Moulting phenology of the harbour seal in southwest Ireland

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Running head: Moulting phenology of the harbour seal in Ireland

Abstract

Studies on the phenology of harbour seal moult have been carried out in the Atlantic and Pacific, however there has been no research into this process in the Republic of Ireland, at the southern edge of the species range in the NE Atlantic. Population estimates of harbour seals are derived by counts primarily during the moulting seasons. In the absence of information on the moult phenology planning the optimal timing of such surveys is impossible. Furthermore, changes in moult phenology may reflect changes in resource availability or competition, or demographic changes. The phenology of the harbour seal moult was investigated in southwest Ireland in this study. Timing of the moult differed among all cohorts, yearlings began moulting first following by adult females and finally adult males. The number of seals hauled out was generally positively related to the proportion of seals in active moult. The timing of the moult period was different to other parts of the species' range and should be considered in determining optimal timing of future surveys for assessing populations abundance and trends in Ireland.

Key words: harbour seal, phenology, moulting, population estimate, Ireland

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INTRODUCTION

Large-scale surveys of harbour seal (*Phoca vitulina vitulina*) populations occurring in rocky-shore habitats in the northeast Atlantic are generally conducted during the annual moult (*e.g.* Reijnders *et al*., 1997; Duck *et al*., 2005; Cronin *et al*., 2007). Thompson & Harwood (1990) suggested that the physiological constraints placed on seals during the moult period may make haul-out frequency likely to remain constant between years, thereby allowing a degree of comparability between moult population estimates. Studies on harbour seal moult have been carried out in Scotland (Thompson & Rothery, 1987) and in Alaska (Daniel *et al*., 2003) however there has been no dedicated research into the process in the Republic of Ireland. The timing of harbour seal population assessment surveys in Ireland to date has been based on best estimates of the peak moulting period in the nearby UK (Cronin *et al.,* 2007). As the timing of moult is known to vary depending on the location of the population (Boulva & McLaren, 1979; Daniel *et al*., 2003) it is crucial that work is carried out to identify the phenology of moulting in Ireland and identify optimal timing of population assessment surveys. Previous studies on moult phenology in seals are based on direct observations of individuals in the field. This is only possible at select haul-out sites that afford good vantage points to observers and unobstructed views of a relatively large group or significant fraction of a population *e.g.* Tugidak Island, Alaska (Daniel *et al*., 2003) and the Moray Firth, Scotland (Thompson & Rothery, 1987). In the absence of such sites, it may be possible to use photogrammetric analysis to investigate the timing of the moult in harbour seals. This was explored in the present study with a view to identifying the phenology of the moult and the optimum date when surveys should be conducted in Ireland, to ensure the most accurate estimates of population size can be made.

The objectives of the study therefore are (i) to establish the timing of the peak moult period of the harbour seal using a novel approach involving photogrammetric analysis and (ii) to examine changes in abundance of harbour seals at haul-out sites in southwest Ireland in relation to moulting.

METHODS

Study area

Harbour seal haul-out distribution along the Irish coastline is predominantly along the northwest, west and southwest coasts, in sheltered bays and estuaries (Cronin *et al.* 2007). The study area comprised a bay in southwest Ireland, Bantry Bay, Co. Cork (51^{o} 36'N, 9^{o} 50'W) where up to 360 harbour seals haul-out during the moulting season, approximately 10% of the national minimum population estimate (Cronin *et al.,* 2007) Haul-out substrate is exclusively rocky and haul-out sites are generally on skerries or islands located adjacent to the mainland shore and relatively accessible by boat for counting/photographing.

Surveys and image capture

Surveys of harbour seal haul-out sites in Bantry Bay were carried out in between 2003-2008 in a Tornado 5.8m Rigid Inflatable Boat (RIB) on at least a weekly basis between June 2003 and October 2005 and on at least a monthly basis between June 2006 and October 2008 and more frequently when weather permitted. Surveys were scheduled to occur within two hours before and after low tide, during daylight hours and not above wind force 4 on the Beaufort scale. The numbers of seals at haul-out sites (Figure 1) were counted using Leica 10 x 42 binoculars and recorded on a Sony Dictaphone. Counts of seals at each haul-out site were carried out independently and simultaneously by two observers and repeated if necessary until consensus was agreed. Counts were initially obtained from a distance of approximately 200m from the haul-out site and at progressively closer ranges whilst preventing disturbance to the seals.

Where possible the RIB was manoeuvred close enough to allow the photographer to take photographs of individual seals without causing disturbance, this effort was mainly concentrated at Garnish Island in inner Bantry Bay. Images were obtained using a digital SLR camera (Canon EOS-IDS) with a 600mm telephoto auto-focus image stabilising lens (Canon 600mm f/4L EF IS USM lens). The telephoto lens was mounted on a specialized tripod head with a gimbal-type design (WH-101 Wimberley Inc ©) for easier manipulation of the large lens and to compensate for the movement of the boat. The aim was to take photographs of the head, flanks and ventrums of all individuals at a site, ideally completely un-obscured by rocks or other animals.

Moult phenology

Image analysis

Over 8500 photographs of individuals were obtained during the survey period 2003-2008. Before any of the raw images could be analysed it was necessary to winnow down the photo catalogue into usable pictures. Each individual photograph was viewed and only those containing dry seals, where at least 80% of the body was visible at an angle giving a clear view of the head and flank, were selected. When photographing the seals multiple passes of haul-out sites were made to ensure clear images of the maximum number of animals were captured, therefore photographs taken on the same day had to be double checked to ensure there was no duplication of the same animal between pictures. This was done visually by comparing pelage patterns and the position of the seal on the shore in relation to distinguishable rock formations, areas of seaweed and other animals. No attempt was made to identify individual seals in photographs taken on different days as each sample was considered an independent random sample of the population available for photographing on that day. A total of 829 photographs of seals were deemed suitable and analysed for moult stage.

Moult staging technique

Three main stages of moult were identified – premoult, active moult, and postmoult, (Table 1, Plate 1) and the moult status of each individual was recorded. For those in active moult the pattern of hair replacement across the body was noted by recording when hair was shedding in five distinct regions (i) head and neck; (ii) the fore and hind flippers and tail; (iii) ventrum; (iv) dorsum and (v) sides. The recognised pattern of hair replacement is that initial shedding of hair first occurs on the head and flippers followed by the ventrum, then the dorsum, with the sides being the last areas to moult (Stutz, 1967; Daniel *et al*., 2003). In cases where this pattern was not observed and the head and flippers were the last areas to shed, this was recorded as 'reverse moult'.

Age and sex determination

Categorising a seal by age and sex purely from an individual photograph proved difficult. Close up images of individuals removed a sense of scale to judge the size of an animal and as most seals were photographed lying on their ventrum very few displayed genitalia. During the pupping season it was possible to identify adult females as those seals that had pups in attendance. Adult males often exhibit wounds and scars around the neck resulting from fights during the breeding season (Thompson & Rothery, 1987); when visible these were used to identify male seals. Individuals without these distinguishing features were classed as being of unknown sex. To distinguish age categories a simple division between adults and yearlings based on Thompson & Rothery (1987) was used, whereby yearlings were identified by their paler, unpatterned pelage which is retained until their first moult. Immature seals over one year were included in the adult category. It was not possible to differentiate between immature and mature adults.

Data Analysis

Images were combined into bi-weekly periods in order to give adequate sample sizes while still allowing relatively fine scale comparisons of timing. Inter-annual comparisons were not possible between all years due to uneven spread of effort across the entire study period; therefore the images from all years were combined into one large dataset, subdivided into the eleven bi-weekly periods. The proportion of seals in the three moult stages were calculated for each bi-weekly period. These results were plotted to illustrate the progression of moult and used to calculate the duration of the moult process and the time period when the peak of moulting occurred.

The start of moult was defined as the earliest date a seal was observed in active moult. The completion of moult was defined using the same criterion as Thompson & Rothery (1987), the time at which 50% of seals were fully moulted. A non-linear, 3-parameter sigmoid regression equation was used to fit a curve to the postmoult data and this was used to estimate the date of moult completion. The peak moult date was defined as the time when the highest proportion of seals were in active moult, the same definition used by Daniel *et al.* (2003). By using the same criteria as the two other key harbour seal moult studies to define the peak moult and completion dates, direct comparisons could be made between the timing of these events at the different sites.

A comparison of the timing of the three moult stages between yearlings and adults was carried out using Wilcoxons signed rank tests to assess if there were differences in the timing of premoult, active moult and postmoult between the age classes. Sample sizes were insufficient to reliably compare the timing of moult between males and females. Counts of the numbers of seals hauled out for the entire Bantry Bay area were collected during surveys and, based on the theory that the proportion of seals in active moult in the photographed sample was representative of the wider population, a linear regression was carried out to investigate the relationship between the proportion of seals (Arcsin transformed) in active moult and the numbers of seals hauled out.

The proportion of seals in active moult that showed a reverse pattern of hair replacement was calculated using data on the shedding of hair from distinct body regions. These data were examined to determine if this pattern was constant for all bi-weekly periods or changed during the moult season.

Environmental Data

Water temperatures from two sites within Bantry Bay (Figure 1) were supplied by the Irish Marine Institute who maintain a network of temperature probes (Onset Stowaway TidBit sensors) around Ireland that provide water temperature readings every hour at multiple depths. Maximum and minimum daily air temperatures and rainfall statistics for Glengarriff (Figure 1) for the duration of the study period were supplied by Met Éireann (the Irish Meteorological Service). Astronomical measurements giving the length of day (the time of actual sunset minus the time of actual sunrise) were supplied by the online meteorological service Weather Underground. Readings were taken from Valentia Observatory (51^{o} 56'N, 10^{o} 14'W), the closest monitoring site to the study area located approximately 70km northwest of Bantry. Based on the outputs of a Generalised additive model (GAM) that examined the influence of environmental factors on the progression of the moult, astronomical data on day lengths from the two other key harbour seal moult study sites, Tugidak, Alaska (Daniel *et al*., 2003), and Orkney, Scotland (Thompson & Rothery, 1987), were obtained for comparative purposes.

Generalised Additive Models (GAMs) were used to examine the relationship between the proportion of seals in active moult, and environmental variables, air and water temperature, rainfall and photoperiod. Month and year were included as nominal variables. A GAM using the binomial distribution and logistic link function was used to examine the relationship between the response variable (proportion of seals in active moult) and the explanatory variables. Stepwise model selection was used to exclude/include variables, and the Akaike Information Criteria (AIC) statistic was used to select the best model.

RESULTS

Moult phenology

Seals in active moult were identified between 1 June and 1 November (Figure 2). The earliest instance was observed on 7 June and moult completion occurred in weeks 38/39 (mean date 27 September). The duration of the harbour seal moult period in southwest Ireland therefore was 16-17 weeks. The peak moult was determined as the time when the highest proportion of seals were in active moult status. This criterion identifies the peak moult time in weeks 36/37 (mean date 13 September).

For the first six weeks of the study the only seals observed in active moult were yearlings. The first incidence of active moult in an adult was not observed until weeks 28/29 (mean date 16 July). 87% of yearlings (n = 38) were in postmoult status by weeks 34/35 (mean date 30 August); however occasional yearlings were still observed to be shedding hair as late as the end of October. There was a significant difference in the timing of premoult between adults and yearlings ($P < 0.05$), however there was no significant difference between the two age classes for active moult or postmoult ($P > 0.05$). The first observed incidence of active moult in a female occurred during weeks 28/29 (mean date 19 July) whereas the first observed incidence of active moult in a male did not occur until weeks 32/33 (mean date 16 August).

Relationship between numbers hauled out and progression of moult

Peak haul-out counts of seals of all ages in Bantry Bay is September 1st. A linear regression on the proportion of seals in active moult and numbers of seals at haul-out sites showed a significant positive relationship ($P < 0.01$, $R^2 = 0.25$) (Figure 3).

Incidence of reverse pattern moulting

Reverse pattern moulting, whereby the head and flippers were the last areas to moult as opposed to the first, was observed in 96 seals, over half the number of those observed in active moult. The frequency of reverse moulting does not appear to be consistent throughout the moult period, with peak occurrence in mid Sept where almost 70% of seals in active moult showed a reverse moult pattern (Figure 4).

Potential influences on the phenology of the moult

The full GAM model contained explanatory variables air and water temperature, rainfall and photoperiod. Stepwise removal of explanatory variables, comparing deviances of full and nested models using F tests suggested that the optimal GAM model for the proportion of seals in active moult contains smoothing functions for daily maximum air temperature and photoperiod (or daylength). This resulted in a model with a lower AIC and more of the deviance explained (81.5%). Only photoperiod was significant ($P < 0.001$) in explaining the proportion of seals in active moult, active moult peaking with daylength of 12.5 hours (mid September).

As the only significant explanatory variable was photoperiod, astronomical data were collated for the three moult study locations. The higher latitudes of the Scottish and Alaskan studies mean that both these sites experience longer periods of visible light during the summer months compared to Ireland, however by October all three sites have approximately the same photoperiod, and between November and April the length of day in Ireland is longer than the more northerly regions (Figure 5).

DISCUSSION

The duration of the harbour seal moult period in southwest Ireland was 17 weeks from the first observed incidence in early June until the mean estimated completion date in late September. Comparisons with data collected in Orkney, Scotland, the closest population where moult timing has been studied, showed that the duration of the moult in Ireland was longer than the 13 weeks recorded in Scotland (Thompson & Rothery, 1987). In both studies, the first observed incidence of moult occurred on June 7, but in Scotland the mean estimated completion date was August 23, more than 4 weeks prior to completion in Ireland.

Peak moult date was defined as the time at which the highest proportion of seals were in active moult, following approach of Daniel *et al*. (2003) and in southwest Ireland this occurred during weeks 36/37 (mean date September 13). In Tugidak, Alaska, harbour seals peak moult occurred during late August/early September, earlier than in southwest Ireland. There is no estimate for peak moult date for seals in Scotland however as completion of moult was observed in August (Thompson & Rothery, 1987) it is likely peak moult occurs much sooner than observed in southwest Ireland.

In both the Scottish and Irish populations' yearlings were the first age class to moult with the adult moult starting later. In Ireland, the adult moult commenced approximately 9 days later than in Scotland (July 16 and July 7 respectively) (Thompson & Rothery, 1987). In Alaska, active moult of yearlings began about a month later than in Ireland or Scotland however the dates of onset of moult in adult seals in Alaska was more similar to Ireland (Daniel *et al*. 2003).

The first observed incidence of active moult in a female in southwest Ireland occurred on July 19 whereas the first observed incidence of active moult in a male did not occur until almost a month later. This suggests that females are commencing the moult earlier than males and while the small sample sizes may affect the level of confidence in such an inference, it is supported by other studies of pinniped moult where females have been observed starting to shed hair earlier than males from the same population (Thompson & Rothery, 1987; Daniel *et al*., 2003; Badosa *et al*., 2006). Age and sex related differences in the timing of the moult are reflected in heterogeneity in haul-out behaviour amongst different age and sex classes, which in populations with non-stable age structure, can lead to severe biases in population estimates (Harkonen *et al.,* 1999), suggesting research on harbour seal population structure and haul-out behaviour at key haul-out sites in Ireland across the moult period would also be worthwhile.

Overall the moulting phenology of harbour seals in southwest Ireland appears to follow the pattern of differences between age and sex classes identified by previous studies, however the actual timing of the moult period is noticeably different. The extent of the moult period is longer (4 weeks), the completion of moult is later (more than 4 weeks) than that recorded in Scotland and Alaska and the peak date is also later than recorded in Alaska.

The latitudinal gradient between the three sites may explain the differences in moult timing, as the only variable which had a significant effect on the proportion of seals in active moult was day length. In Scotland and Alaska the length of day in July is up to two hours longer than in Ireland. Photoperiodism is recognised as the most important synchroniser of seasonal functions in mammals (Hoffman, 2004). Given the importance of epidermal temperature on hair replacement it is possible that at higher latitudes where the summer period has longer day lengths for a relatively short time the moult process would occur over a shorter time period than at lower latitudes where the duration of summer is longer.

The pelage cycle is closely related to the annual cycle with respect to environmental factors but also life processes particularly reproduction (Ling, 1970; Ashwell-Erickson *et al.,* 1986). In mammals which undergo a suspended embryonic development, there appears to be a close relationship between blastocyst implantation and moulting *e.g.* weasels (*Mustela erminea)*, mink (*Mustela vison)* and muledeer (*Odocoileus hemionus)* (Dolnick, 1959; Wright, 1963). In most seal species, females moult approximately one month after mating, whereas in males the delay is more variable (Ling 1970), the exception being the subtropical Hawaiian monk seal (*Monachus schauinslandi)* in which breeding and moulting overlap (Ling, 1972). The later timing of the peak and completion of the moult in harbour seals in Ireland compared to other parts of their range could be linked to potential geographical related differences in pupping phenology (e.g. Temte et al., 1991). Indeed recent evidence suggests later pupping in harbour seals in Ireland (Cronin unpublished) compared to other parts of their European range (e.g. Gjerta & Borset, 1992; Thompson & Wheeler, 2008; Reijnders *et al*., 2010) and is being explored further.

By recording the progression of shedding hair pattern across the body, this study has discovered an interesting phenomenon whereby a large proportion of the seals in southwest Ireland showed a reverse pattern of hair replacement. The recognised pattern of hair replacement for most pinnipeds, including harbour seals, has been recorded as starting on the head and flippers, then on the ventrum followed by the dorsum, with the sides being the last areas to moult (Stutz 1967; Daniel *et al*. 2003), yet this study observed the head and flippers as being the last areas to moult in 48% of the seals in active moult. Daniel *et al*. (2003) observed, although did not quantify, several cases of reverse moulting patterns for all cohorts of harbour seals in Tugidak, Alaska. Reverse moult has been recorded in starving grey (*H. grypus*) and harp (*Pagophilus groenlanicus*) seal pups in the Gulf of St. Lawrence and has been associated with poor nutritional condition (Lydersen *et al.,* 2000). The seals observed in reverse moult in southwest Ireland however showed no evident physical signs of being nutritionally compromised, however, a dedicated study on body condition using ultrasound measurements of blubber thickness and/or labelled water dilution techniques (e.g. Reilly & Fedak, 1990) would be worthwhile.

Photogrammetric techniques were shown to be effective in identifying stages of moult in individual harbour seals and with sufficient photographic effort across the moult period can enable the phenology of the moult to be established. Field measurements of the progression of the moult are labour intensive and often difficult to conduct, with in-situ subjective classification of individuals (from a distance) into pre-defined categories invariably leading to sampling bias. Our approach of capturing images of individuals across the moult period with subsequent analysis in the laboratory is an approach that provides more opportunity for quality control over the subsequent categorisation process. Photo catalogues of harbour seals exist across parts of the species range resulting from mark recapture studies (e.g. Hastings *et al.*, 2001; Cunningham *et al.,* 2009) and could retrospectively be utilised to examine potential changes in the timing of the moult in these regions. As temporal changes in the timing of the harbour seal moult have been observed (e.g. Daniel *et al.,* 2003) ideally sample effort would be high enough to allow between year comparisons, changes in moult phenology may reflect changes in resource availability or demographic changes.

Accurate information on the timing of moult is of importance to the increasing numbers of researchers using remote sensing devices deployed on animals to track movement and behaviour (e.g. Cronin & McConnell, 2008). Expensive radio and satellite tags are traditionally glued to the pelage of animals and lost when the fur is shed. A greater understanding of the timing of moult would allow researchers to determine the optimal time for instrument attachment, thus reducing potential time loss through capturing unsuitable animals, maximising the data collection period and also reducing the potential loss of equipment.

Fundamentally this study has shown that the assumption that the annual moult for seals in Ireland occurs from late July to mid-August (Cronin *et al.,* 2007), the same time as those in the UK (Bonner, 1972) is incorrect; the peak in moult occurs in early September, with actual completion being considerably later in mid-October. The significant relationship between haul-out counts and the proportion of seals in active moult suggests that the timing of moult influences haul-out behaviour, and therefore will influence the numbers of seals ashore for estimates of population size. A long-term harbour seal monitoring program is currently under development in Ireland (no census of the species has been conducted since 2003) and it is critical that such information is integrated into this process to identify optimal survey timing based on phenology of the moult in Ireland as opposed to elsewhere across the species range, as was the case during the 2003 harbour seal census (Cronin *et al.,* 2007).

When the timing of once-off surveys to establish population estimates is based on such information, it can have significant consequences for the accuracy of population estimates.

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Plate 1: Harbour seals in the three main defined moult stages (a) premoult; (b) active moult; (c) postmoult

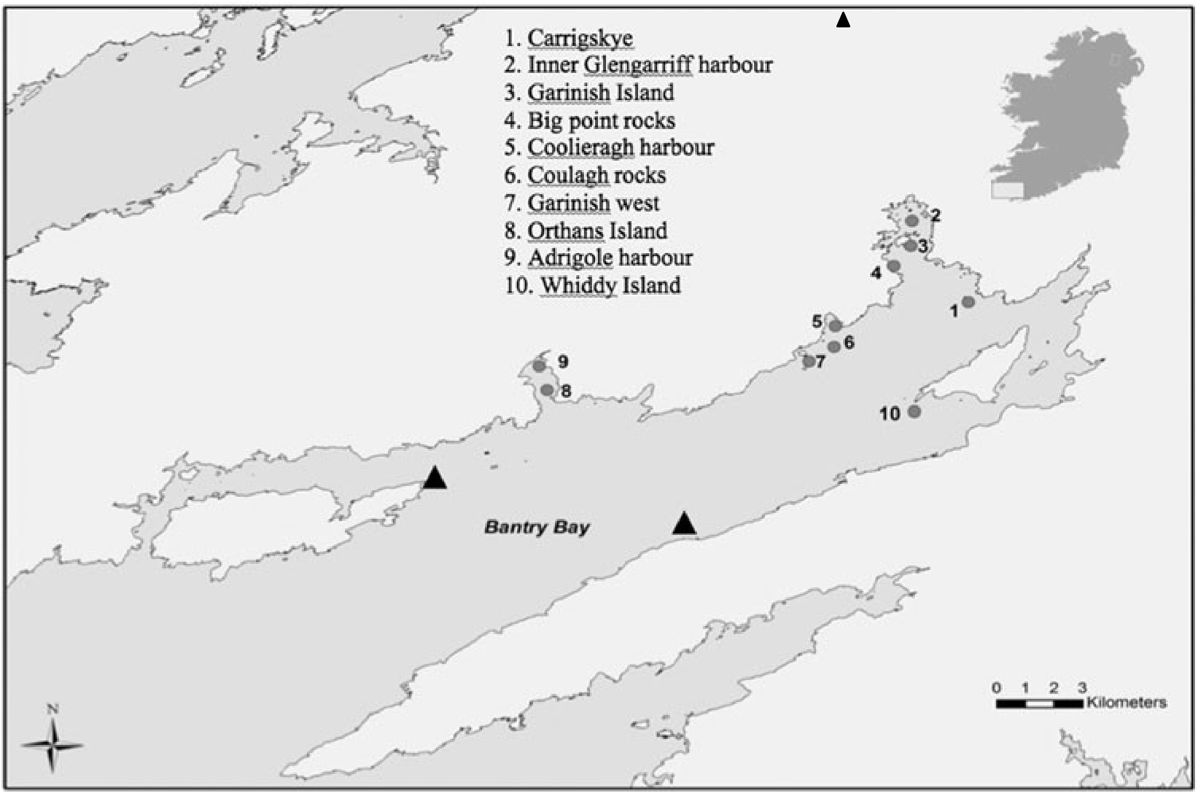

Fig. 1. Harbour seal haul-out sites and environmental monitoring sites in Bantry Bay, Co. Ireland, Ireland

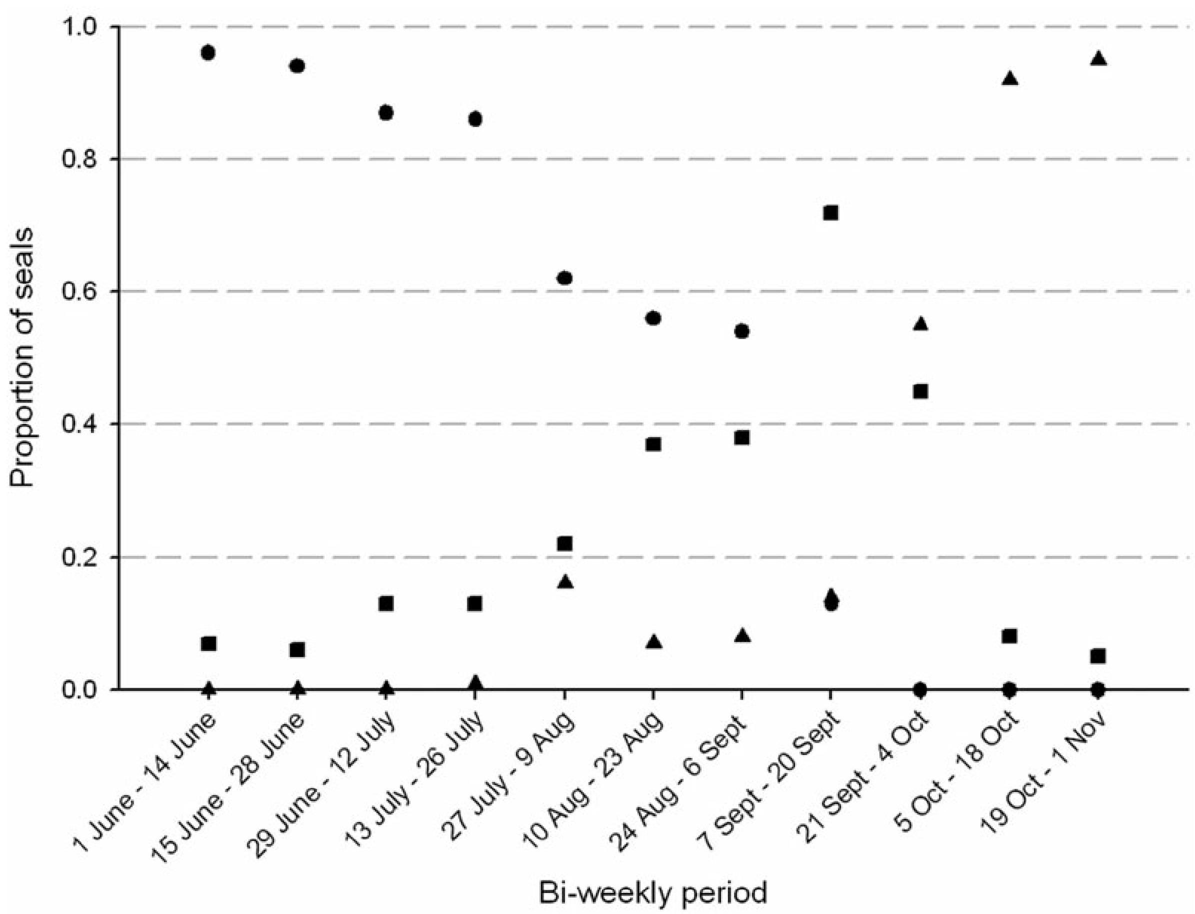

Fig. 2. Changes in the progression of moult status for all seals: premoult (circles), active moult (squares), and postmoult (triangles)

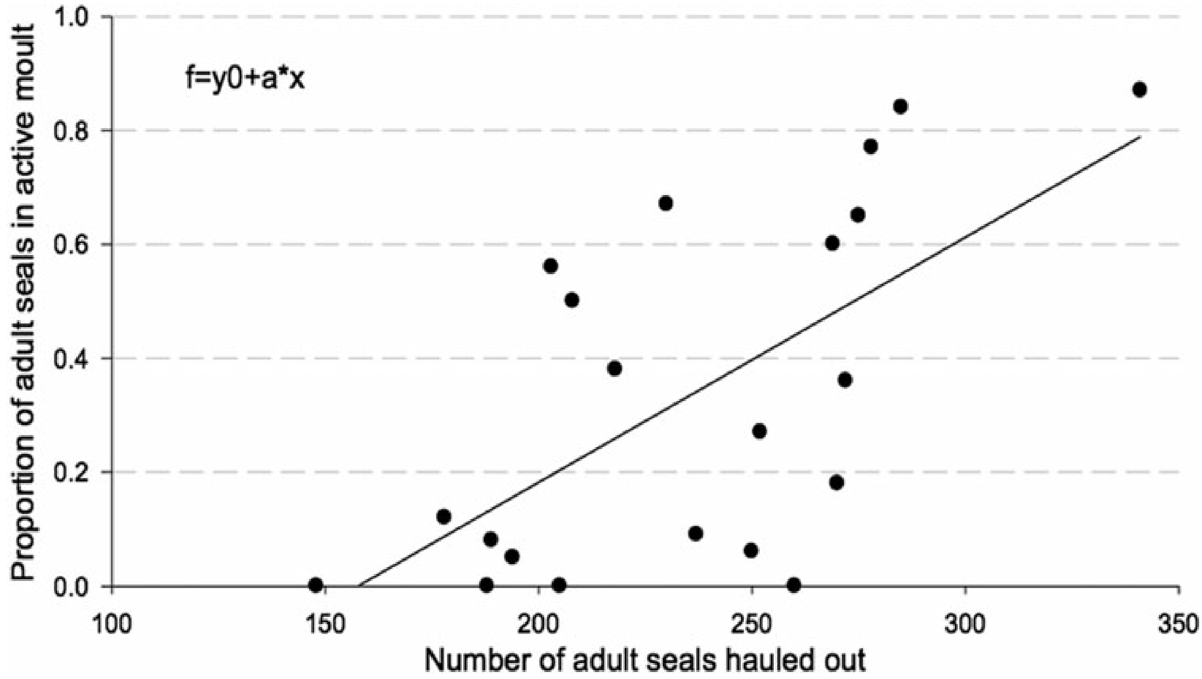

Fig. 3. Linear regression showing positive relationship ($P<0.01$ $R^2= 0.25$) between the numbers of seals hauled out and the proportion of seals in active moult

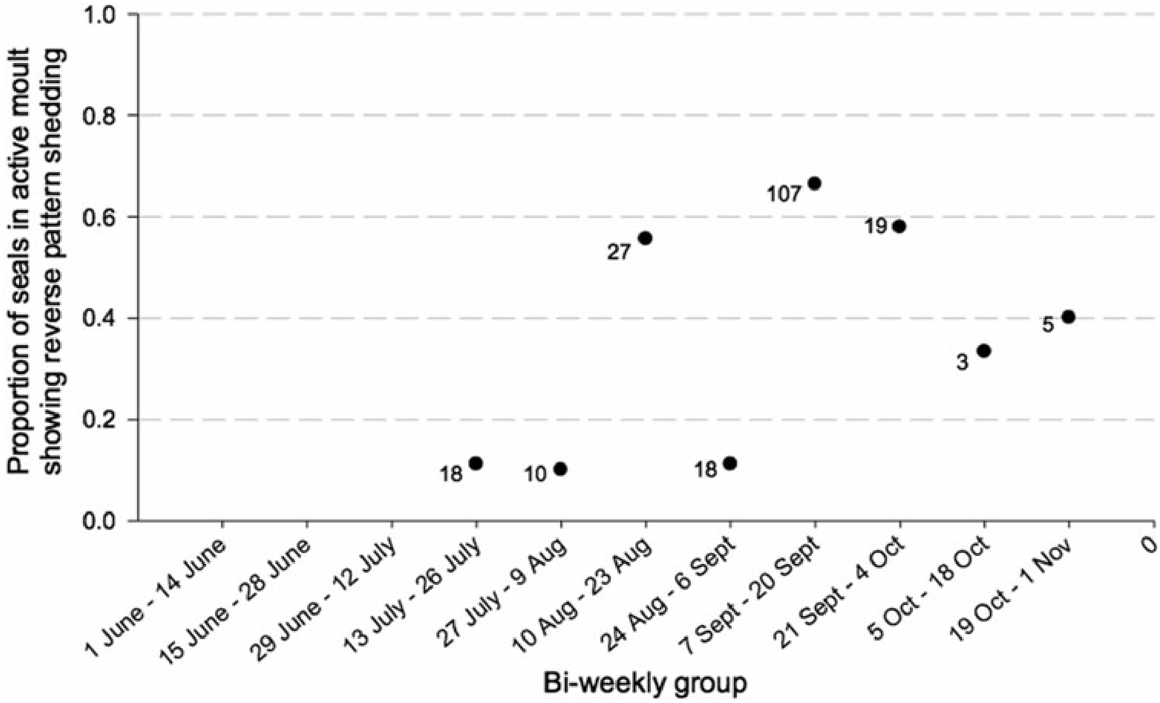

Fig. 4. Proportion of seals in active moult showing a reverse pattern of hair replacement (datapoint label = sample size)

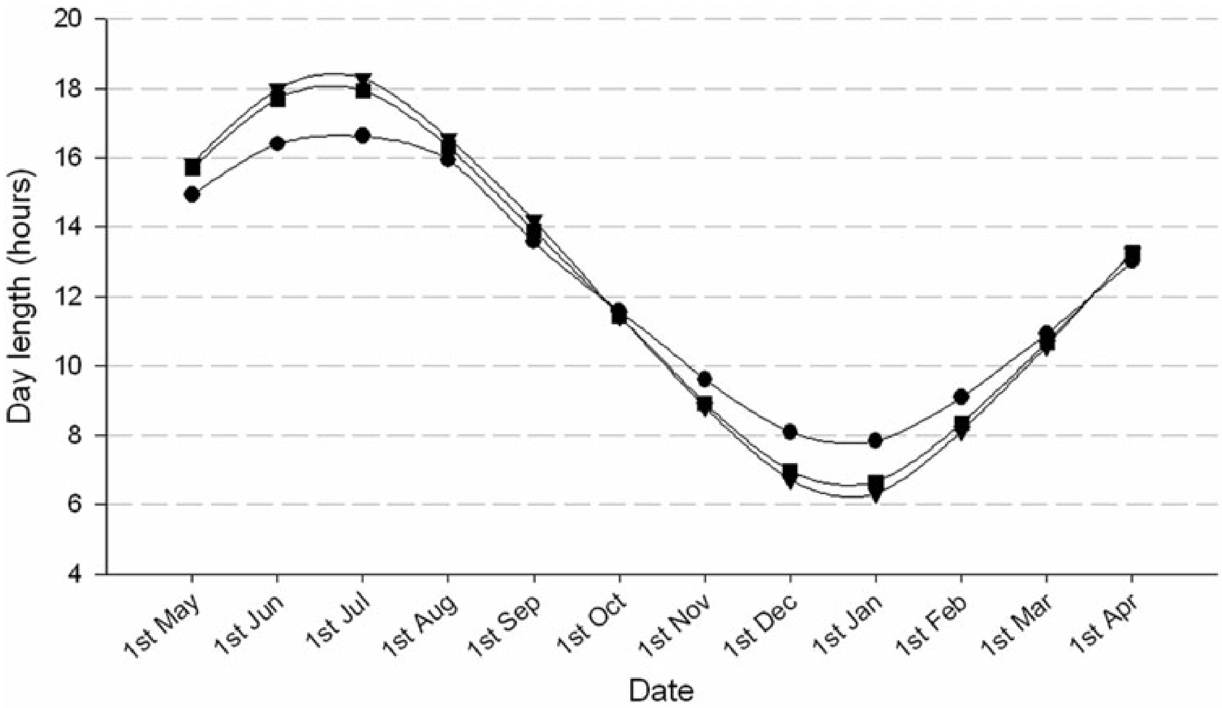

Fig. 5. Comparison of day lengths at Valentia, southwest Ireland (circles), Kirkwall, Orkney, Scotland (triangles) and Kodiak, Alaska (squares)

Table 1: Classification criteria used to determine moult status of harbour seals in southwest Ireland (adapted from Allen *et al*., 1993; Stutz, 1967)

Moult Stage	Sub-category	Description
Premoult	Pre-premoult	No indication of hair replacement having been initiated, although pelage may look slightly shabby.
	Actual premoult	Hair visibly degenerating. Coat has visibly changed colour to a dull brown, tawny, sepia or cinnamon colour and pelage patterns have started to fade.
Active moult	-	Obvious hair loss with patches of new hair visible through old pelage.
Postmoult	-	No old hair remaining, complete 'clean' new coat.