SEX AND AGE CHARACTERISTICS OF NORTHERN FULMARS *FULMARUS GLACIALIS* USED IN PROGRAMS TO MONITOR PLASTIC INGESTION

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ABSTRACT

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Carcasses of beached or accidentally killed Northern Fulmars *Fulmarus glacialis*, collected for monitoring plastic ingestion, have shown that the incidence of litter may vary over time and by region. Age, sex, and season of fulmar collection appear to affect the quantity of plastics ingested. More detailed analyses of monitoring data thus require reliable and consistent methods for assessing age and sex. Methods were first described in a monitoring manual in 2004 and later in international guidelines, but age and sex definition required further clarification. A large dataset of 3,790 dissected birds now allows for detailed descriptions of sex and age characteristics for different seasons. Such results may assist in further improvement and calibration of age and sex determination among the international research teams participating in this type of monitoring.

Key words: *Fulmarus glacialis*, sex and age, dissection methods, plastic ingestion, monitoring, beached birds, longline victims

INTRODUCTION

The Oslo-Paris Commission (OSPAR) and European Union (EU) Marine Strategy Framework Directive (MSFD) aim to safeguard and monitor the ecological quality of the European oceans. With respect to marine litter, these programs monitor the changing abundance of plastic on the ocean surface by analysing stomach contents of Northern Fulmars *Fulmarus glacialis* (hereafter fulmar). North Sea data show that fulmars realistically reflect geographic and temporal patterns of plastic pollution on the sea surface (Kühn et al., 2022; Van Franeker et al., 2021). Fulmars, as opportunistic scavengers, have been known to ingest plastics. As a result, since 2002, all countries bordering the North Sea agreed to collect beachcast dead fulmars for monitoring purposes (Van Franeker et al., 2005, 2011, 2021). The same sampling approach has been applied elsewhere, although mostly in incidental studies rather than in long-term monitoring programs (see De Bruin et al., 2024, and references therein). Consequently, this plastic monitoring approach has been recommended for regions outside the North Sea (Arctic Monitoring and Assessment Programme [AMAP], 2021; Linnebjerg et al., 2021; Savoca et al., 2024). Guidelines for dissection and data analysis were first published by Van Franeker (2004) and later by OSPAR (2015), ensuring standardized protocols. Therefore, comparison of fulmar plastic ingestion is now possible within their distribution range. Results of monitoring are reported to OSPAR annually, and regular OSPAR Intermediate Assessments provide overviews of aggregated North Sea data (e.g., Kühn et al., 2022).

Within OSPAR, results are combined for all fulmars of different sexes and age categories (OSPAR, 2015; Van Franeker et al., 2011, 2021). The pilot study for the monitoring project, based on fulmars beached in the Netherlands, showed that younger birds, on average, had higher stomach loads of plastics than adults (Van Franeker & Meijboom, 2002). No other variables were found to affect variation in the quantity of plastics in the stomachs of fulmars collected in the Netherlands. However, to allow for alternative data presentations, the source data submitted to the OSPAR Secretariat include non-obligatory data fields for the sex and age of each bird, if known. Using these data, detailed scientific analyses of plastic ingestion may include four age classes: juvenile (first year of life from August to next year July); second-year (next year, from August to July); immature (older than second year but not yet breeding); and adult (showing evidence of having bred or being capable of doing so). In data submissions to the OSPAR Secretariat, the juvenile to immature age classes are grouped as "non-adult" and breeding birds as "adult" (OSPAR, 2015). The dissection manual for the monitoring project (Van Franeker, 2004), therefore, provides guidance to assign birds to the four more specific age classes. Reporting of monitoring data with all ages combined is acceptable for long-term analyses, provided that the age composition of annual samples does not change substantially. However, more recent data formats incorporate the annual proportion of adults versus non-adults as a covariate to explain long-term trends (Van Franeker et al., 2021).

The Dutch and North Sea monitoring approach has gradually been implemented in studies elsewhere. Contrary to the North Sea monitoring, some of these studies use birds from specific seasons, locations, and capture methods, showing that variables such as sex, breeding status, and time of collection are closely intertwined (e.g., Collard et al., 2024; Snæþórsson, 2024, Van Franeker et al., 2022). Broadly, the annual cycle of fulmars is as follows: colonies are largely deserted during much of September and October, after which visits by prospecting birds or holders of nest sites gradually increase over winter, with peak attendance and pair bonding occurring from March to April. In May, this is followed by a pre-breeding exodus of breeders. Egg laying occurs from late May to early June, followed by an approximately seven-week incubation period and a seven-week nestling period in which both partners participate. Chicks fledge in late August to early September (Fisher, 1952). Van Franeker et al. (2022) showed that male breeding birds carry lower plastic loads than breeding females during the mating season, likely because males defend nest sites by spitting stomach oil (and plastics) against intruding birds. After hatching, both parents feed the chick, resulting in a reduction ("reset") in adult plastic loads and an increase in plastic loads in chicks, as has been demonstrated in different Procellariiform species (Collard et al., 2024; Rodriguez et al., 2025). The method by which birds are collected may influence stomach contents due to potential regurgitation—for example, when birds are collected by shooting or with a long-handled net (fleyg; Lavers et al., 2021). In a monitoring program, trend analyses remain valid as long as sampling is consistent with respect to area, season, and capture method. However, when comparing data across regions, detailed information on sex and age composition of the samples, as well as sampling methods, is required.

The guidance provided in the dissection manual (Van Franeker, 2004) appears to lack sufficient detail for consistent categorization of the four age classes. Some of the decisive characteristics have an element of subjective judgement that require calibration among researchers. Therefore, calibration of dissection techniques through workshops and inter-observer blind checks should be conducted on a regular basis. The establishment of a photographic reference library could further reduce bias and support training of new practitioners. A first attempt at providing photographic support is included as an appendix to this paper (see Photographic Guide: Appendix, available on the website). To address the growing need for detailed written and visual guidance, this paper aims to (1) specify the methods used in fulmar dissections by expanding the existing guidelines, and (2) demonstrate how these methods yield quantitative results for different sex and age characteristics. Although this paper provides highly specialized information for fulmar studies, it may also serve as a model for establishing standardized age and sex classification protocols in other seabird species.

PHOTOGRAPHIC GUIDE

A supplementary photographic reference library is included as an appendix to this paper (see Photographic Guide, available on the website) to provide detailed visual guidance to practitioners.

METHODS

The data in this study were extracted from the fulmar Oracle database, which has been compiled gradually by the first author since the early 1980s. From this database, we selected the records for 3,790 fulmars that had been dissected (and thus sexed and aged) by Jan van Franeker (JAF) and/or Susanne Kühn (SKU). JAF has been developing these methods since the late 1970s (Van Franeker, 1983), and since 2011, both authors have worked closely together to ensure methodological consistency. The dataset comprises primarily fulmars from the Netherlands and other countries bordering the North Sea but also includes records of fulmars from farther north in the eastern North Atlantic. Most birds were collected as either beached birds or as bycatch from longline fisheries in the region. Both sample types were collected year-round and include all age classes. Recent evidence indicates that fulmars caught as longline bycatch in the Faroe Islands do not regurgitate stomach contents when hooked (Kühn et al., 2025) and are therefore comparable to beached birds in terms of plastics found in the stomach.

To evaluate sex and age characteristics in relation to potential seasonal variations in plastic ingestion, data were analysed by day of year or grouped by month. Dates were assigned using the Julian calendar (1–365, 1–12). However, because fulmars hatch primarily in July, their first month of life is August. For first- and second-year fulmars, age-related analyses were therefore often based on a "fulmar year," defined as 01 August to 31 July of the following year (bird-year day; bird-year month). This approach allows changes in characteristics to be tracked relative to fledging. Sex- and age-class related characteristics have been illustrated in Van Franeker (2004) but are described here in more detail.

Necropsy Procedures

Sex organs in birds are positioned in the upper frontal region of the belly cavity, close to the frontal end of the kidneys (Fig. 1; Photographic Guide: Appendix). At hatching, these organs are very small and may be easily destroyed if dissection is not performed with sufficient care. After opening the abdominal cavity, the stomach and intestines should be pulled aside with extreme care, starting from the posterior region. The kidneys should not be touched until the sex organs have been located. The search should focus on the left side of the body, as females only develop the left sex organ. Males have testes on both sides, although the left side is often slightly larger.

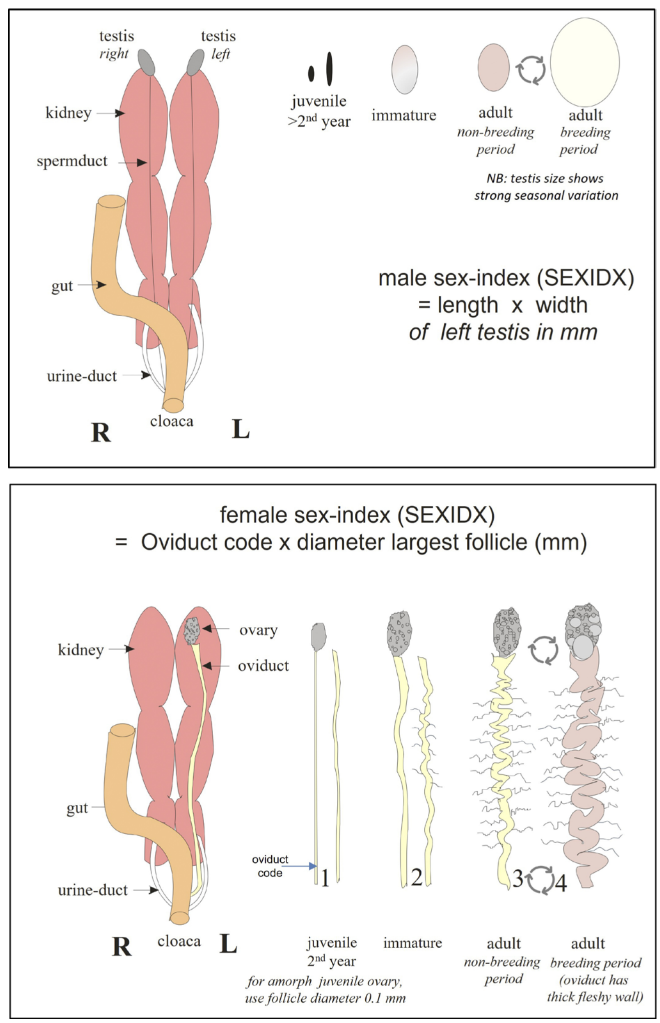

Fig. 1. Age-dependent development of sex organs in the Northern Fulmar *Fulmarus glacialis* by age class and the calculation of male and female sex-indexes (SEXIDX). The sex organs are viewed from the ventral side (L = left, R = right side of the body).

Juveniles (JU)

Juvenile male fulmars start life with very small, elongate black testes, which can be best described as a "mouse dropping." These structures are situated in a tissue string originating at the front of both the right and left kidneys and can be difficult to detect. The male sex-index (SEXIDX) refers to the testis measurement, calculated as length × width (mm). In fledglings, testes typically measure 4–5 mm in length and ~1 mm in width. By convention, the left testis is measured.

Juvenile female fulmars have an amorphic ovary located on the left side of the body, in which separate follicles cannot yet be distinguished. The amorphic ovary is almost flat and lies against the frontal end of the left kidney. It is hard to detect and highly delicate, and may be inadvertently wiped off during dissection. The female sex-index (SEXIDX) is calculated as the product of the oviduct developmental stage (coded numerically) × the diameter (mm) of the largest follicle in the ovary. At hatching, the oviduct is very thin and straight (stage 1) and, as mentioned, follicles cannot be distinguished and are assigned a nominal size of 0.1 mm. The initial SEXIDX in females is thus 0.1. Detection of the single amorphous ovary and thin oviduct is more challenging than detection of the testis in juvenile males. If neither male nor female sex organs can be found during dissection, one might assume the bird is female with SEXIDX = 0.1; however, this assumption should be avoided. If no sex organs are found despite thorough examination, the field for SEXIDX should be left blank (i.e., recorded as unknown). An important characteristic for aging both female and male fulmars is the Bursa of Fabricius (hereafter–bursa). This is a glandlike organ involved in the immune function of young birds. It is positioned at the dorsal side of the intestine, close to the cloaca (Fig. 2). Examination of the bursa requires the intestines to be carefully lifted and displaced posteriorly from the body cavity. For this reason, assessment of bursa presence and size should be conducted only after the development of the sexual organs has been fully evaluated. The bursa is attached to the intestine between the points where the ureters enter the cloacal area. Because the skin of the cloacal area may differ in appearance from surrounding tissues, it can be mistaken for the bursa. It is therefore important to confirm that the structure identified is a distinct gland located on, but separate from, the intestine. Unlike surrounding tissues, it can be pulled away from the intestine with tweezers (Photographic Guide: Appendix, Fig. A1). Juveniles start their life with a relatively large bursa, which regresses with age. In all birds, the presence and size of the bursa are recorded using a size index (BURIDX), defined as length × width (mm). Bursa absence is recorded as 0 × 0 mm, yielding a BURIDX of zero. Detection of the bursa may be complicated by decay, hunting damage, partial scavenging, or excessive intestinal fat deposition in the carcass. If absence cannot be determined with certainty, the BURIDX field in data records should be left blank (i.e., recorded as unknown).

Second-Year Birds (2Y)

Birds are classified as second-year individuals if they exhibit juvenile-like characteristics but show at least one indicator of increased age. A relatively small or absent bursa combined with all other indicators suggesting a juvenile status may indicate a second-year bird. Additional indicators include, in females, a partially developed ovary with some visible follicles, and in males, slightly enlarged but still elongated and black testes. Evidence such as the presence of different generations of secondary feathers or coverts, or active moult (see section on moult below), may indicate that the bird is older than one year, even when sex organs and bursa presence appear juvenile.

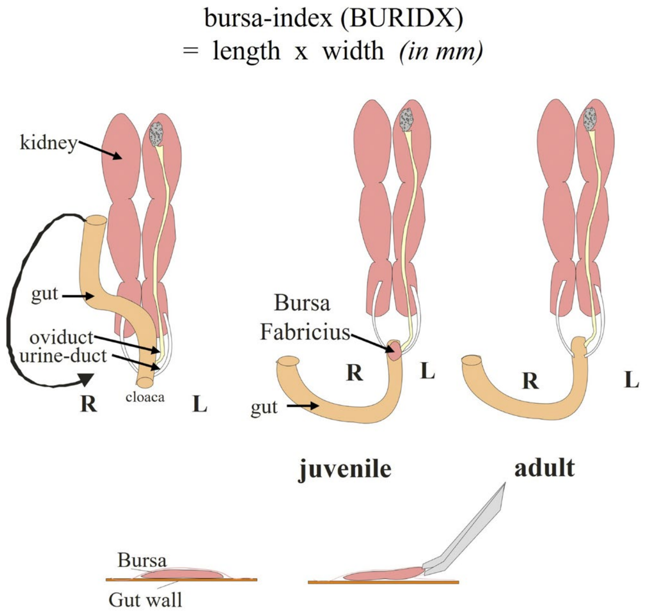

Fig. 2. Location of the Bursa of Fabricius and calculation of its size index (BURIDX), an age indicator in both sexes of the Northern Fulmar *Fulmarus glacialis*. The sample shown is a female bird, viewed from the ventral side (L = left, R = right side of the body). The bursa is located on the dorsal side of the gut, near the cloaca, where the urine-ducts and sperm ducts or oviducts open into the cloacal area. It can be located by pulling the distal gut backwards to expose its dorsal surface. The bursa is large and swollen in chicks but gradually regresses during juvenile/young life stages and is absent in immatures and adults. A small or flattened bursa may be distinguished from the somewhat transparent cloacal area in the gut wall by gently separating it from the gut using forceps.

Immatures (IM) and Adults (AD)

Birds lacking a bursa and exhibiting clearly developed sex organs are classified as immature or adult. Compared to juveniles and second-year birds, testes in males become clearly larger, broader (less elongate), and lose their black colour. In females, ovarian follicles are clearly visible and of variable size, and the oviduct is thicker and becomes curly. Distinguishing between the two older age classes (immature and adult) is not straightforward. As in other long-lived species, the development of the sex organs with age is a gradual process. In addition, the sex organs exhibit pronounced seasonal variation. Age at first breeding in fulmars averages nine years or more (Ollason & Dunnet, 1978). In this study, the adult age class is restricted to birds that have reached breeding age.

Testes size and appearance vary substantially through the breeding season and must be considered when evaluating age class. In adult males, testes substantially enlarge during April–May and become whitish-milky in colour. During the pair-formation period, sperm ducts become visibly filled with whitish semen. Thereafter, these enlarged milky testes rapidly regress to an inactive state, typically measuring 7–8 mm in length and 4–5 mm in width (left testis). In fresh carcasses during the non-breeding season, testes are generally fleshy, with a brownish or light-greyish colour. At this stage, adult testes may resemble those of immature birds. However, immature testes typically have a darker grey colour. The extent of seasonal variation will increase with age, from immature to subadult to adult stages. In older immature birds, testes may increase in size during the pair-formation period and may become milky-coloured, but do not reach the large, distinctly whitish appearance observed in adults. For most of the year, testis size in immature birds is similar to that of adults in the non-breeding season; however, immature testes tend to be darker, greyish, less fleshy in appearance.

Internal organs become discoloured after death, particularly in beached birds, but also in longline bycatch if not frozen promptly. Although testes colour is described on dissection forms, it is not recorded in the database due to its variability following decay of the carcass. At the time of dissection, testis size, shape, and colour should be considered when classifying males as immature or adult in both dissection records and in the database.

Adult females are characterized by an ovary with numerous clearly visible follicles and a wide, strongly curled oviduct. This oviduct "hangs" in the body cavity from the posterior region of the female, suspended in transparent tissue that is full of stretch marks, from near the ovary to the cloacal area. Most of the year, this oviduct has a thin, semi-transparent wall; however, during the reproductive period, it becomes thick and fleshy. At the onset of the breeding season, several follicles in adult females enlarge, one of which develops into an ovulated egg. Following ovulation, its follicle remains a relatively large, hollow cup that subsequently regresses into a temporary, yellowish spot, the "corpus luteum." As in males, the sex organs of older immature to subadult females exhibit increasing seasonal growth and regression, even in non-breeding individuals. During the non-breeding period, the oviduct may become slightly curlier and may show some stretch marks (oviduct code 2). However, in our ageing system, females are classified as adults only if they have produced an egg or are clearly capable of doing so. Such individuals show a wider, strongly curved oviduct, as well as stretch marks (oviduct code 3 in winter, oviduct code 4 in the short egg-laying period). These features are often readily visible during dissection when stomach and intestines are displaced.

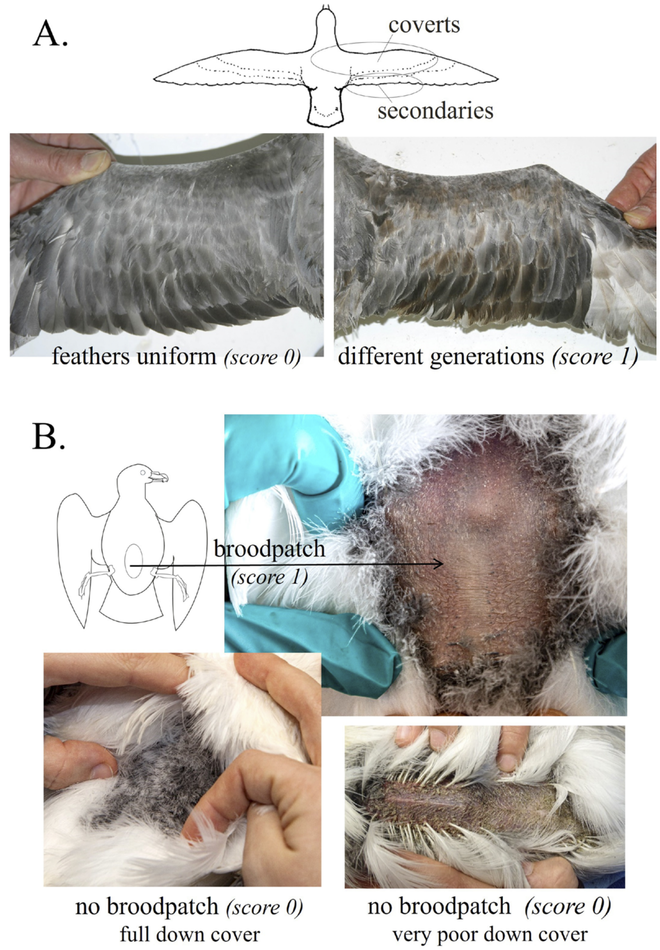

Fig. 3. Scoring age-dependent plumage characters in Northern Fulmars *Fulmarus glacialis*. (A) Differences in feather generation among secondaries and coverts, visible as variation in wear and colour, scored as: 0 = no differences (all feathers of same generation); 1 = differences present (multiple feather generations); blank = not recorded or uncertain. (B) Presence of an incubation or brood patch, scored as: 0 = no bare patch; 1 = bare broodpatch present (including early or late stages); blank = not recorded or unclear. Note: Some birds may have poorly-developed down, which may also be evident on the breast. In decaying specimens, down feathers from the abdominal area may be easily wiped off during handling of the carcass and should not be interpreted as an incubation patch.

Moult

In addition to the sex organ development and the presence of a bursa, feather moult can provide useful supplementary information (Figs. 3–5), mainly to distinguish juveniles from other age groups. However, moult should be used to support, rather than determine, age classification. Over most of their first year, fulmars will have a uniform, fresh plumage, with all coverts, flight feathers, and tail feathers belonging to the same generation and no evidence of active moult. Moult typically begins toward the end of the first year. Thereafter, most fulmars display different generations of secondary feathers and coverts on the back and/or upper wing.

Newer feather generations appear fresh grey, but older generations have a more brownish tinge and show wear at the tips (Fig. 3A). Unfortunately, in dirty or wet carcasses found on beaches or recovered from longlines, distinguishing between feather generations in secondaries or coverts may be difficult. Pyle (2008) described further details of feather shapes in primary and tail feathers, as well as potential age characteristic sequences in moult of secondaries and coverts. The dirty and wet plumages in most of the birds in our study, however, prevented reliable assessment of these finer characteristics. We have noted the narrow, attenuated tips of primaries in recently fledged juveniles, but this feature was not sufficiently clear to use as a formal age character. Similarly, recently fledged birds tend to have a soft and often ridged nasal tube, but we do not recommend this feature as a formal juvenile age character. After the first year of life, and depending on the time of year, fulmars undergo active moult of primaries and the tail feathers. Moult of the primaries starts with inner feathers (p1–p4) and progresses outward. Tail moult typically begins once primary moult is well underway and appears to occur in a random sequence of feathers, with the left and right rectrices replaced in a superficially symmetrical but erratic pattern. Moult of primaries and tail feathers is scored according to the British Trust for Ornithology (BTO) system from 0 (missing feather) to 5 (fully grown feather) (Fig. 4; Ginn & Melville, 1983).

In the standard procedures, active moult of breast feathers is recorded, as can be easily observed on the inner side of the skin: newly growing feathers have soft white shafts, and fully grown feathers are present as rigid pins (Fig. 5).

Incubation Patch

Finally, the presence of a bare incubation patch serves as an indicator of the adult age class. In a true incubation patch, the skin is typically firm and fleshy, usually somewhat wrinkled, with veins clearly visible in the skin (Fig. 3B). However, as with internal sex organs, older immatures ("subadults") gradually develop an incubation patch (as reported, for example, in albatrosses; Hector 1988). Therefore, the presence of an incubation patch alone is not decisive for classification as an adult and should only be used as an indicator together with clear signs of active breeding. Caution is required when examining older carcasses of beached birds, as down plumage on the belly area is easily lost, leaving a smooth, bare skin that should not be mistaken for an incubation patch.

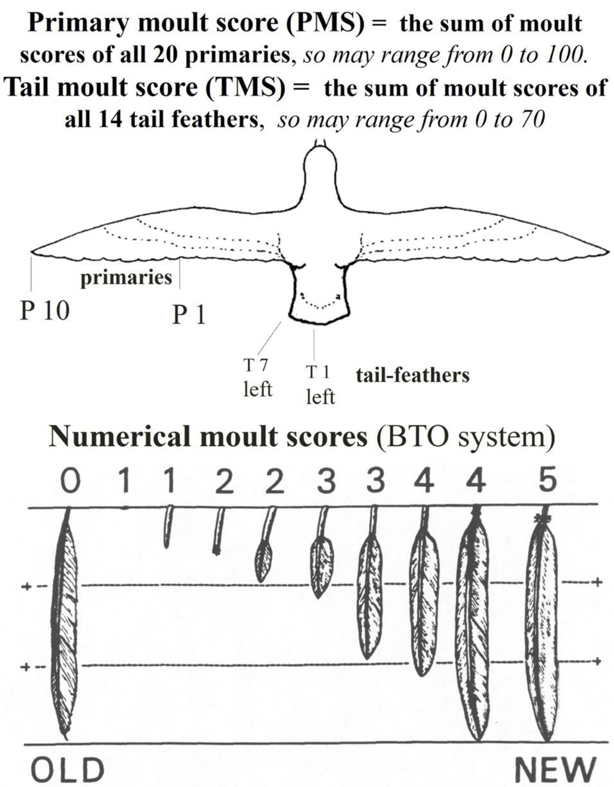

Fig. 4. Moult of primaries and tail feathers in Northern Fulmars *Fulmarus glacialis* is scored using the system developed by the British Trust for Ornithology (BTO; Ginn & Melville, 1983). For each feather, the moult stage is scored as: 0 = old feather remaining; 1 = feather missing or new feather completely in pin; 2 = new feather just emerging from the sheath up to one-third grown; 3 = new feather between one- and two-thirds grown; 4 = new feather more than two thirds grown and with remains of waxy sheath at its base; 5 = new feather fully developed with no trace of waxy sheath remaining at base. The "reset" date for the moult score in fulmars, i.e., when moulted feathers switch from new (score 5) to old (score 0) is arbitrarily set to the first of April. In cases of an atypical number of feathers (very rare in primaries, incidental in tail), the total score is recalculated to the standard potential score of 0–100 for primaries and 0–70 for tail. Delayed or arrested moult (due to energetic constraints) may result in the presence of clearly different feather generations after the reset date. In such cases, all feathers should be score as "old" (score 0), regardless of visible differences.

RESULTS AND DISCUSSION

Assigning age to fulmars involves integrating information on bursa and sex organ development, supported by seasonal context and moult

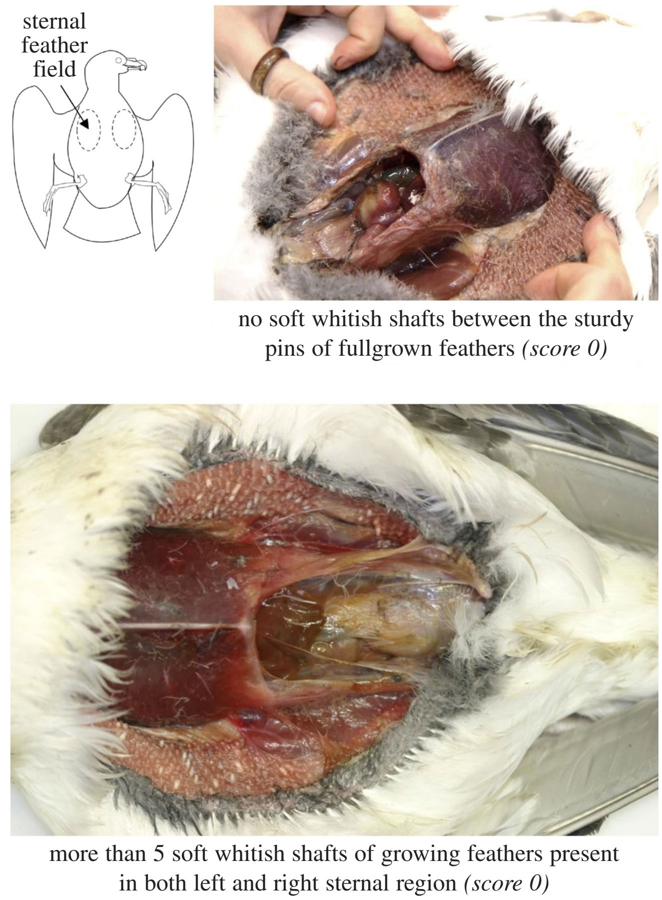

Fig. 5. Active moult of body feathers in Northern Fulmars *Fulmarus glacialis* is scored by the number of moulting feathers visible in either the left or right sternal feather field. Moulting feathers are internally visible as broad, soft, whitish feather shafts in between the sturdy pins of non-moulting feathers. Scores are as follows: 0 = no visible moult; 1 = one to four moulting feathers; 2 = five or more moulting feathers.

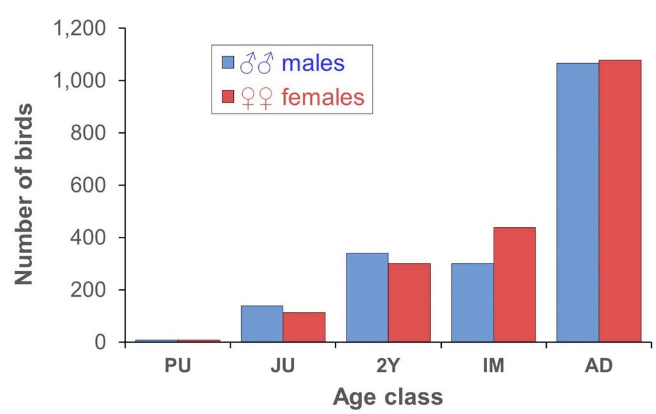

Fig. 6. Sex and age assignments in 3,790 Northern Fulmars *Fulmarus glacialis* of known sex and age, dissected by the authors. PU = pulli; JU = juvenile; 2Y = second-year; IM = immature; AD = adult.

patterns. The information presented here offers additional descriptions and graphical illustrations that expand on earlier guidelines by Van Franeker (2004) and OSPAR (2015). A total of 3,790 fulmars were sexed and aged by the authors to quantitatively illustrate the decision criteria described above, including seasonal variation. Of these, 1,853 birds were sexed as males, comprising seven pre-fledging chicks

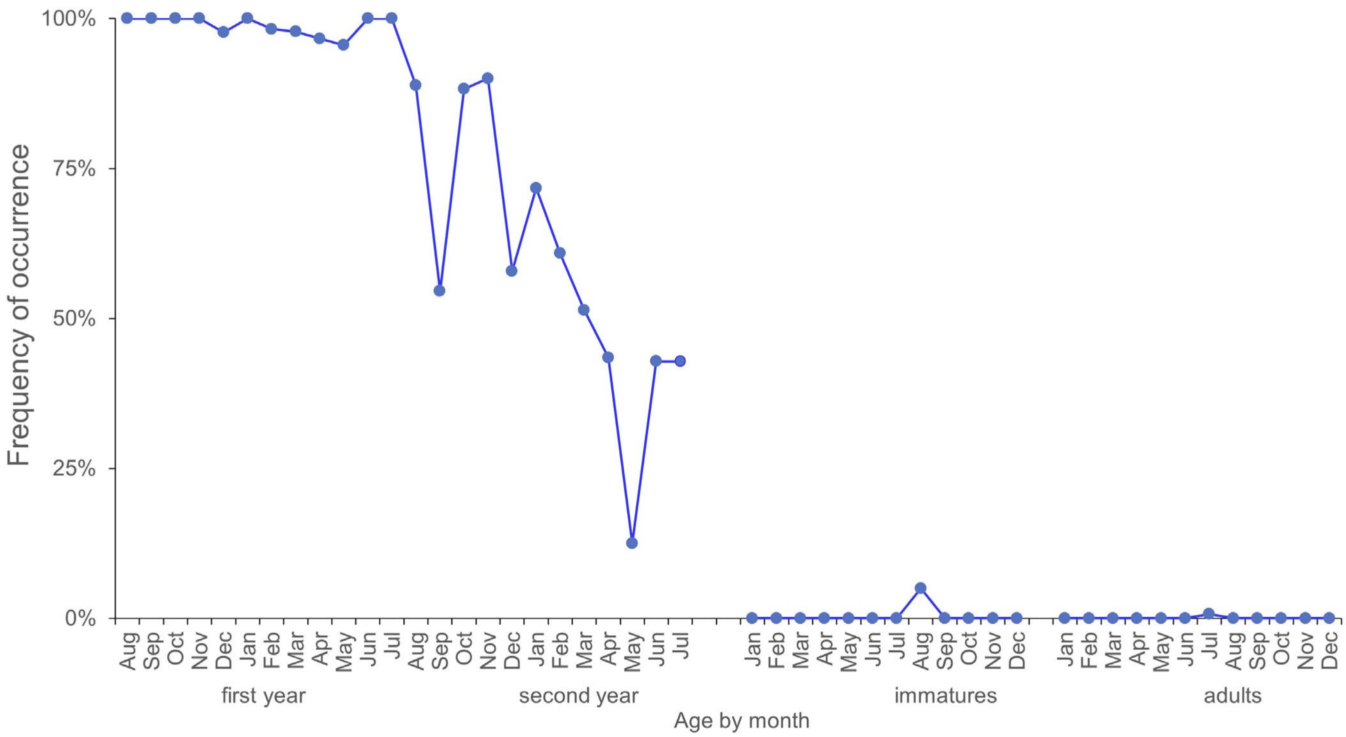

Fig. 7. Monthly frequency of occurrence of the Bursa of Fabricius in Northern Fulmars *Fulmarus glacialis* across age classes. For first- and second-year birds, months are presented from August to July to reflect age progression starting with birth of the chick. For older birds, months follow the standard calendar sequence (January to December) to illustrate seasonal variation.

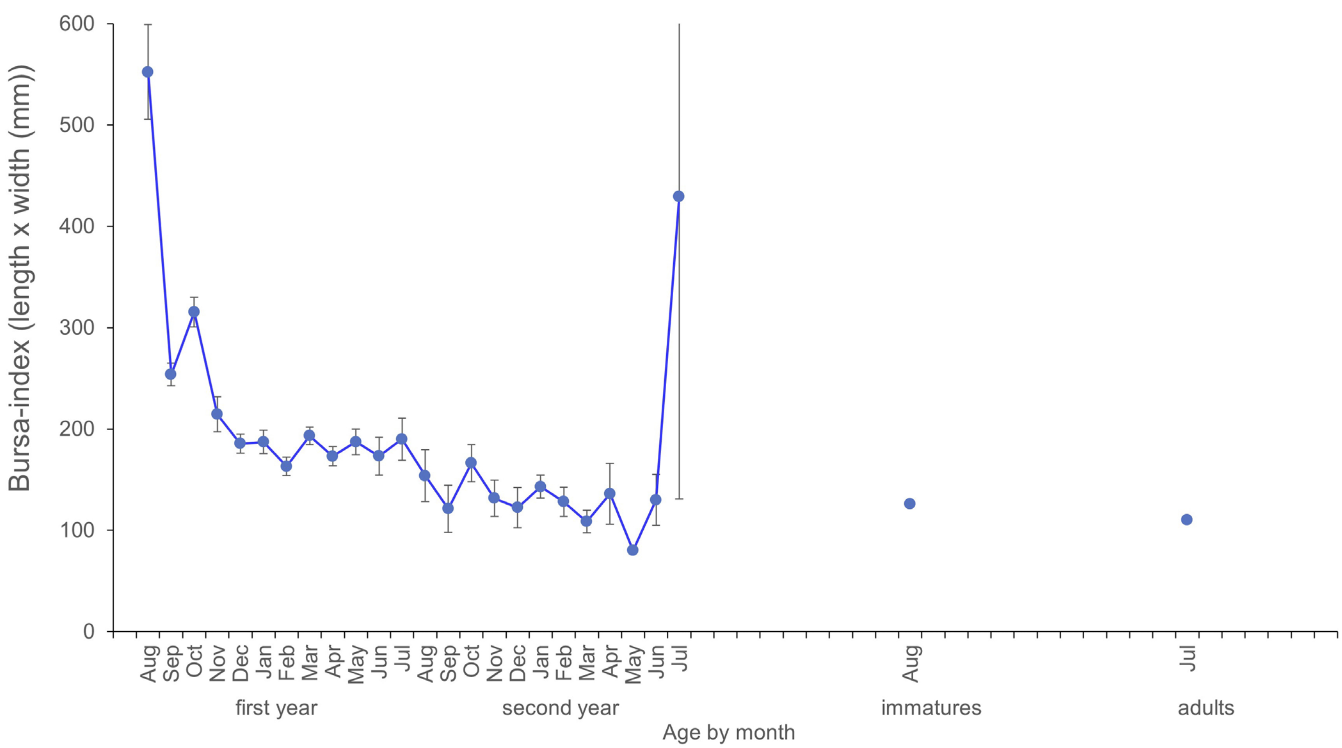

Fig. 8. Bursa of Fabricius size index (BURIDX; length × width) with standard errors in Northern Fulmars *Fulmarus glacialis* in which bursa was present. For first- and second-year birds, months are presented from August to July to reflect age progression starting with birth of the chick. For older birds, months follow the standard calendar sequence (January to December) to illustrate seasonal variation.

(pulli, PU) collected from nest-sites, 340 juveniles (JU), 139 second-year birds (2Y), 301 immatures (IM), and 1,066 adults (AD) (Fig. 6). Females totalled 1,937 birds: eight PU, 300 JU, 113 2Y, 438 IM, and 1,078 AD. In most analyses, the small number of chicks were combined with juveniles, as all belong to the first-year age class.

Bursa of Fabricius

As noted, the bursa was present in almost all first-year birds (pulli and juveniles). Among second-year individuals, the bursa occurred less frequently as birds aged and disappeared in more than half of the birds towards the end of the second year (Fig. 7; Appendix, Fig. A1). The data suggest that a small number of birds may still retain remnants of the bursa at the start of their third year. During these years, the size of the bursa also gradually decreased, from an index of ~200 to ~100 (Fig. 8). Very large bursae were seen in pre-fledging chicks in August (average index > 500), with high values for fledglings in September and October (indexes ~300). The unusually high value in July at the end of the second year (Figs. 8, 9) was due to a single outlier and small sample size, as indicated by the high standard error.

In immature or adult birds, the bursa was generally absent. Two exceptions were recorded, in which sex organs and moult patterns clearly indicated a subadult or adult age, despite the presence of a bursa (Figs. 8, 9).

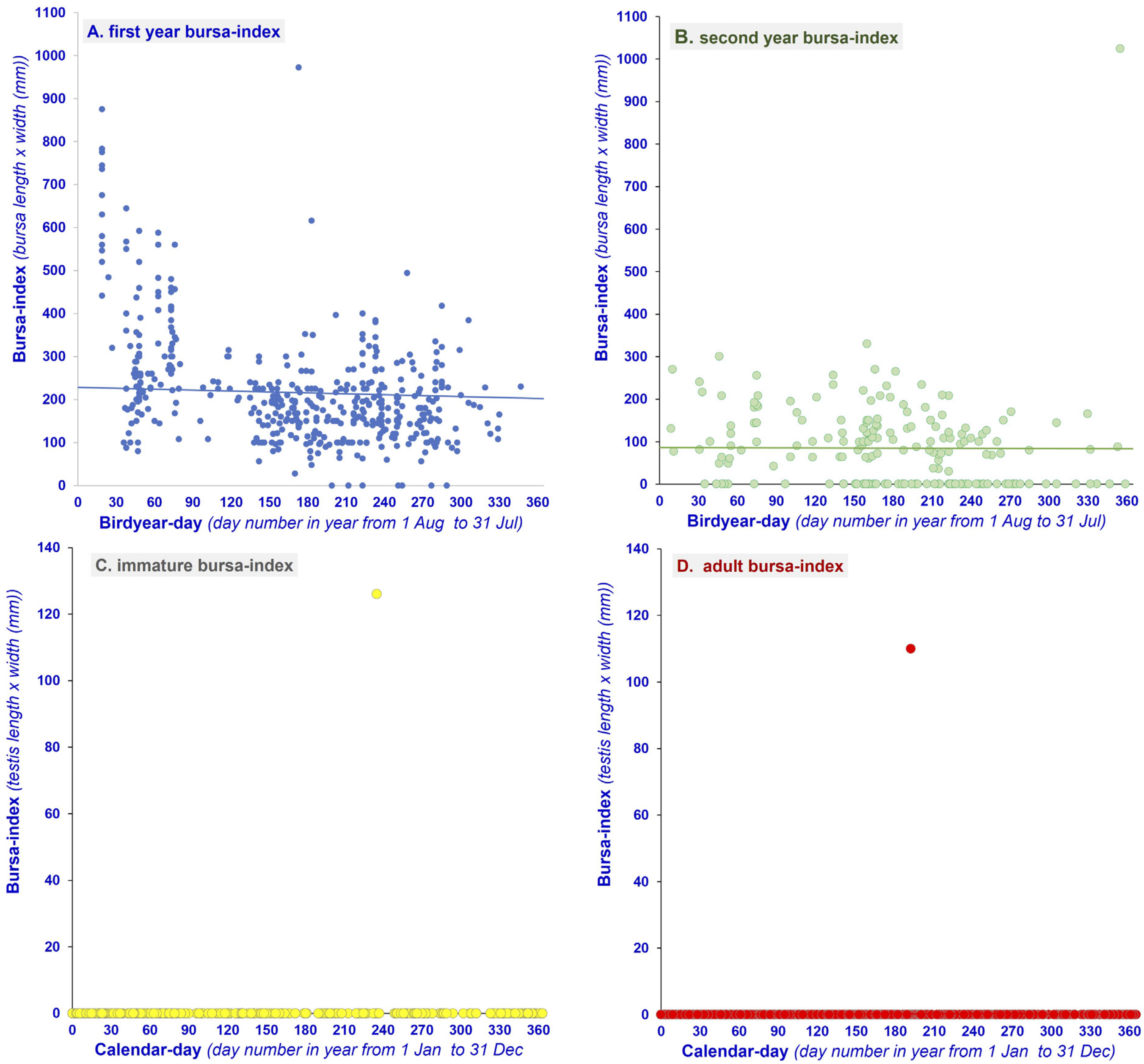

Fig. 9. Individual Bursa of Fabricius sizes (BURIDX) plotted by day for the different age classes in Northern Fulmars *Fulmarus glacialis*. For first- and second-year birds (A, B), dates are presented from August to July to reflect age progression starting with birth of the chick. For older birds (C, D), dates follow the standard calendar sequence (January to December) to illustrate seasonal variation. Note the different y-axis scales for BURIDX.

Male Sex-Index in Different Age Classes

In juvenile male fulmars (Figs. 10, 11; Photographic Guide: Appendix, Fig. A2), the small, black testis averaged 4.5 × 1.5 mm (SEXIDX 7.0). In second-year birds, testes were only slightly larger. A more substantial increase in testis size occurred in immatures, with the largest values recorded in adults, averaging 10.4 × 6.6 mm (Table 1). In the older age classes, the annual mean values are affected by seasonal variation, as testes grow substantially during the reproductive season. Figures 10 and 11 show weak seasonal variation in immatures (Fig. 11C), and strong seasonal variation in adults (Fig. 11D). Outside the reproductive season, the SEXIDX in adult males fluctuated between 30 and 40. The onset of reproduction becomes visible during late February, followed by strong testes growth in March and April (i.e., to SEXIDX > 100). Regression of the testes to a non-breeding size begins in May. In this classification framework, some testis growth occurs in immatures during summer; however, birds with SEXIDX values > 150 were consistently classified as adults.

With increasing age, testes shape also changed, from elongated (more than three times longer than wide) to a more spherical shape (less than twice as long as wide). This shift in shape occurred primarily after the second year. The distinction between immatures and adults based on shape alone is limited; therefore, age classification was usually based on overall size and colouration (Fig. 12).

Female Sex-Index in Different Age Classes

In female fulmars (Table 2; Figs. 13, 14; Photographic Guide: Appendix, Figs. A3–A5), the oviduct during the first year is straight and thin (code 1), and no ovarian follicles are present (follicle diameter scaled as 0.1 mm). In second-year fulmars, the oviduct was occasionally classified as slightly thicker (code 2), and some follicles in the ovary were visible and could be measured. In both of these younger age classes, SEXIDX values were well under 0.5. In the older age classes, the annual averages were affected by seasonal variation, with SEXIDX increasing slightly during the reproductive season in birds labelled as immatures and more markedly in adults (Figs. 13, 14C–D). Outside the reproductive season, the female SEXIDX in immatures fluctuated between 3 and 4, and it exceeded 5 in adults (Fig. 15). Seasonal changes became apparent from late April, with indexes peaking in May. Regression of female sex organs began as early as May and was largely complete by June–July.

In immature females, the modest seasonal increase in SEXIDX during the reproductive season results from an increase in size of some follicles. The oviduct remains in stage 2, even when some maturation occurs; it retains a thin, semi-transparent wall, although it may increase slightly in width and show some initial curvature and stretch marks.

In adult females, the oviduct widens and develops firmer tissue during the reproduction season, progressing from stage 3 to stage 4. Several follicles may increase substantially in size, although typically only one egg continues to develop and is ovulated into the oviduct. After release of the egg, the ruptured follicle is shaped as a beaker. The large diameter of the developing follicle with the egg, or the diameter of the post-ovulatory follicle, contributes strongly to the elevated SEXIDX in reproducing adult females.

Moult in Different Age Classes

The timing of primary and tail feather moult shifts with increasing age and is influenced by breeding activity (Fig. 16).

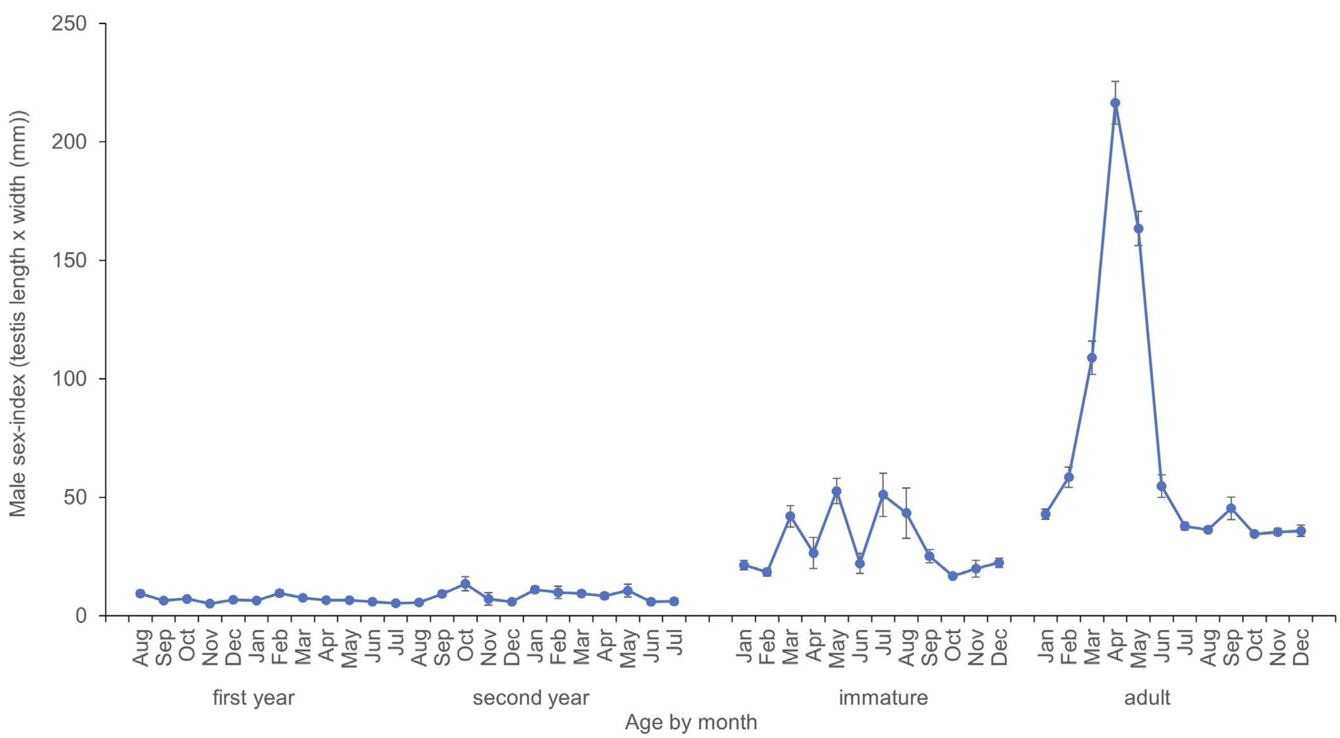

Fig. 10. Monthly average male sex-index (SEXIDX) with standard errors in Northern Fulmar *Fulmarus glacialis* across age classes. For first- and second-year birds, months are presented from August to July to reflect age progression starting with birth of the chick. For older birds, months follow the standard calendar sequence (January to December) to illustrate seasonal variation.

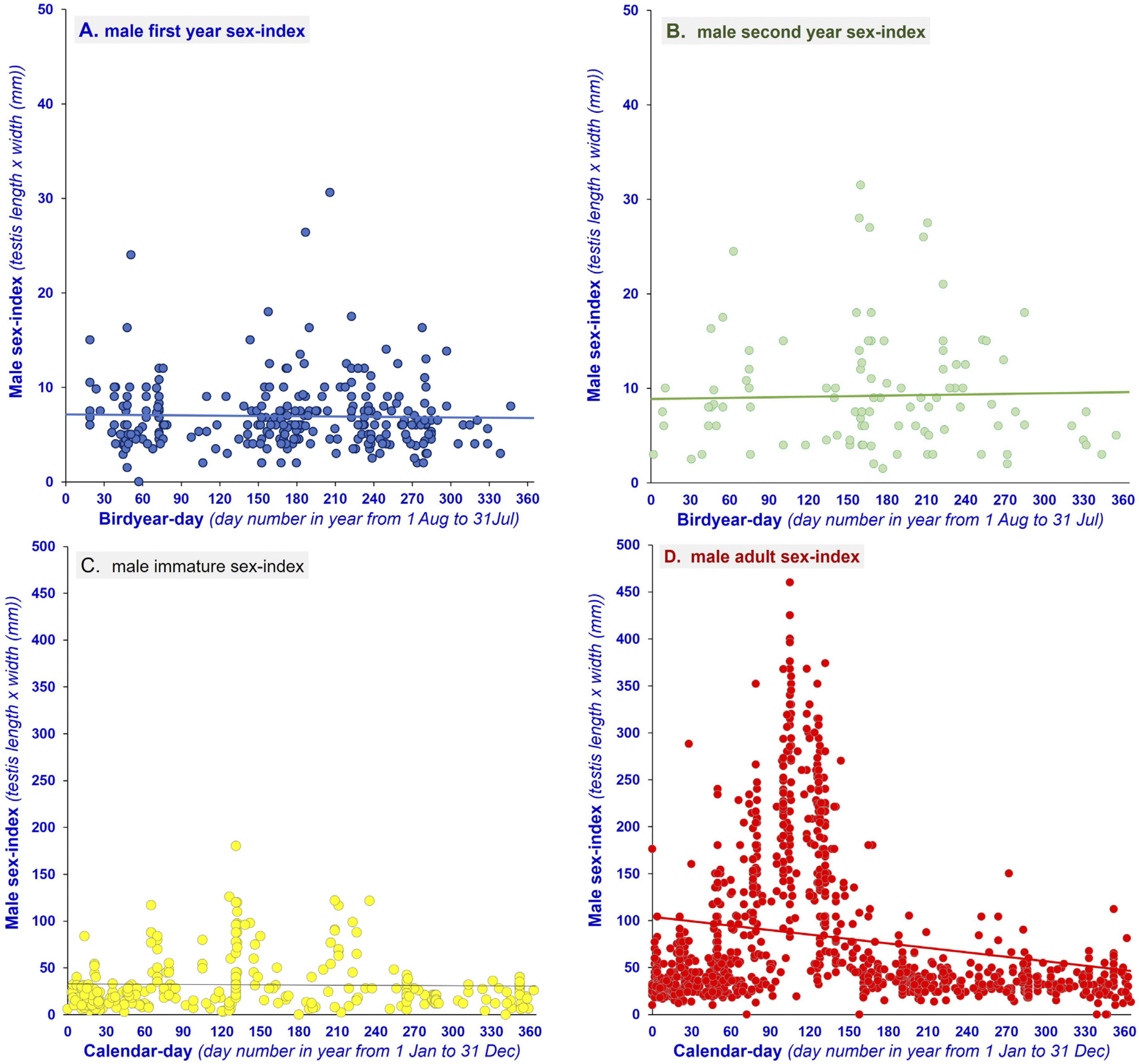

Fig. 11. Sex-index (SEXIDX) of individual male Northern Fulmars *Fulmarus glacialis* plotted by day of year across age classes. For first- and second-year birds (A, B), months are presented from August to July to reflect age progression starting with birth of the chick. For older birds (C, D), dates follow the standard calendar sequence (January to December) to illustrate seasonal changes in relation to breeding period. Note the ten-fold difference in y-axis scale between panels A and B, and C and D.

Table 1. Male Northern Fulmar *Fulmarus glacialis* sex organ details for different age classes with standard errors (SE)

Age class	*n*	Testis length ± SE (mm)	Testis width ± SE (mm)	Testis index ± SE	Testis length/width ± SE
First year	346	4.50 ± 0.06	1.51 ± 0.03	6.99 ± 0.19	3.22 ± 0.06
Second year	139	4.92 ± 0.12	1.78 ± 0.07	9.22 ± 0.54	3.14 ± 0.12
Immature	301	7.15 ± 0.14	3.92 ± 0.11	32.03 ± 1.60	2.05 ± 0.05
Adult	1,061	10.40 ± 0.13	6.56 ± 0.11	81.91 ± 2.48	1.70 ± 0.01

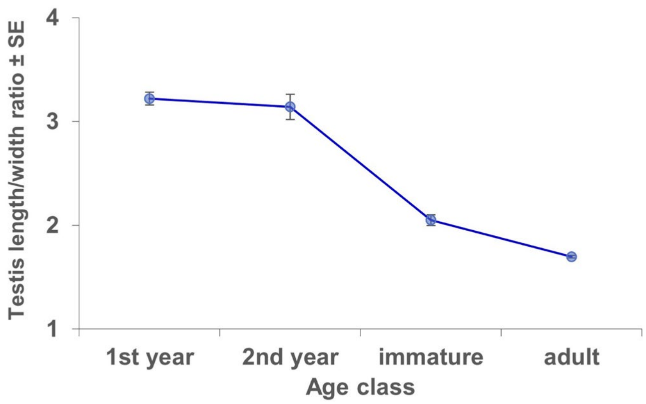

Fig. 12. Shape of testis of Northern Fulmars *Fulmarus glacialis* shown as length divided by width ± standard error (SE) in different age classes.

October. In contrast, adult birds tend to postpone their primary and tail moult until after breeding, either following breeding failure or after fledging of the chick, and they subsequently moult as quickly as possible. In successfully breeding adults, primary moult starts with the inner few primaries in late August, when the chick is nearly fledged, and it approaches completion in October. Tail moult begins in October and is completed by January.

In this system, active moult of secondaries and coverts is not assessed; instead, only the presence or absence of different feather generations is recorded. In the first year, the plumage of secondaries and coverts is usually uniform; only in the last three months do differences among age classes become evident. Most second-year birds to adults show different feather generations in all months of the year (Fig. 17). Accordingly, birds with a bursa and no primary or secondary moult are likely juveniles, whereas birds with a (smaller) bursa and primary and/or secondary moult can be classified as second-year birds.

Table 2. Female Northern Fulmar *Fulmarus glacialis* sex organ details for different age classes with standard errors (SE)

Age class	*n*	Oviduct code ± SE	Follicle diameter ± SE (mm)	Sex index ± SE
First year	302	1.01 ± 0.01	0.18 ± 0.02	0.19 ± 0.02
Second year	113	1.07 ± 0.02	0.37± 0.05	0.40 ± 0.06
Immature	417	1.72 ± 0.02	1.76 ± 0.04	3.23 ± 0.10
Adult	1036	3.11 ± 0.01	3.12 ± 0.12	10.72 ± 0.53

High energy demands are associated with breeding but also with moult (Croxall, 1982). Juvenile birds start primary moult in the last two months of their first year (i.e., June and July), with completion of primary moult occurring in September. Tail moult of juveniles starts in August and approaches completion in October.

Active moult of body feathers is only recorded internally in the breast feather fields. Data show that first-year birds may start active moult in

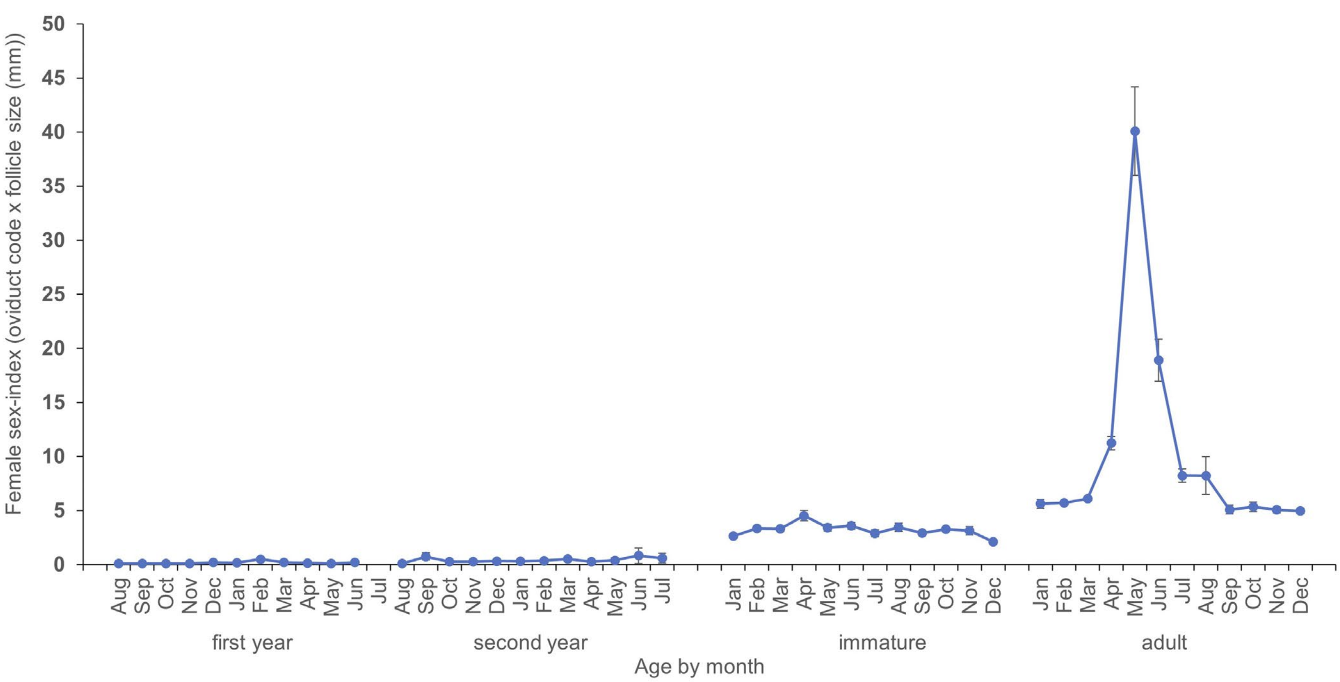

Fig. 13. Monthly average female sex-index (SEXIDX) with standard errors in Northern Fulmar *Fulmarus glacialis* across age classes. For first- and second-year birds, months are presented from August to July to reflect age progression starting with birth of the chick. For older birds, months follow the standard calendar sequence (January to December) sequence to illustrate seasonal variations.

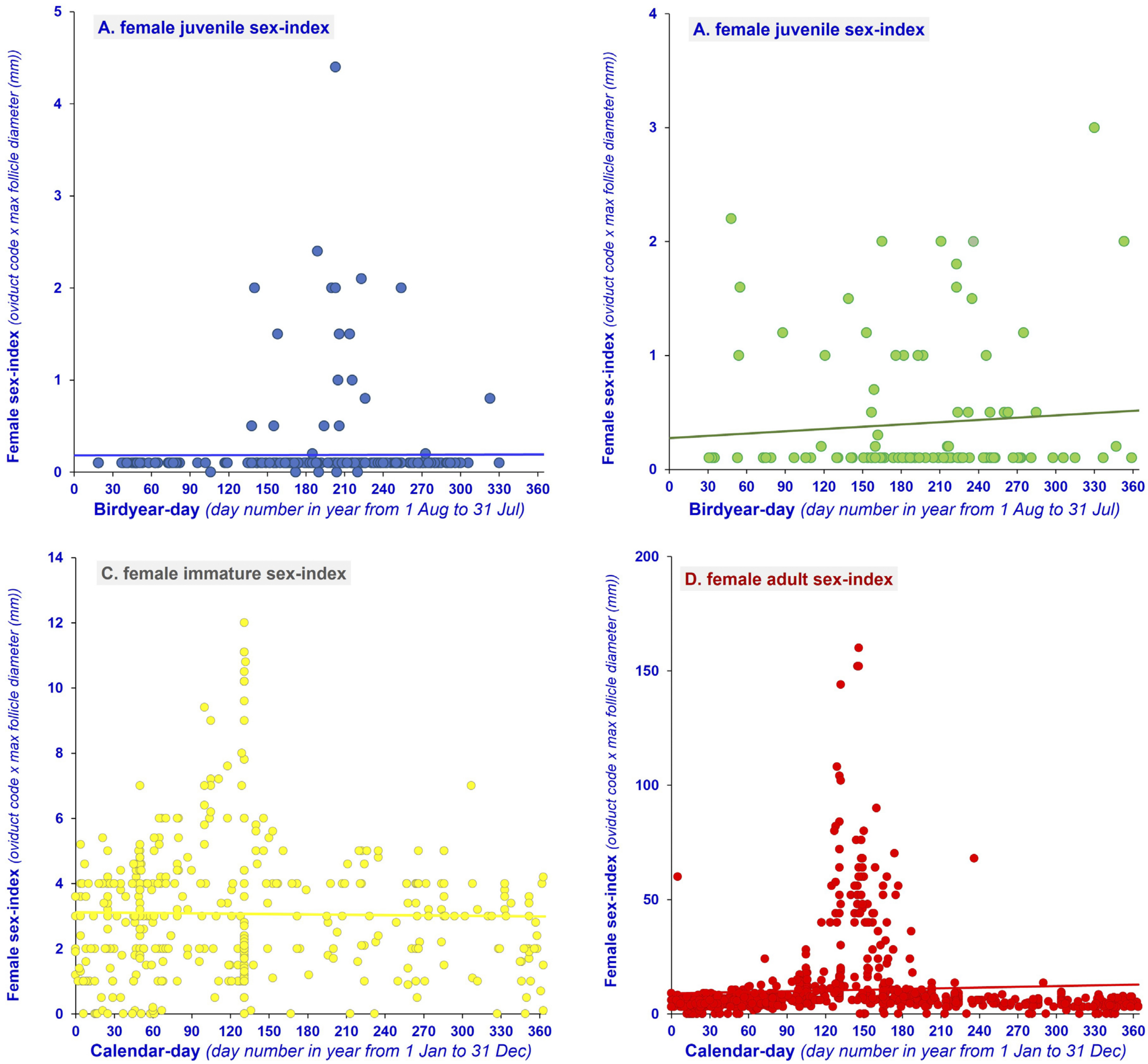

Fig. 14. Sex-index of individual female Northern Fulmars *Fulmarus glacialis* plotted by day of year across age classes. Note that in panels A and B, day number is given from 01 August to 31 July to emphasize age progression starting with birth of the chick, whereas in figures C and D, days follow the standard calendar year, from the 01 January to the 31 December, to illustrate seasonal changes in relation to the breeding period. Note the substantial differences in the y-axis scale for the SEXIDX.

April, and that during their second year, most individuals moult without a clear seasonal pattern. In immatures, moult appears to be limited during summer, whereas in adults it is largely absent from April to August and is likely postponed until after the breeding season (Fig. 18).

Incubation patches, ranging from early down loss to regrowth, are observed in adult birds from May to July, occasionally extending into early August (Fig. 19). A proportion of birds classified as immature also developed incubation patches in May and June. These birds may be considered adolescents, likely undergoing hormonal development toward sexual maturity but not yet actively breeding. No evidence of incubation patch formation was observed in first- and second-year birds.

CONCLUSION

This study aimed to provide practical information on sex and age assignments in fulmars, complementing previously published guidelines (OSPAR, 2015; Van Franeker, 2004). The data show that classifying fulmars as first- and second-year birds is straightforward, based on the shape and size of sexual organs and the presence of the bursa. Differentiation between the immature and breeding adult life stages is more complicated. In females, oviduct morphology is generally indicative in females. In males, however, classification is more complex, as testes in adult breeders regress during the non-breeding season to a size similar to those of immature males. Subjective judgement of

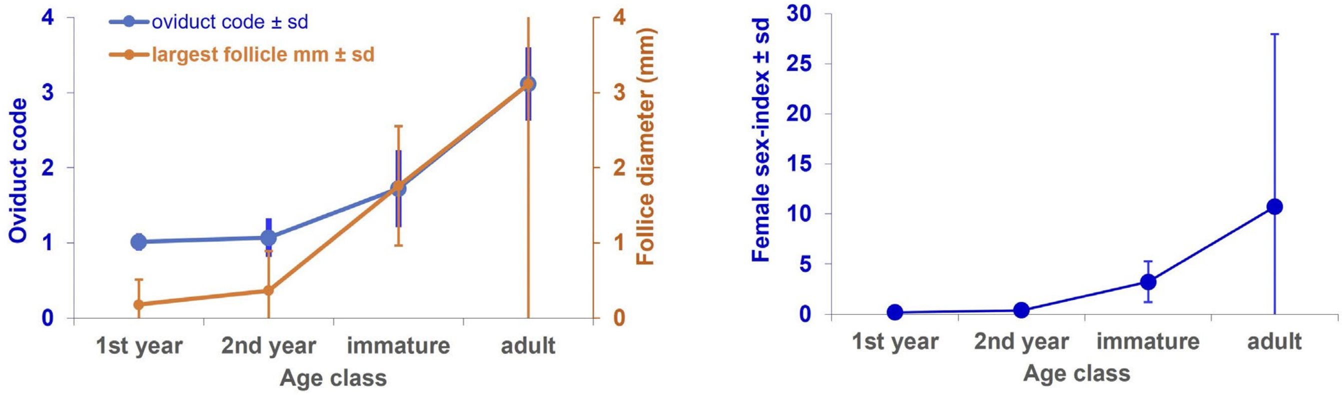

Fig. 15. Development of Northern Fulmars *Fulmarus glacialis* female sex organs in different age classes. In order to illustrate seasonal changes during the reproductive season, these graphs show standard deviations (sd) rather than standard errors.

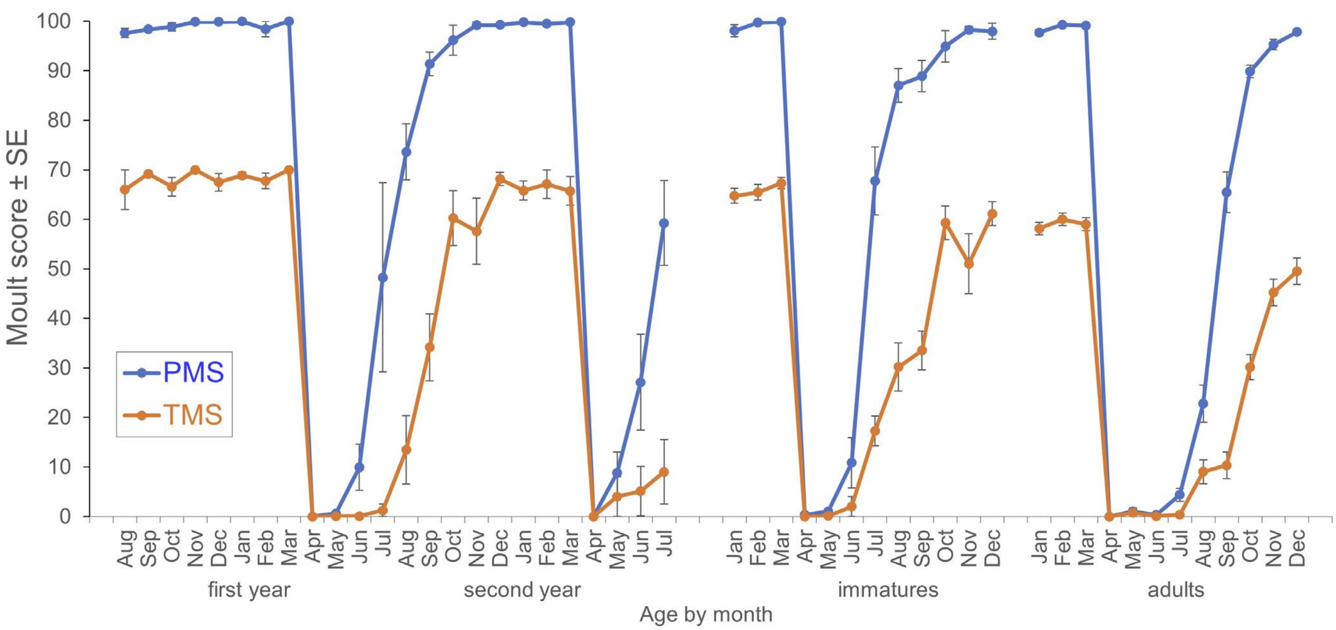

Fig. 16. Timing of moult of primaries and tail feathers by monthly average moult scores in Northern Fulmars *Fulmarus glacialis* in different age classes (Primary Moult Score, PMS; Tail Moult Score, TMS). Note that during the first two years of life, months are shown from August to July to illustrate age progression starting with birth of the chick. In older birds, months follow the standard calendar year (January to December) to illustrate seasonal variations. By definition, feather age changes from moult score 5 (new) to moult score 0 on 01 April. Consequently, overall scores change from 0 to 100 for primary feathers and 0 to 70 for tail feathers. Exceptional cases of delayed or arrested moult may therefore be obscured by this approach but become visible in adult tail-moult scores during January–March.

shape (somewhat rounder in adult males) or colour (less grey but more fleshy-to-creamy in adults) can assist the classification, but characteristics may vary through the annual cycle. Plumage characteristics associated with moult may occasionally assist in age determination but moult is mostly indicative rather than conclusive. Overall, accurate age and sex assignment is complex and relies on the integration of multiple traits, and it requires continuous training and calibration among observers in order to ensure consistency. This is particularly important in the context of fulmars as bioindicators of plastic pollution, given the relationship between demographic characteristics and plastic loads.

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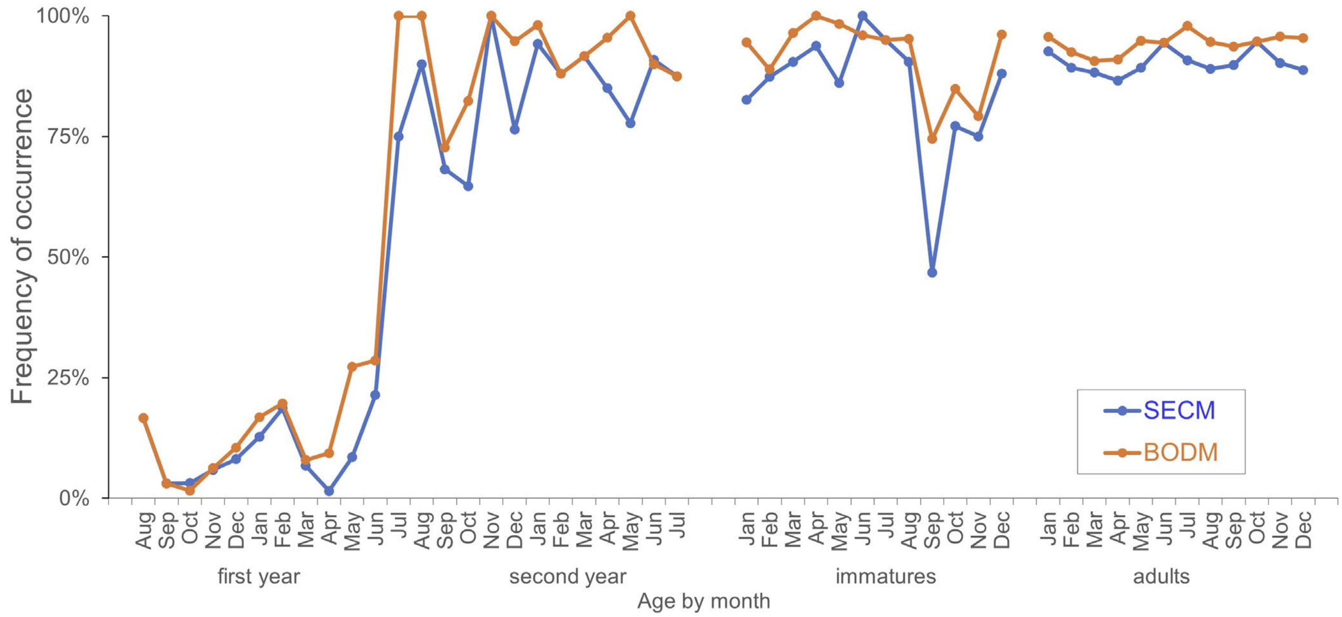

Fig. 17. Frequency of occurrence of different generations of secondaries (SECM) and coverts (BODM) in Northern Fulmars *Fulmarus glacialis* of different age classes. For first- and second-year birds, months are presented from August to July to reflect age progression starting with birth of the chick. For older birds, the months follow the standard calendar sequence (January to December) to illustrate seasonal variations.

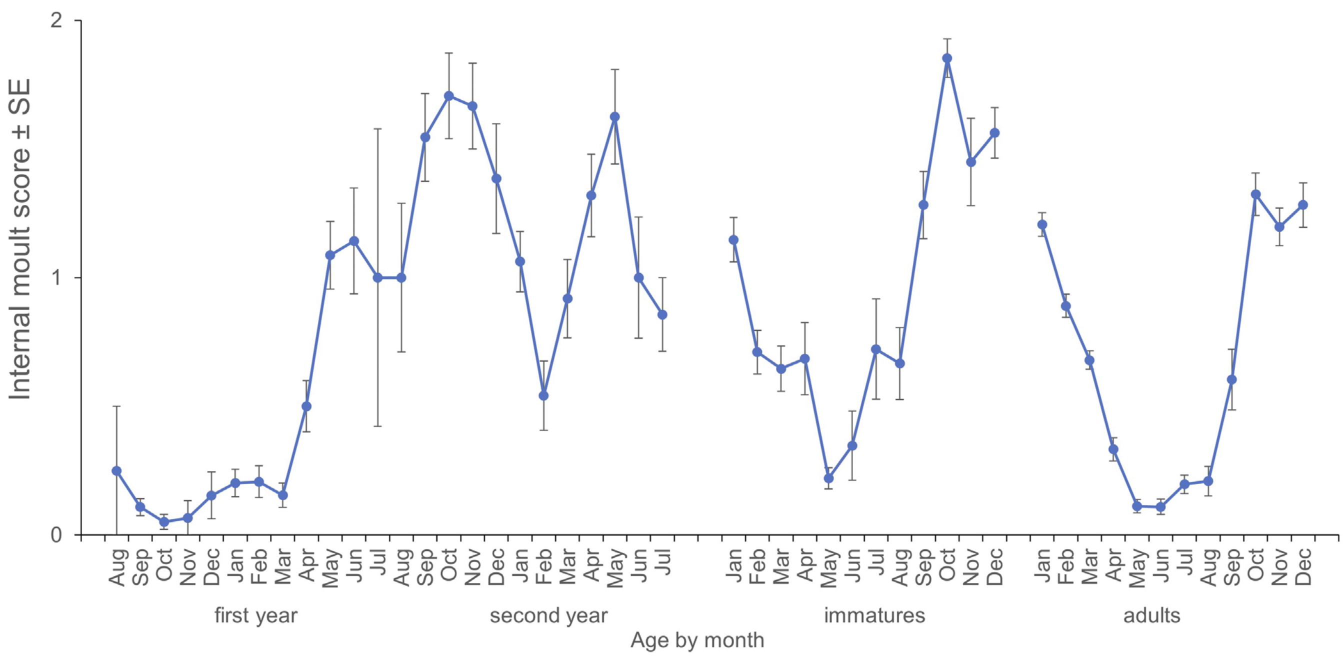

Fig. 18. Monthly average internal moult score in breast feathers in Northern Fulmars *Fulmarus glacialis*, scored as 0 if there is no moult, 1 when few feathers are moulting, and 2 when more than five feathers are moulting within a feather field. For first- and second-year birds, months are presented from August to July to reflect age progression starting with birth of the chick. For older birds, the months follow the standard calendar sequence (January to December) to illustrate seasonal variations.

AUTHOR CONTRIBUTIONS

JAF: Conceptualization, methodology, laboratory analysis, data validation, data curation, formal analysis, writing—original draft. SKU: Laboratory analysis, data validation, data curation, writing—review & editing, project administration.

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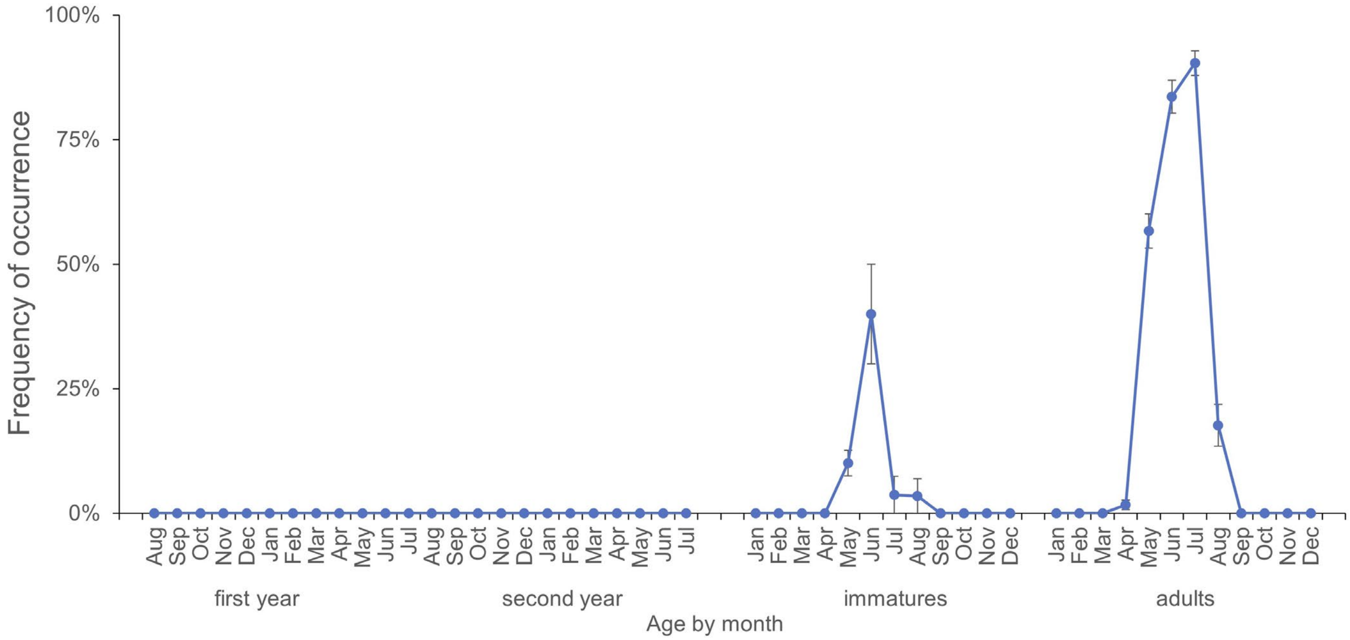

Fig. 19. Frequency of occurrence of an incubation patch (bare, forming, or disappearing) in Northern Fulmars *Fulmarus glacialis* by month in different age classes. For first- and second-year birds, months are presented from August to July to reflect age progression starting with birth of the chick. For older birds, the months follow the standard calendar sequence (January to December) to illustrate seasonal variations.

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