle of ocean quahog show that timing and duration of gametogenesis can vary between years and spawning activity can be year-round (Jones 1981; Mann 1982; Rowell et al. 1990).

Quahog fishery started in Iceland few years ago. Subsequently some investigations were initiated including surveys on distribution and abundance of the species in Icelandic waters (Eiríksson 1988; Thórarinsdóttir and Einarsson 1994 a & b). The quahog is widely, but patchily, distributed around the coast of Iceland and can be found in high densities. Only limided research has been done on the biology of *A. islandica* in Icelandic waters. This study describes some aspects of the biology of ocean quahog with the aim of facilitating future assessments of the quahog stock.

Materials and methods

Sampling of *Arctica islandica* (Linnaeus) off the NW coast of Iceland was done with hydrolic dredge on grounds with silty sand sediments (Table 1; Fig.1) . During a sanitation survey on shellfish grounds off NW Iceland 214 specimens were sampled from a single population in order to study the age structure and growth of *A. islandica* (Aðalvík, Fig. 1). The study of size at sexual maturity was based on pooled samples of ocean quahog (118 individuals in all) from seven locations visited during a survey on distribution and abundance of the species in the Vestfirðir area (NW Iceland, Fig. 1).

In the laboratory, shell height along the axis of maximum growth was measured to the nearest mm with vernier calipers. The left valve of each individual was embedded in resin and cross-sectioned with a diamond saw along the axis of maximum growth (through the hinge tooth). Acetate peels of the cross-sections (see Ropes 1985) were examined microscopically and internal growth lines in the hinge tooth counted in order to determine the age of the animals. The growth lines in the hinge tooth have been shown to correspond in number to those in the valve itself (Thompson et al. 1980a,b).

To analyse the growth of *A. islandica*, the von Bertalanffy growth curve was fitted to the shell height vs age data by non-linear least squares:

$$H_t = H_\infty[1-e^{-K(t-t_0)}]$$

where H_t = shell height at age t, H_∞ = asymptotic maximum shell height, K = growth constant and t_0 = theoretical time with zero height (Haukioja and Hakala 1979). In this study, t_0 was set to zero.

For the study of size and age at maturity the animals were sampled from a relatively wide geographical area (Fig. 1). For details on preparation of specimens for histological examination of gonadal tissue the reader is refered to Thorarinsdóttir and Einarsson (1994). After preparation the gonadal developmental stage of individuals was determined microscopically and designated to one of three stages: immature (stage 1: undifferentiated gonads), intermediate (stage 2: the individual can be differentiatied as male or female but tubules display varying degree of development) and mature (stage 3: tubules normally completely filling the gonadal area) using the criteria described in Ropes et al. (1984) and Rowell et al. (1990). For the same individuals acetate peels were made in order to establish their age (method as described before).

Data on size, age, sex and developmental stage of gonads was pooled and divided into groups according to size and age, 5mm and 5 years respectively. For each sex, logistic curve was fitted to the percentage of mature individuals (stage 3) vs groups. Maturity was defined by the inflection point on the logistic curve, where 50% of the individuals in a size- or age-group were mature.

Results

The Aðalvík population: Ocean quahogs from Aðalvík were 31 to 100 mm in shell height and 7 to 202 years of age (Fig. 2). Parameter estimates by fitting the height vs age to the von Bertalanffy model are listed in Table 2. Quahogs in Aðalvík were growing relatively fast for the first twenty years but from then on the growth declined gradually although growth never ceased completely. By the age of twenty, the quahogs had attained the size of 63 mm and had reached the maximum asymptotic height, 81 mm, at the age of sixty. Considerable variations in size at age occurred within the Aðalvík population, e.g. ten years old quahogs were between 35 and 59 mm in shell height and fifty one year old individuals ranged from 67 to 87 mm in shell height.

Although some quahogs in Aðalvík had reached very high age, the age classes between sixty and two hundred years were represented by relatively few individuals (Fig. 3). More than 80% of the shells were younger than sixty years of age. Three modes were evident in the age histogram with mean age approximately at 10, 30 and 50 years, respectively.

The Vestfirðir area: Fitted von Bertalanffy growth curves to size at age for males and females, respectively, from the Vestfirðir area were significantly different ($F_{0.05,2,110}$= 5.22, P= 0.007; Fig. 4). Males were growing faster than females in the initial growth phase. At the age of ten the males had raeched the size of 39 mm, however, at that age the females were only 28 mm in shell height. At the size of 60 mm and at the age of 24 and 32 years, males and females, respectively, the growth started to decline. However, the females had a less marked decrease in growth and at the size of 70 mm both males and female were at the same age (45 years). According to the fitted von Bertalanffy parameters, females grew to a larger infinit shell height (Table 2) and the oldest individuals in the sample were all females (Fig. 4).

Statistics on pooled samples of the ocean quahog from the whole Vestfirðir area are summarised in Table 3. Of the 118 shells examined only four were found to be sexually undifferentiated with mean shell height and mean age of 45.0 mm and 19.5 years, respectively. At intermediate stage both males and females had a mean size of about 60 mm. Although there was no significant difference in mean age between sexes (P>> 0.05), there was an indication that males were somewhat younger when starting gonadal development, mean age 39 and 47 years males and females, respectively. Likewise with sexually mature quahogs the mean size of males and females was approximately the same (shell height ~70 mm) and the mean age indicated that males were younger than females when reaching maturity (mean age 49 and 56, males and females, respectively; no significant difference P>>0.05).

Sexual maturity of *A. islandica* from Vestfirðir showed good relationship with size. For both sexes the proportion of mature individuals in size groups increased sharply from 0% to around 30 %, in 45 mm and 50 mm size group, respectively, and had attained full maturity (50%) at the size of 55 mm (Fig. 5). At 70 - 75 mm shell height all quahogs were 100% mature. No evident relationship was between age and attainment of sexual maturity (Fig. 6).

Discussion

The Aðalvík population: Growth of *Arctica islandica* from Aðalvík was similar to what has been observed for ocean quahog from the Middle Atlantic Bight (data based on aged specimens and same linear dimension as used in this study, Thompson et al. 1980a). In both studies the quahogs had reached about 60 mm shell height at the age of fifteen to twenty years after which there appeared to be a shift from a rapid growth phase to an extended period of slow growth. A distinct change from fast to slow growth has also been found in *A. islandica* in the North Sea at the age of ten to fifteen years (Witbaard and Duineveld 1990). The distinguished change in growth rate of *A. islandica* from Aðalvík coincided with the size at sexual maturity, i.e. approximately 55 mm shell height (Fig. 2 & 5). Change in growth rate in relation with onset of reproduction is well known phenomenon among bivalves and is believed to indicate the point where physiological changes take place within the animal, and when the main energy input is shifted from somatic growth to reproduction (Calow 1981).

Three modes occurred in the age frequency distribution for the Aðalvík population with peaks at approximately 20 years interval (Fig. 3). In a study of length-frequency distributions of a *A. islandica* population, sampled over a ten years period off the Atlantic coast of the United States, Murawski et al. (1982) did not see any sign of recruitment. Moreover, it appears that no significant recruitment of quahogs have taken place during the last 20 to 30 years (Anon.1993). There are indications that ocean quahog populations have only occasional reqruitment and it can be speculated that in Aðalvík strong recruitment events have only occurred approximately every twenty years for the last fifty years or so.

The Vestfirðir area: Sex related difference in growth was observed for ocean quahog from the Vestfirðir area. Young males were growing faster than females and were bigger than females at given age (Fig. 4). At the age of 25 years males were 61 mm in shell height compared with 53 mm for female quahogs (von Bertalanffy growth model). The decline in growth rate started earlier for

males than for females. At the size of approximately 70 mm, females had compensated the growth difference and at that size both sexes were of the same age. In his paper, Fritz (1991) also suggested sex related difference in growth in *A. islandica*. His study indicated that females had faster growth rates than males which is entirely opposite to what was found in present study. However, his study was based on relatively few individuals (25 males and 22 females). All shells were older than 30 years of age, except one female individual and the rest of the females were older than 50 years of age (Fig. 6 in Fritz 1991). It is difficult to get a true picture of ontogenetic shell growth when young individuals are missing from a data set. Therefore, the results from the current study and those from Fritz's investigation, are not strictly comparable and do not reveal any further understanding of the relevance of our findings.

All *A. islandica* older than one hundred years of age were females (Fig. 4). This has been demonstrated for ocean quahog from other regions although based on limited number of individuals (this study: 5 indiv.; Rowell et al. 1990: 2 indiv.; Fritz 1991: 3 indiv.). These records strongly indicate that female quahogs live longer than males.

Reports on the onset of gametogenesis of quahogs have shown that males begin producing germinal cells at a smaller size and younger age than females (Ropes et al. 1984; Rowell 1990). Off the Vestfirðir, however, both sexes were of identical size (about 40 mm shell height) at the onset of development of reproductive tissue (intermediate stage, see Table 3) but as a consequence of faster growth the males were younger than females at the intermediate stage. Furthermore, the sexual maturity of both sexes from the Vestfirðir area was closely linked with size,but there appeared to be no association between sexual maturity and age (Fig. 5 & 6). Size related maturity in quahogs from Vestfirðir is in agreement with records from Nova Scotia (Rowell 1990) and Long Island (New York, Ropes et al. 1984), but the fact that sexual maturity is also related to age in *A. islandica* off the west coast of N-America is in contrast to what has been found in the present study.

Latitudinal variation in shell growth for bivalve populations is well documented (e.g. MacDonald and Thompson 1985; Sato 1994). The fact that the study of sexual maturity of ocean quahog was based on pooled samples from a relatively wide geographical area (Fig. 1), may have contributed to the considerable variation in size at age (Fig. 4) and for that reason made useless the comparison of growth curves of males and females. There is, however, accumulating evidence demonstrating that local variability in growth can often exceed variation along a latitudinal gradient (Appeldoorn 1983; Beukema and Meehan 1985; MacDonald and Thompson 1985). *A. islandica* from the Aðalvík population also had substantial variation in size at age (Fig. 2) indicating that locally the difference in individual growth rate can be as large as differences over a broader geographical area. Therefore, the observed difference in growth between sexes of *A. islandica* from

the Vestfirðir area is considered to be reliable. However, more research is needed to support this statement.

Acknowledgements

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Table 1. Positions of sampling sites of *Arctica islandica* and water depth at each location, based on survey on distribution and abundance of ocean quahog in NW Iceland (Thorarinsdóttir and Einarsson, 1994).

Location	Position	Depth (m)
Tálknafjörður	65°39N - 23°56W	17
Arnarfjörður	65°46N - 23°54W	23
Kópanes	65°50N - 24°03W	37
Svalvogar	65°51N - 24°02W	43
Aðalvík	66°22N - 23°03W	10
Hælavík	66°27N - 22°41W	24
Reykjarfjörður	66°17N - 22°03W	23
Húnafjörður	65°37N - 20°37W	20

Table 2. *Arctica islandica*. Estimates of the von Bertalanffy parameters for shell height at age data. H_∞ = asymptotic maximum shell height in mm; K = growth constant.

Data set	n	H_∞	K
Aðalvík	214	81.0	0.077
Vestfirðir (males)	51	70.4	0.081
Vestfirðir (females)	63	80.0	0.043

Table 3. *Arctica islandica* from Vestfirðir area. Number of individuals at each gonadal developmental stage (immature, intermediate and mature), range in size (shell height in mm) and mean shell height for each developmental stage (including standar deviation, SD). Age range (years), mean age and standard deviation (SD) of each developmental stage is also shown.

	Immature	**Intermediate**		**Mature**	
		Males	Females	Males	Females
n	4	12	25	39	38
Size range	28-64	41-80	40-81	50-88	52-93
Mean size	45.0	59.8	60.6	68.0	71.5
SD	18.17	9.67	11.78	8.19	10.82
Age range	6-43	9-58	16-92	10-97	23-120
Mean age	19.5	39.3	46.6	48.9	55.7
SD	17.29	17.28	22.72	19.88	27.84

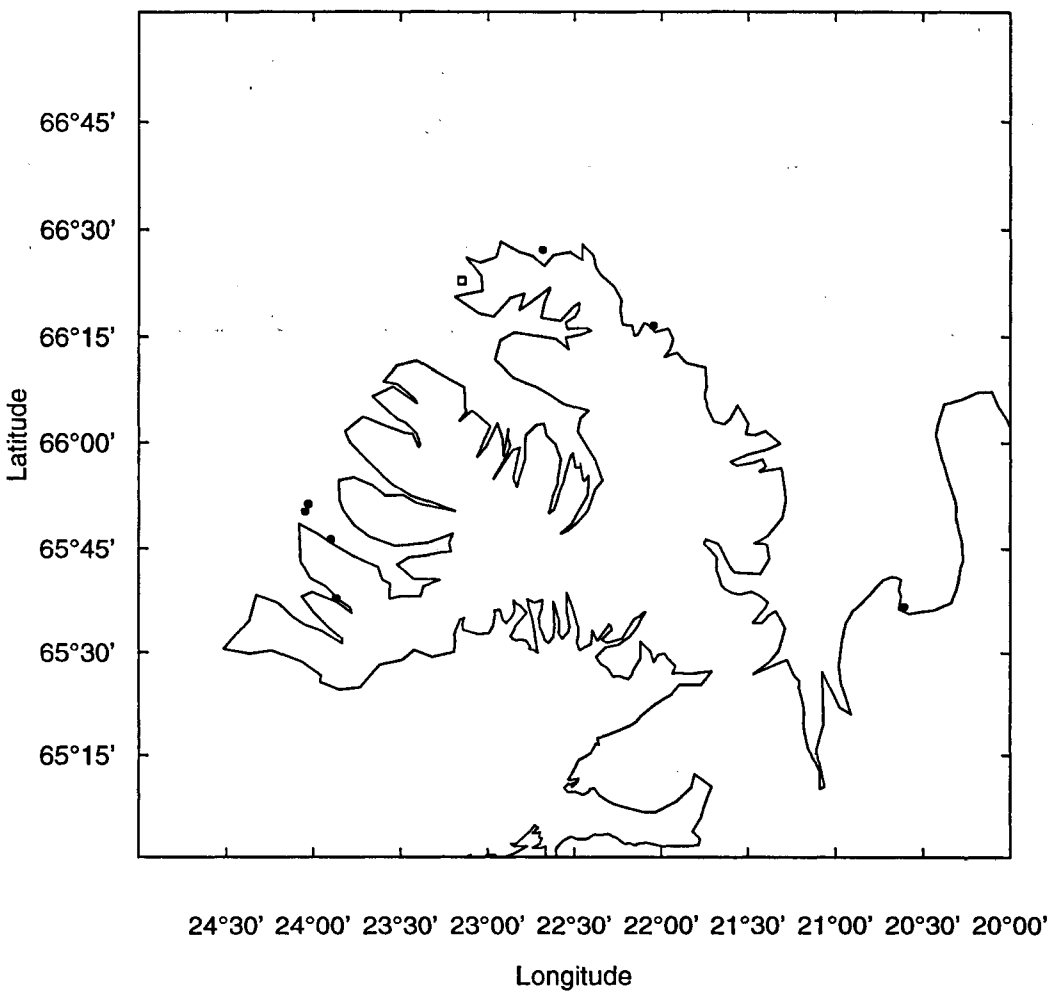

Figure 1. *Arctica islandica.* Sampling locations off NW Iceland. □ sample taken during a sanitation survey in January 1994, • samples taken for the study of maturity of *A. islandica* during a survey on distribution and abundance of ocean quahog, January - March, 1994.

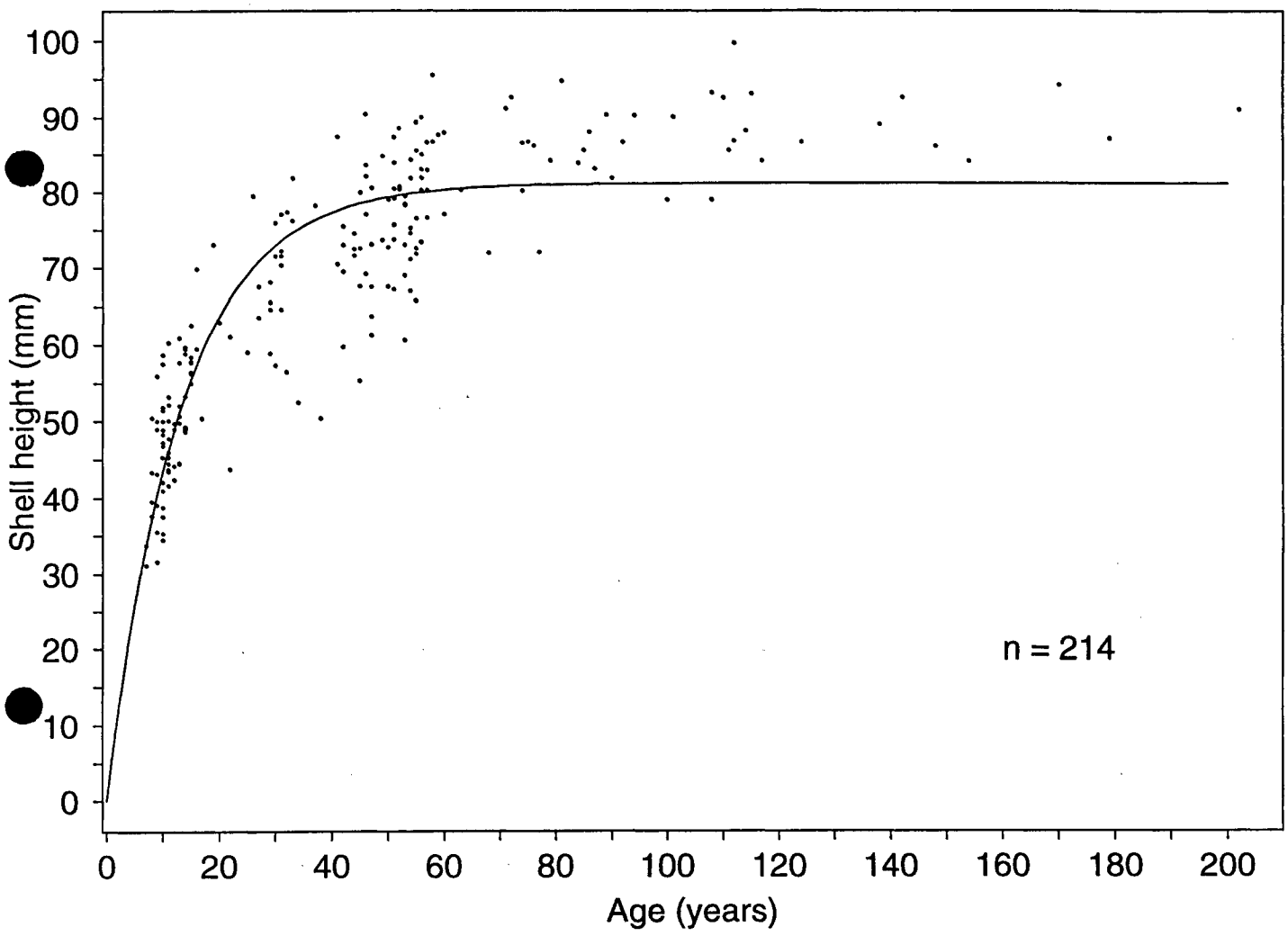

Figure 2. *Arctica islandica* from Aðalvík. Observed shell height at age and fitted von Bertalanffy growth curve.

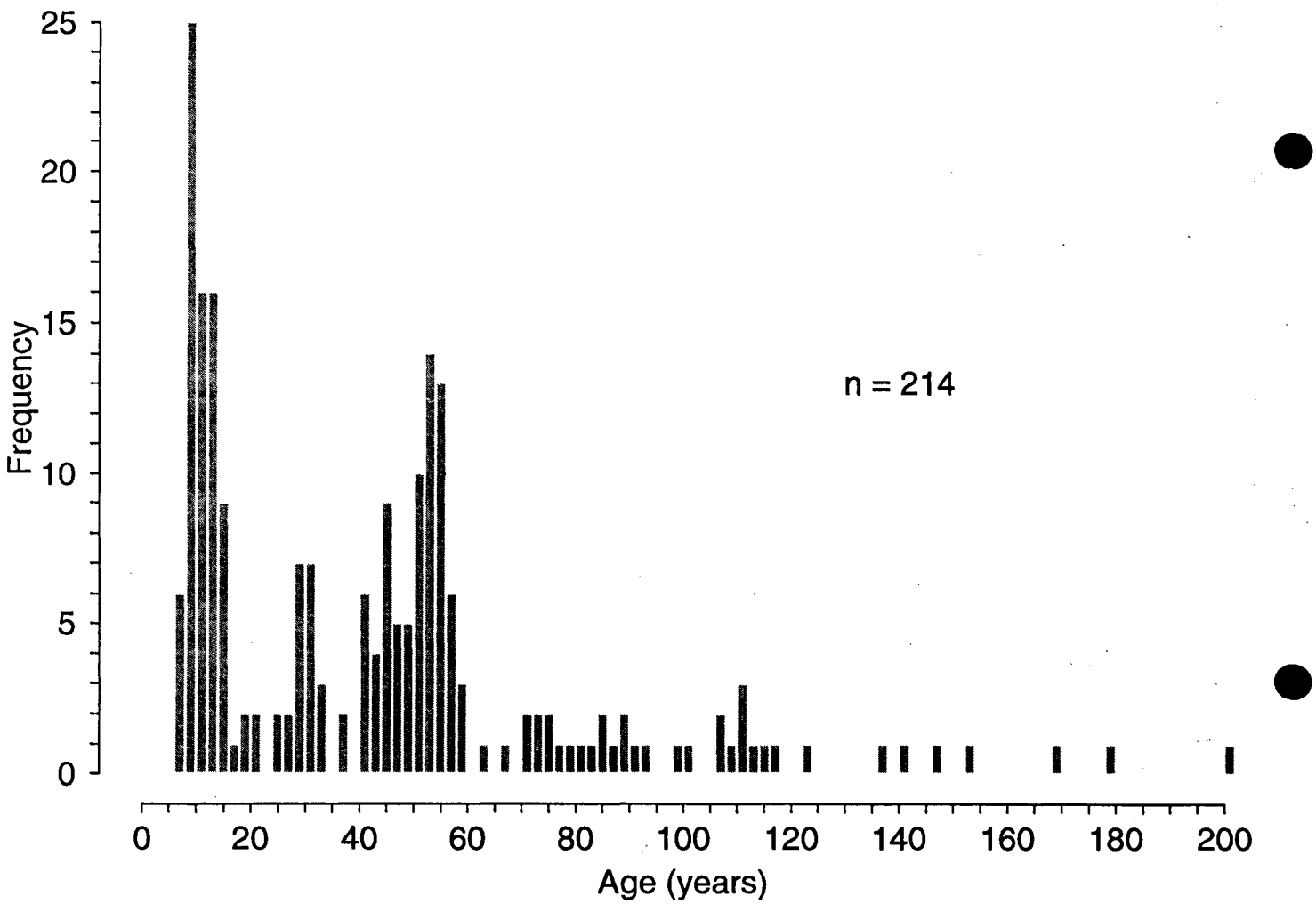

Figure 3. Age-frequency histogram for *Arctica islandica* from Aðalvík. Bars represent the frequency of two years age classes.

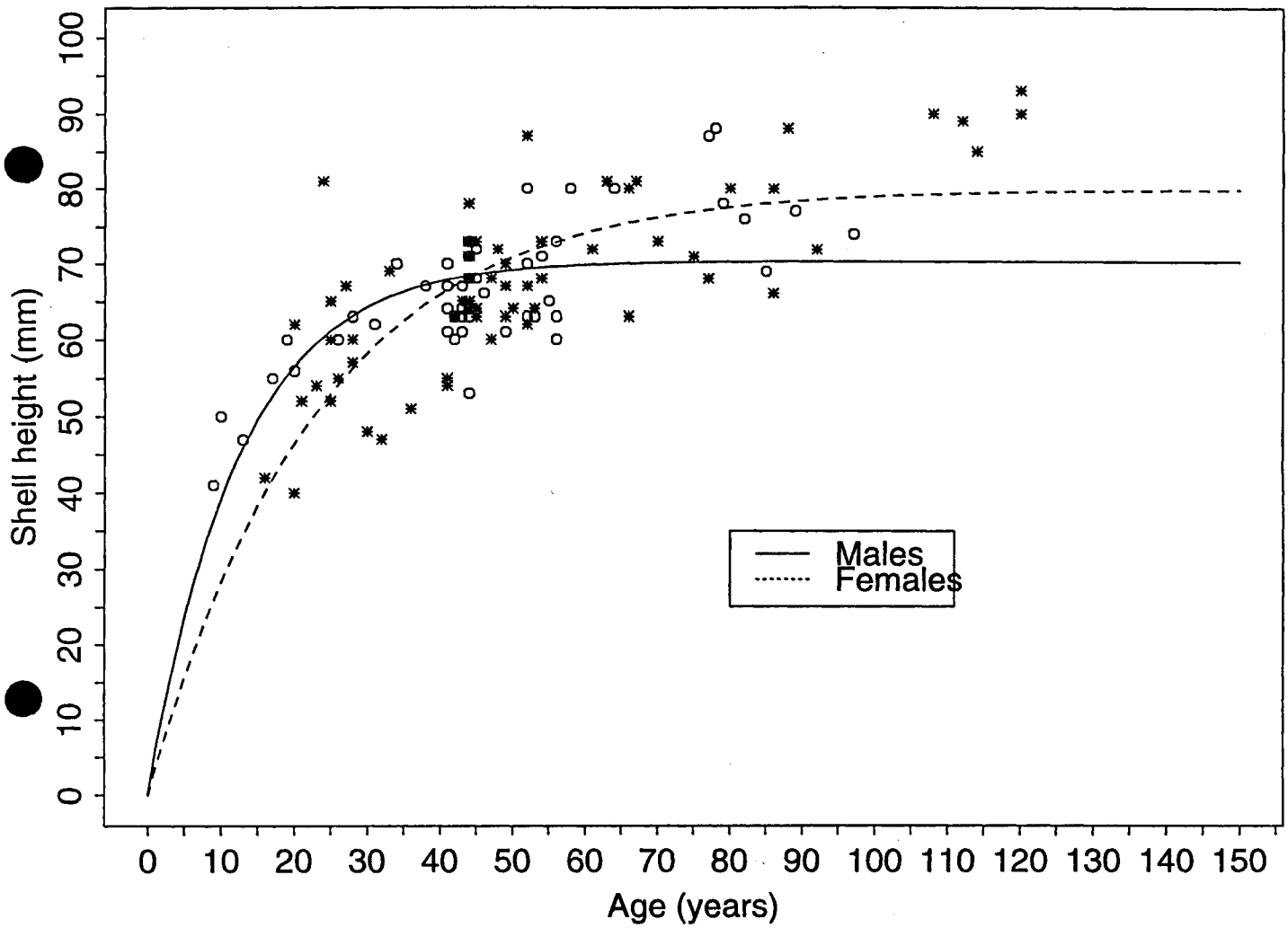

Figure 4. *Arctica islandica* from Vestfirðir area. Observed shell height at age and fitted von Bertalanffy growth curves for males (O) and females (*).

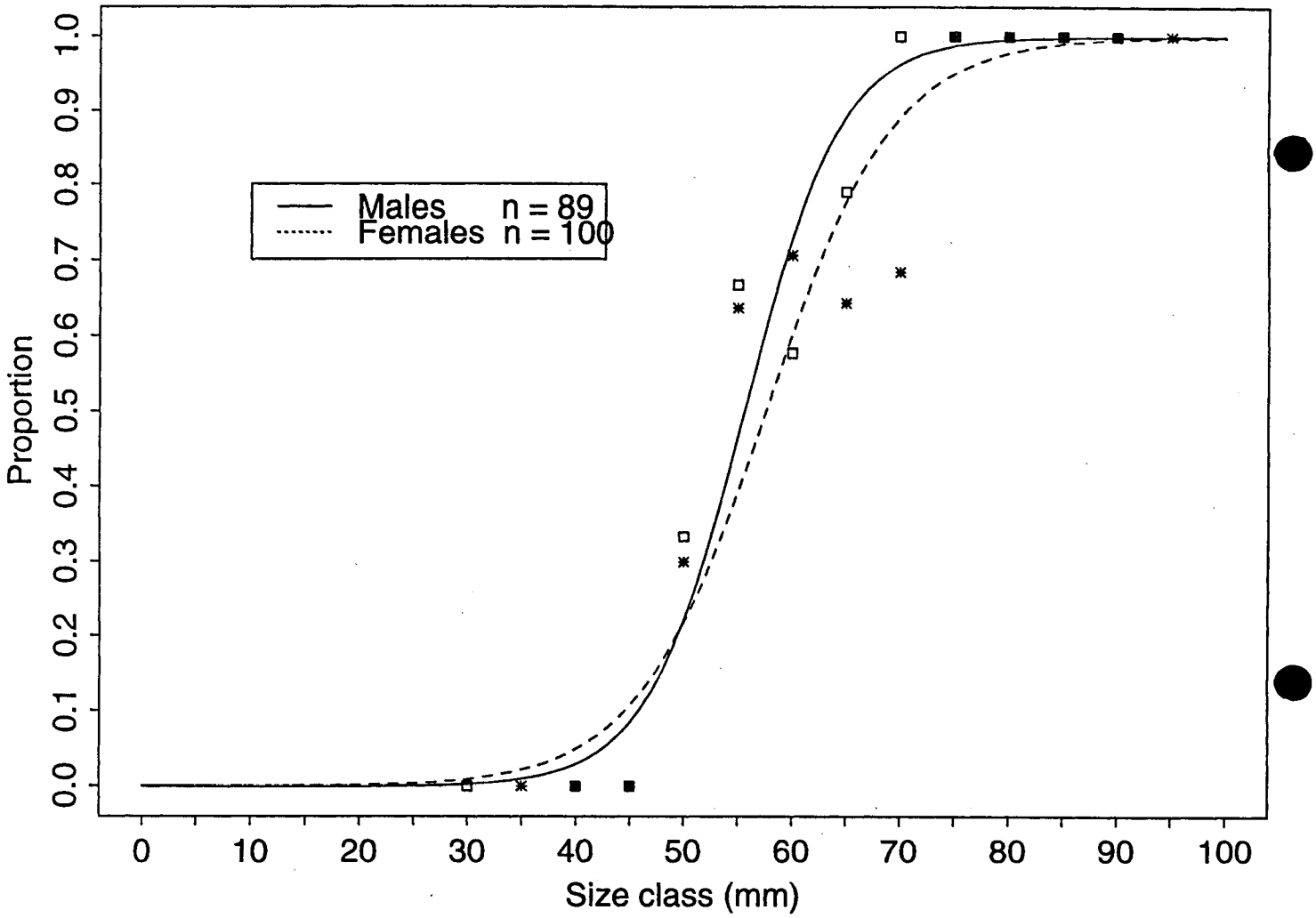

Figure 5. *Arctica islandica* from Vestfirðir area. Proportion of sexually mature males (□) and females (*) within size groups (5 mm groups) and fitted logistic curves.

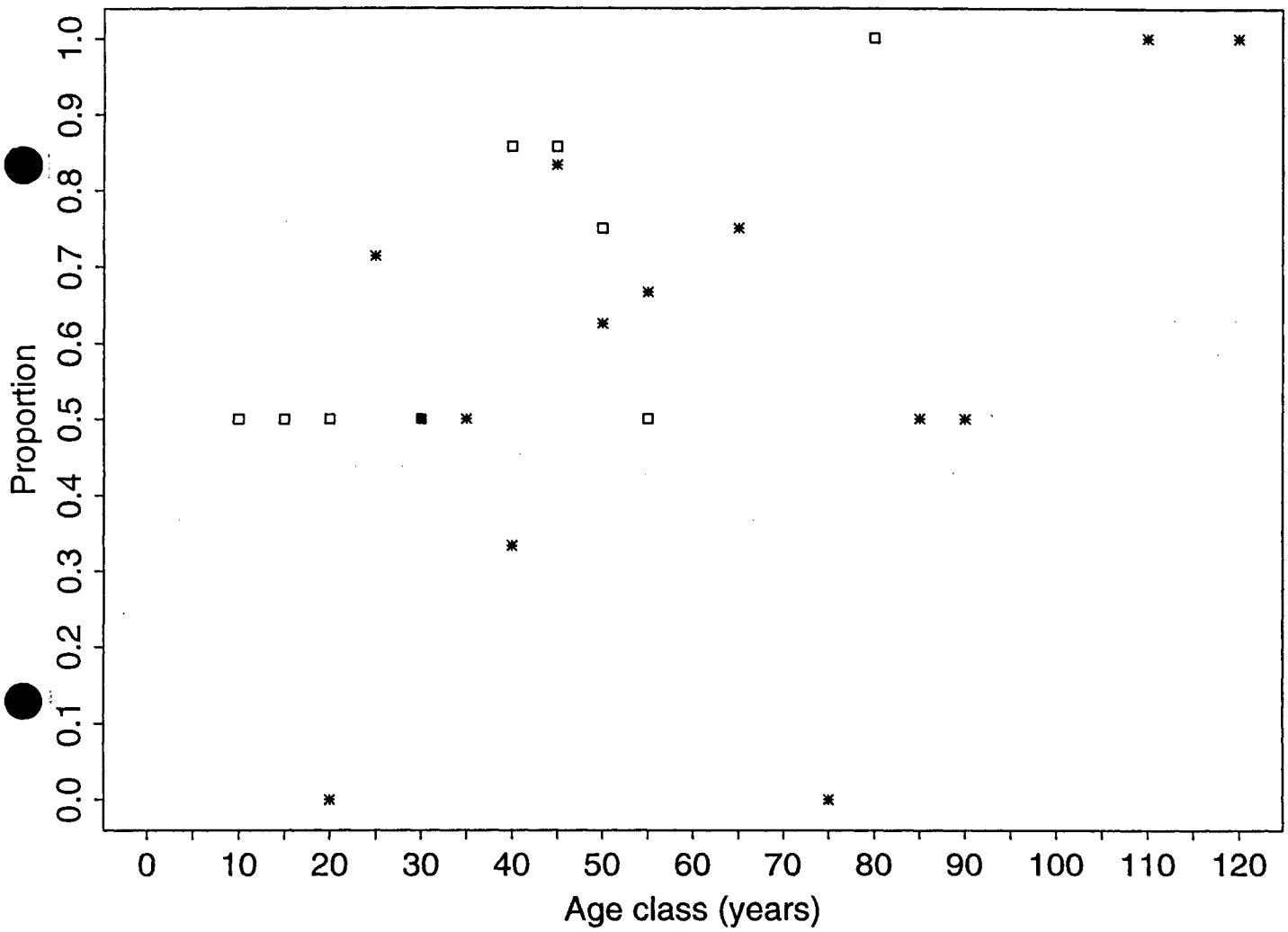

Figure 6. *Arctica islandica* from Vestfirðir area. Proportion of sexually mature males (□) and females (*) within age groups (5 years groups).