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Short Note

Molt Chronology of a Male Mediterranean Monk Seal (*Monachus monachus*) from the Eastern Mediterranean Sea

Kimonas Koemtzopoulos,[1] Styliani Adamantopoulou,[1] Panagiotis Dendrinos,[1] Anastasia Komnenou,[2] Eleni Tounta,[1] and Alexandros A. Karamanlidis[1]

[1]*MOm/Hellenic Society for the Study and Protection of the Monk Seal, Solomou Street 18, 10682 Athens, Greece E-mail: akaramanlidis@gmail.com*

[2]*Exotic & Wildlife Medicine Unit, Clinic of Companion Animals, Department of Clinical Studies, Faculty of Health Sciences, School of Veterinary Medicine, Aristotle University of Thessaloniki, 54627 Thessaloniki, Greece*

The complete replacement of degraded fur through shedding or molting is an important aspect of the life history of mammals that can have significant effects on their behavior (Dawson et al., 2000) and, ultimately, determine their individual fitness (Beltran et al., 2018a). In semi-aquatic animals, such as pinnipeds, additional selection pressures apply due to the increased thermal conductivity of their marine habitat. This fact practically separates phocid seals (family Phocidae) that inhabit both polar and non-polar environments from sea lions and fur seals (family Otariidae) that inhabit almost exclusively temperate and tropical environments (Beltran et al., 2018a). Furthermore, partly to offset some of the additional thermoregulatory costs associated with molting, some pinnipeds may move to warmer waters (Boily, 1995), while others may spend more time on land (Carlens et al., 2006). Within the Pinnipedia, members of the tribe Monachini (i.e., northern and southern elephant seals [*Mirounga angustirostris* & *leonina*], and monk seals [*Monachus monachu*s and *Neomonachus* sp.]) hold a unique position as they are the only seals to shed their fur with large sheets of cornified epidermis (Ling, 1970). Information on the molting process is available for some Arctic seals (e.g., spotted seals [*Phoca largha*], ringed seals [*Pusa hispida*], bearded seals [*Erignathus barbatus*]) and is important for conservation and management purposes (Thometz et al., 2021). Despite its importance, however, molting is still poorly understood in many species (Beltran et al., 2018a), including the Mediterranean monk seal (*Monachus monachus*).

The Mediterranean monk seal is the rarest extant species of seal and the only resident pinniped in the Mediterranean Sea. This species has been listed as "Endangered" by the International Union for Conservation of Nature (IUCN), and the global population has been estimated at fewer than 700 individuals (Karamanlidis & Dendrinos, 2015). The largest Mediterranean monk seal subpopulation, currently occupying more than 90% of the species' Area of Occupancy (AOO), occurs mainly around the islands and the coasts of mainland Greece, Turkey, and Cyprus in the eastern Mediterranean Sea (Karamanlidis et al., 2019) and has recently been showing encouraging signs of subpopulation recovery (Nicolaou et al., 2019; Dendrinos et al., 2020). Improving our knowledge of the species' life history, including the chronology of molt (i.e., sequential timing of the main molting events), is essential to understanding the demographic parameters and ecological needs of Mediterranean monk seal populations (Samaranch & González, 2000) and, consequently, for designing and implementing effective conservation measures.

Mediterranean monk seals and their close relatives, Hawaiian monk seals (*Neomonachus schauinslandi*), are known to undergo annual "catastrophic" molts, which involve the rapid, nearly simultaneous shedding of all pelage (Badosa et al., 2006; Robinson et al., 2020). Detailed information on the molting patterns, mainly on the molting phenology of the species, is available only for the Mediterranean monk seal subpopulation at Cabo Blanco in the northern Atlantic (Badosa et al., 1998, 2006; Samaranch & González, 2000). In the subpopulation in Cabo Blanco, the molt chronology from birth to the acquisition of the bull pelage of male Mediterranean monk seals has been documented so far only in one single individual (Badosa et al., 2006). Only circumstantial information exists on the molting patterns of wild (Güçlüsoy & Savaş, 2003) and rehabilitated (Androukaki et al., 2002) monk seals in the eastern Mediterranean subpopulation. Considering the possibility of population-specific differences in the

molting patterns and the existing major differences in basic ecological and demographic parameters between the Mediterranean monk seal subpopulations in Cabo Blanco and the eastern Mediterranean (Karamanlidis et al., 2016), molt information from Cabo Blanco may not apply equally to the eastern Mediterranean population. This note describes for the first time the complete molting chronology of a male Mediterranean monk seal from the eastern Mediterranean subpopulation.

The study involves an orphan male Mediterranean monk seal pup that was found on 14 November 2016 on the Chalkidiki Peninsula in northern Greece and admitted to a dedicated rehabilitation program (Androukaki et al., 2003) on 17 November 2016 at an estimated age of 18 d postpartum. After 121 d of rehabilitation, the pup (code-named "Bill") was released on 18 March 2017 in the National Marine Park of Alonissos, Northern Sporades (NMPANS), a marine protected area dedicated to the protection of the Mediterranean monk seal where human activity is closely monitored (Karamanlidis et al., 2004). Upon release, the seal bore a pair of yellow plastic tags (Temple Tags Inc., Temple, TX, USA) on its hind flippers and an identification microchip. Information on the molt chronology was collected through the Hellenic Monk Seal Rescue and Information Network, a citizen-science project dedicated to recording monk seal presence in Greece (Adamantopoulou et al., 1999). All of the information was collected by citizens, verified by our research team—either on site or using the provided audiovisual material (i.e., photographs and/or video)—and presented using the age classification by Samaranch & González (2000)—that is, (1) *pup* – dependent on the mother, without signs of sexual maturity and growing; (2) *juvenile* – not dependent on the mother, without signs of sexual maturity and growing; (3) *subadult* – growing, some occasionally with signs of sexual maturity; and (4) *adult* – not growing and showing signs of sexual maturity.

Pup

Upon admission to the rehabilitation program, the seal bore the characteristic black lanugo fur of Mediterranean monk seal pups, with the sexually dimorphic patch on the ventral side (Figure 1A). Molt of the lanugo fur started on 2 December 2016 at the age of 33 d postpartum (Figure 1B) and was completed on 13 January 2017 at 75 d postpartum. The first molt started from the back of the head, progressing rapidly around the neck and anterior dorsal body area, followed by the ventral body area, the snout, the fore flippers, and finally the hind flippers. Upon completion of the first molt, the seal had a uniformly grey pelage (Figure 1C).

Juvenile

On 22 August 2017 (Figure 1D) and on 29 April 2018 (Figure 1E), the seal was observed resting and molting on open beaches in the NMPANS; large portions of the pelage, mainly on the dorsal body area of the animal, were brown. These molting events occurred 221 and 250 d after the last-observed molt, respectively. On both observations, the seal still had its yellow flipper tags.

Subadult

On 14 March 2019, 319 d after the last-observed molt, the seal was observed as a subadult resting and molting on an open beach in the NMPANS. Large portions of the pelage, mainly on the dorsal body area of the animal, were brown, and molting had started on the face (Figure 1F). At this time, the seal had lost its yellow flipper tags but was identifiable through distinctive marking (i.e., part of the tail was missing). During the same time period, we also received information of the seal showing signs of sexual maturity when it approached humans exhibiting his erect penis. On 28 April 2020, the seal was observed resting on an open beach with a freshly molted pelage. Based on this observation, we suspect the annual molt to have taken place sometime in March 2020. The seal was observed for the last time in this characteristic grey pelage on 26 October 2020 (Figure 1G).

Adult

Following an interval of 134 d since the last observation, the seal was observed on 9 March 2021 at an age of 4 y and 4 mo (i.e., 1,590 d), bearing the characteristic black pelage of a Mediterranean monk seal bull (Figure 1H). At this point, the white patch of fur on the ventral body area of the seal was very similar to the one it had as a neonatal pup (Figure 2). The milestones of the molting chronology, as established during the study, are presented in Figure 3.

Most aquatic mammals undergo an annual molt (Beltran et al., 2018b). In pinnipeds, molting patterns are affected by numerous factors which, in turn, may result in population-specific (i.e., geographic) differences (Daniel et al., 2003). Despite significant differences in basic population parameters and social behavior between the Mediterranean monk seal subpopulations in Cabo Blanco and the eastern Mediterranean Sea (Karamanlidis et al., 2016), the information recorded regarding the molting chronology between the two subpopulations was very similar in several aspects.

In both subpopulations, the adult pelage was obtained through a process that involved several

Figure 1. Milestones in the development of the adult pelage of a male Mediterranean monk seal (*Monachus monachus*) in Greece, presented in chronological order: (A) neonatal male seal with characteristic lanugo fur (© Dendrinos/MOm), (B) male seal pup undergoing the first molt (© Tounta/MOm), (C) male seal pup having completed the first molt (© Dendrinos/MOm), (D) juvenile male seal undergoing the second molt (© Dendrinos/MOm), (E) juvenile male seal undergoing the third molt (© Schnellmann/MOm), (F) subadult male seal undergoing the fourth molt (© Dendrinos/MOm), (G) subadult male seal with his characteristic greyish pelage (© Koemtzopoulos/MOm), and (H) adult seal bull after the fifth molt (© Ndrevataj/MOm).

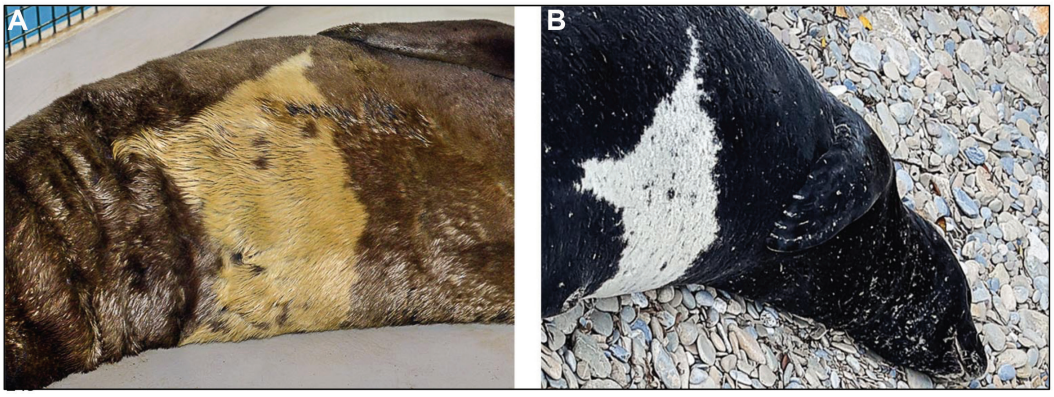

Figure 2. Comparison of the white-yellowish patch of fur on the ventral body area of a male Mediterranean monk seal from the eastern Mediterranean subpopulation: (A) neonatal pup (© Dendrinos/MOm); and (B) adult bull (© Ndrevataj/MOm).

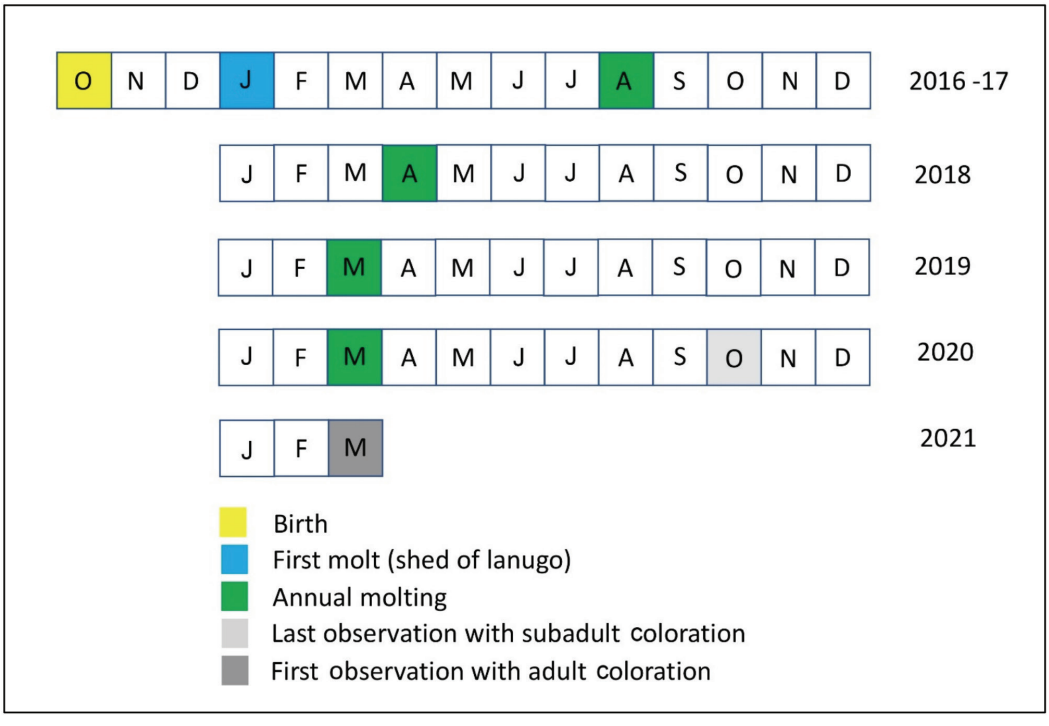

Figure 3. Graphical representation of the milestones in the molting chronology, from birth to the acquisition of the adult pelage, of a male Mediterranean monk seal in Greece

interannual molts (Samaranch & González, 2000), which, in the case of males, generally occurs in March-April (Badosa et al., 2006). During the molt, the pelage turned from grey to brown, and the process was initiated at the head (Badosa et al., 2006). In both subpopulations, the development of the adult pelage and presumably the Attainment of Sexual Maturity (ASM) were observed at approximately the same age (i.e., 1,507 d postpartum in Cabo Blanco vs 1,590 d in Greece). Also, in both subpopulations, there was a noticeable similarity in pelage pattern and coloring between pups and adult males (Samaranch & González, 2000).

However, differences in the molting chronology between the monk seal subpopulations in Cabo Blanco and the eastern Mediterranean were also found. In Cabo Blanco, the process of developing the adult male pelage involved at least two annual molts with a molt interval of approximately 1 y (Badosa et al., 2006). In contrast, in Greece, at least four molts were recorded, with a molt interval of 221 to 365 d. Given the limited amount of available data, we cannot explain these differences. Molt patterns (i.e., chronology and phenology) in seals in general are influenced by a number of factors such as sex and reproductive status (Daniel et al., 2003), photoperiod, temperature (Mo et al., 2000), and body condition (Young & Ferguson, 2013).

The molting chronology of male Mediterranean monk seals has now been described for only a single individual in both the subpopulations of Cabo Blanco and the eastern Mediterranean. Further research is necessary to understand this biological aspect of the species; however, even this limited chronological information can be useful for the management and conservation of the species. For example, the ASM (which, in the case of the Mediterranean monk seal is closely linked with the development of the adult pelage; Samaranch & González, 2000) is a key factor in successful population modeling (Gazo et al., 2000) and may serve as an index in population management (Fowler & Siniff, 1992). Given the information obtained in this study, the ASM of > 4 y used by Martínez-Jauregui et al. (2012) in their study in the Cabo Blanco subpopulation should be used in similar studies in Greece.

Mediterranean monk seals spend a considerable amount of time on land during molting. Also, their population in Greece has been showing encouraging signs of partial recovery (Dendrinos et al., 2020). As part of this recovery, several monk seals, both rehabilitated and wild, have been seen resting and molting on open beaches and close to human settlements. Therefore, information on the molting chronology should aid management decisions in cases of adult males reported on land and falsely believed to require medical assistance.

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Literature Cited

Adamantopoulou, S., Androukaki, E., & Kotomatas, S. (1999). The distribution of the Mediterranean monk seal in Greece based on an information network. *Contributions to the Zoogeography and Ecology of the Eastern Mediterranean Region*, *1*, 399-404.

Androukaki, E., Fatsea, E., t' Hart, L., Osterhaus, A. D. M. E., Tounta, E., & Kotomatas, S. (2002). Growth and development of Mediterranean monk seal pups during rehabilitation. *The Monachus Guardian*, *5*(1), 43-46.

Androukaki, E., Fatsea, E., 't Hart, L., Osterhaus, A. D. M. E., Tounta, E., & Komnenou, N. (2003). Treating stranded Mediterranean monk seal pups in Greece. *15th Biennial Conference on the Biology of Marine Mammals*, Greensboro, NC.

Badosa, E., Pastor, T., Gazo, M., & Aguilar, A. (2006). Moult in the Mediterranean monk seal from Cap Blanc, western Sahara. *African Zoology*, *41*(2), 183-192. https://doi.org/10.1080/15627020.2006.11407354

Badosa, E., Grau, E., Aparicio, F., Layna, J. F., & Cedenilla, M. A. (1998). Individual variation and sexual dimorphism of coloration in Mediterranean monk seal pups (*Monachus monachus*). *Marine Mammal Science*, *14*(2), 390-393. https://doi.org/10.1111/j.1748-7692.1998.tb00732.x

Beltran, R. S., Burns, J. M., & Breed, G. A. (2018a). Convergence of biannual moulting strategies across birds and mammals. *Proceedings of the Royal Society B: Biological Sciences*, *285*(1878), 20180318. https://doi.org10.1098/rspb.2018.0318

Beltran, R. S., Ruscher-Hill, B., Kirkham, A. L., & Burns, J. M. (2018b). An evaluation of three-dimensional photogrammetric and morphometric techniques for estimating volume and mass in Weddell seals *Leptonychotes weddellii*. *PLOS ONE*, *13*(1), e0189865. https://doi.org/10.1371/journal.pone.0189865

Boily, P. (1995). Theoretical heat-flux in water and habitat selection of phocid seals and beluga whales during the annual molt. *Journal of Theoretical Biology*, *172*(3), 235-244.

Carlens, H., Lydersen, C., Krafft, B. A., & Kovacs, K. M. (2006). Spring haul-out behavior of ringed seals (*Pusa hispida*) in Kongsfjorden, Svalbard. *Marine Mammal Science*, *22*(2), 379-393. https://doi.org/10.1111/j.1748-7692.2006.00034.x

Daniel, R. G., Jemison, L. A., Pendleton, G. W., & Crowley, S. M. (2003). Molting phenology of harbor seals on Tugidak Island, Alaska. *Marine Mammal Science*, *19*(1), 128-140. https://doi.org/10.1111/j.1748-7692.2003.tb01097.x

Dawson, T. J., Blaney, C. E., Munn, A. J., Krockenberger, A., & Maloney, S. K. (2000). Thermoregulation by kangaroos from mesic and arid habitats: Influence of temperature on routes of heat loss in eastern grey kangaroos (*Macropus giganteus*) and red kangaroos (*Macropus rufus*). *Physiological and Biochemical Zoology*, *73*(3), 374-381. https://doi.org/10.1086/316751

Dendrinos, P., Karamanlidis, A. A., Adamantopoulou, S., Koemtzopoulos, K., Komnenou, A., & Tounta, E. (2020). *LIFE-IP 4 NATURA: Integrated actions for the conservation and management of Natura 2000 sites, species, habitats and ecosystems in Greece. Deliverable Action A.1: Action Plan for the Mediterranean monk seal (*Monachus monachus*)*. Hellenic Ministry of Environment and Energy. 105 pp.; Annexes, 12 pp.

Fowler, C. W., & Siniff, D. B. (1992). Determining population status and the use of biological indices in the management of marine mammals. In D. R. McCullough & R. H. Barrett (Eds.), *Wildlife 2001: Populations* (pp. 1025-1037). Springer. https://doi.org/10.1007/978-94-011-2868-1_78

Gazo, M., González, L. M., & Grau, E. (2000). Age at first parturition in Mediterranean monk seal monitored long-term. *Marine Mammal Science*, *16*(1), 257-260. https://doi.org/10.1111/j.1748-7692.2000.tb00919.x

Güçlüsoy, H., & Savaş, Y. (2003). Status of the Mediterranean monk seal (*Monachus monachus*) in the Foça Pilot Monk Seal Conservation area, Turkey. *Zoology in the Middle East*, *28*(1), 5-16. https://doi.org/10.1080/09397140.2003.10637951

Karamanlidis, A. A., & Dendrinos, P. (2015). *Monachus monachus*. In International Union for Conservation of Nature (Ed.), *The IUCN red list of threatened species 2015: e.T13653A45227543*. IUCN.

Karamanlidis, A. A., Adamantopoulou, S., Tounta, E., & Dendrinos, P. (2019). *Monachus monachus* eastern Mediterranean subpopulation. In International Union for Conservation of Nature (Ed.), *The IUCN red list of threatened species 2019: e.T120868935A120869697*. IUCN.

Karamanlidis, A. A., Dendrinos, P., Tounta, E., & Kotomatas, S. (2004). Monitoring human activity in an area dedicated to the protection of the endangered Mediterranean monk seal. *Coastal Management*, *32*(3), 293-306. https://doi.org/10.1080/08920750490448523

Karamanlidis, A. A., Dendrinos, P., Fernández de Larrinoa, P., Gücü, A. C., Johnson, W. M., Kiraç, C. O., & Pires, R. (2016). The Mediterranean monk seal *Monachus monachus*: Status, biology, threats, and conservation priorities. *Mammal Review*, *46*(2), 92-105. https://doi.org/10.1111/mam.12053

Ling, J. K. (1970). Pelage and molting in wild mammals with special reference to aquatic forms. *Quarterly Review of Biology*, *45*(1), 16-54. https://doi.org/10.1086/406361

Martínez-Jauregui, M., Tavecchia, G., Cedenilla, M. A., Coulson, T., Fernández de Larrinoa, P., Muñoz, M., & González, L. M. (2012). Population resilience of the Mediterranean monk seal *Monachus monachus* at Cabo Blanco peninsula. *Marine Ecology Progress Series*, *461*, 273-281. https://doi.org/10.3354/meps09811

Mo, G. L., Gili, C., & Ferrando, P. (2000). Do photoperiod and temperature influence the molt cycle of *Phoca vitulina* in captivity? *Marine Mammal Science*, *16*(3), 570-577. https://doi.org/10.1111/j.1748-7692.2000.tb00952.x

Nicolaou, H., Dendrinos, P., Marcou, M., Michaelides, S., & Karamanlidis, A. A. (2019). Re-establishment of the Mediterranean monk seal *Monachus monachus* in Cyprus: Priorities for conservation. *Oryx*, *55*(4), 526-528. https://doi.org/10.1017/S0030605319000759

Robinson, S. J., Harting, A. L., Mercer, T., Johanos, T. C., Baker, J. D., & Littnan, C. L. (2020). Sighting patterns reveal unobserved pupping events to revise reproductive rate estimates for Hawaiian monk seals in the main Hawaiian Islands. *Marine Mammal Science*, *37*(2), 420-432. https://doi.org/10.1111/mms.12761

Samaranch, R., & González, L. M. (2000). Changes in morphology with age in Mediterranean monk seals (*Monachus monachus*). *Marine Mammal Science*, *16*(1), 141-157. https://doi.org/10.1111/j.1748-7692.2000.tb00909.x

Thometz, N. M., Hermann-Sorensen, H., Russell, B., Rosen, D. A. S., & Reichmuth, C. (2021). Molting strategies of Arctic seals drive annual patterns in metabolism. *Conservation Physiology*, *9*(1), coaa112. https://doi.org/10.1093/conphys/coaa112

Young, B. G., & Ferguson, S. H. (2013). Seasons of the ringed seal: Pelagic open-water hyperphagy, benthic feeding over winter and spring fasting during molt. *Wildlife Research*, *40*(1), 52-60. https://doi.org/10.1071/WR12168