Using 'pup multipliers' to estimate demographic parameters of Mediterranean monk seals in the eastern Mediterranean Sea

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ABSTRACT: A thorough understanding of population demographics is important in planning and evaluating conservation actions. At the same time, it is also essential that conservation management strives to minimize uncertainty in decision making in order to avoid management errors, which in the case of endangered species might affect their persistence. Mediterranean monk seals are endangered and have been notoriously difficult to count, especially in the eastern Mediterranean Sea, where abundance estimates have relied mainly on expert judgement. To address this problem, a new approach to estimating the species' demographics using 'pup multipliers' is introduced. Adopting a conservative and a more optimistic approach and following a review of the available species- and taxa-specific data, the following multipliers were proposed: 2.5—3.5 for estimating the number of mature individuals, and 4.5—6.0 for estimating the total number of individuals. These multipliers were then used to calculate, in a formal way, the population demographics of the Mediterranean monk seal in the eastern Mediterranean Sea and globally. In their current form, the pup multipliers proposed present a number of strengths, but also several caveats, limitations and/or points of concern and should therefore not be considered a panacea in the conservation of the species, but merely the starting point of efforts for further development. These efforts should ultimately aim at developing a population-specific pup multiplier for the Mediterranean monk seal that is based on a common monitoring approach between various countries and includes the collection of newborn pup count data from across the species' range in the eastern Mediterranean Sea.

KEY WORDS: *Monachus monachus* · Pinnipeds · Conservation · Endangered species · Population estimates · Total abundance

1. INTRODUCTION

Thoroughly understanding population demographics is of utmost importance in planning (Chapron et al. 2003) and evaluating conservation actions (Demerdzhiev et al. 2015). At the same time, it is also essential that conservation management strives to minimize uncertainty in decision making (Regan et al. 2005, Horswill et al. preprint doi:10.1101/2021.07.01.450685) in order to avoid, as much as possible, management errors, which in the case of endangered species might affect their persistence (Ceriani et al.

2021). Among the numerous demographic parameters monitored in wildlife populations that are of special importance to conservationists and stakeholders are the number of mature individuals (Mace et al. 2008) and the total population size (Morgan 1999), as they are directly associated with species persistence.

Assessing the number of mature individuals and the total population size has been an integral and important part of the management and conservation of seals (Pinnipedia). Various methodologies have been used to estimate these basic demographic parameters, in-

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cluding, for example, counts of hauled-out animals (Brasseur et al. 2015) and photoidentification and tagging (Forcada & Robinson 2006). However, thoroughly understanding population demography and how it is affected by numerous biological parameters based on such methodologies is not always straightforward, because seals spend considerable time at sea (i.e. out of sight or reach), where they might not be counted. To address this difficulty, conservationists have often estimated total abundance and pup production, in both otariids and phocids (Duck & Thompson 2007, Chilvers 2021) and then used these parameters to define 'pup multipliers' (i.e. ratio of total population numbers to the number of pups; Russell et al. 2019). Harwood & Prime (1978) originally suggested that a ratio between 3.5:1 and 4.5:1 would be appropriate for estimating the total size of increasing populations of most polygynous pinnipeds; however, since then, our understanding of the assumptions and the data behind the development of pup multipliers has improved, and several species-specific multipliers have been developed and used in the management and conservation of seals (see reference list in Table 1).

The Mediterranean monk seal *Monachus monachus* is one of the most endangered seals on Earth and an 'evolutionarily distinct and globally endangered' mammal (Isaac et al. 2007); following a notable recovery in the last 2 decades, the species was listed in 2023 on the Red List of the International Union for Conservation of Nature (IUCN) as Vulnerable (Karamanlidis et al. 2023). Mediterranean monk seals survive currently in 3 subpopulations in the northeastern Atlantic Ocean and the eastern Mediterranean Sea (Karamanlidis 2024). In the Atlantic Ocean, the species has disappeared from most of its original range and survives only along a small stretch of coastline at the Cabo Blanco peninsula (Mauritania/Western Sahara) and in the archipelago of Madeira (Portugal). Systematic, standardized photoidentification studies carried out in the most important pupping and resting sites (i.e. marine caves) in the region have resulted in detailed, reliable demographic data (Karamanlidis 2024). These indicate that both subpopulations are recovering, but also that they suffer from low pup survival rates (Fernández de Larrinoa et al. 2021, Pires et al. 2023); joint analysis of the available photoidentification and telemetry data (Fernández de Larrinoa et al. 2021, Pires et al. 2023) and genetic data (Rey-Iglesia et al. 2021) suggest furthermore that these 2 subpopulations are isolated from each other. Our understanding of the demographic and the overall conservation status of the Mediterranean monk seal in the northeastern Atlantic Ocean is considered good (Karamanlidis 2024).

In the eastern Mediterranean Sea (i.e. mainly in Albania, Greece, Türkiye and Cyprus), systematic monitoring efforts, including photoidentification studies similar to the ones in the Atlantic Ocean, have been carried out throughout the range of the species (e.g. Greece: Bundone & Panou 2022; Türkiye: Gülce et al. 2014; Cyprus: Nicolaou et al. 2019). However, despite these efforts, actual seal numbers in the region remain largely unknown (Panou et al. 2023) and are still based primarily on expert judgement (Karamanlidis et al. 2019). Some of the reasons why photoidentification efforts in the eastern Mediterranean Sea have been less successful than in the Atlantic Ocean include:

• The high number of marine caves potentially available and actually used by Mediterranean monk seals in the region makes systematic photoidentification studies logistically challenging. For example, due to the distinct morphological characteristics of its coastline, Greece alone has >7500 islands and islets (Triantis & Mylonas 2009) and countless marine caves are potentially available to the species. Currently the terrestrial habitat of the Mediterranean monk seal in Greece comprises more than 500 and 100 marine caves that have been documented to have been used for resting and pupping respectively. Similarly, the terrestrial habitat of the Mediterranean monk seal in Albania, Türkiye and Cyprus includes numerous marine caves all along their coastlines (Karamanlidis 2024).

• Some of the most suitable caves for Mediterranean monk seals in the region are not frequented by the species because of increased human pressure (Kıraç & Savaş 2019). In addition, some individuals in the eastern Mediterranean monk seal subpopulation do not use the main pupping and resting caves, which are often prioritized for photoidentification studies, anyway. These individuals may include adult males that use the main pupping and resting caves less frequently during the pupping season or adult females that move out of the main pupping sites in order to reduce intra-specific competition (Karamanlidis 2024). The fact that Mediterranean monk seals have been recently recorded in Greece to rest at sea complicates matters further (Karamanlidis et al. 2017).

• Mediterranean monk seals in the eastern Mediterranean Sea have been showing a notable recovery recently, which has manifested itself in the increase of the extent of the terrestrial habitat used (Panou et al. 2022) and the subsequent increase in the range of the species (Adamantopoulou et al. 2022). During this recovery, seals in the region have been recorded

using also 'suboptimal habitat' (i.e. caves with underwater entrances and/or no resting surface) (Karamanlidis 2024), which are difficult to monitor, or open beaches (Dendrinos et al. 2022), which are difficult to identify because of their high number (i.e. Greece has >16 000 km of coastline with countless open beaches).

• Mediterranean monk seals in the eastern Mediterranean Sea move extensively between the coastal waters of several countries (Karamanlidis 2024), which may result in double counting, if monitoring efforts are not coordinated.

Taking into account these limitations, it is easy to understand why estimating the demographic parameters for the Mediterranean monk seal subpopulation in the eastern Mediterranean Sea or even on a national level is considered an extremely difficult (and inexact) task (Kurt & Gücü 2021, Pietroluongo et al. 2022). Because of the general lack of detailed demographic data, our understanding of the conservation status of the Mediterranean monk seal subpopulation in the eastern Mediterranean Sea is considered less detailed than that of the subpopulations in the Atlantic Ocean (Karamanlidis 2024), which in turn might impede the development of coherent conservation and management strategies for the species in the region (Baylis et al. 2019). Considering furthermore that the aforementioned limitations of photo-identification studies in the eastern Mediterranean Sea are not likely to be overcome soon, the development of an alternative way to estimate the basic demographic parameters for the Mediterranean monk seal in the eastern Mediterranean Sea would be beneficial for the overall management and conservation of the species.

The aims of the study were (1) to propose pup multipliers for the Mediterranean monk seal that could be used to estimate the number of mature (termed 'mature multiplier') and the total number of individuals in a given management unit (termed 'total population multiplier') in the eastern Mediterranean Sea, and (2) use these multipliers to estimate in a formal way the basic demographic parameters of the eastern Mediterranean subpopulation and the global population of the Mediterranean monk seal.

2. METHODS

Pup multipliers for the Mediterranean monk seal in the eastern Mediterranean were proposed following (1) a review of relevant information and the inference of the respective multipliers based on data from the Mediterranean monk seal subpopulations in the Cabo Blanco and the archipelago of Madeira, and select reproductive nuclei in Greece for which relevant data were available (i.e. at the islet of Astakida and the island of Gyaros in the Aegean Sea); and (2) a thorough review of the scientific literature in order to identify, infer and/or summarize pup multipliers used in the monitoring, management and conservation of other seal species.

Taking into account the overall limited understanding of the species' demographics in the eastern Mediterranean Sea and in order to address as many demographic scenarios and population trajectories as possible (i.e. from decreasing to increasing populations), 2 multipliers were arbitrarily proposed for each demographic parameter: 1 multiplier following a conservative approach that should be considered the minimum estimate, and 1 multiplier following a more optimistic approach that should be considered the maximum estimate of each demographic parameter respectively.

The proposed pup multipliers were then used in the calculation of the number of mature and the total number of Mediterranean monk seals in the range countries of the species in the eastern Mediterranean Sea and globally. When calculating the demographics of Mediterranean monk seals in the eastern Mediterranean Sea, the IUCN Criteria were applied (IUCN Standards and Petitions Committee 2022), and a remainder population was added to include all the individuals that are currently not covered by systematic monitoring efforts. It should be noted that because of irregular pupping, Albania has been included in this group. The demographic parameters of this remainder population were determined also arbitrarily following a conservative approach.

3. RESULTS

The results of the review of the scientific literature and of the inferences of pup multipliers to estimate the number of mature and the total number of Mediterranean monk seals in the eastern Mediterranean Sea are presented in Table 1.

Mature multipliers ranged between 2.00 and 3.71 in select subpopulations and reproductive nuclei of the Mediterranean monk seal and between 1.45 and 3.53 in phocids and otariids. Total population multipliers ranged between 3.00 and 7.71 in select subpopulations and reproductive nuclei of the Mediterranean monk seal, and between 3.50 and 6.75 and between 3.16 and 5.59 in phocids and otariids, respectively

Table 1. Pup multipliers for various pinniped species and some of their subpopulations/reproductive nuclei. N_{mature}: number of mature individuals; N_{total}: total number of individuals; N_{pup}: mean number of pups born annually

Species	N_{mature}	N_{total}	N_{pup}	Mature multiplier	Total population multiplier	Reference
Phocidae						
Mediterranean monk seal *Monachus monachus*						
Archipelago of Madeira	13	27	3.5	3.71	7.71	Pires et al. (2023); R. Pires (pers. comm.) and Instituto das Florestas e Conservação da Natureza (IFCN) (unpubl. data) in Karamanlidis et al. (2023)
Cabo Blanco	184	350	70	2.63	5.00	Fernández de Larrinoa et al. (2021); Fernandez de Larrinoa (pers. comm.) and CBD Habitat (unpubl. data) in Karamanlidis et al. (2023)
Astakida	12	18	6	2.00	3.00	MOm (2008)[a]
Gyaros	18		8	2.25		Karamanlidis & Dendrinos (2012)[a]
Baikal seal *Pusa sibirica*		131800	23600		5.58	Goodman (2016)
Grey seal *Halichoerus grypus*					3.50–5.40	Hewer (1964), Mansfield & Beck (1977), Stobo & Zwanenburg (1990), Haug et al. (1994), Hammill et al. (1998), Hauksson (2007), Nilssen & Haug (2007)
Harp seal *Pagophilus groenlandicus*		6800000	1039000		6.54	Hammill et al. (2021)
Hawaiian monk seal *Neomonachus schauinslandi*	632	1209	179	3.53	6.75	Littnan et al. (2015), J. Baker (pers. comm.) in Karamanlidis et al. (2023)
Otaridae						
Antarctic fur seal *Arctocephalus gazella*					4.10	Payne (1979), Page et al. (2003)
Australian fur seal *A. pusillus doriferus*					3.95–4.50	Goldsworthy et al. (2003), Kirkwood et al. (2005, 2010), Gibbens & Arnould (2009)
Australian sea lion *Neophoca cinerea*					3.8–4.8	Gales et al. (1994), Goldsworthy & Page (2007), Goldsworthy et al. (2010)
California sea lion *Zalophus californianus*					4.32–5.59	Carretta et al. (2016), Laake et al. (2018)
Guadalupe fur seal *A. townsendi*					4.5	Hernández-Camacho & Trites (2018)
New Zealand fur seal *A. forsteri*					4.76–4.90	Taylor (1982), Shaughnessy et al. (1997), Goldsworthy & Page (2007), Chilvers (2021)
New Zealand sea lion *Phocarctos hookeri*	3031		2084	1.45	4.40–5.08	Gales & Fletcher (1999), Chilvers (2015), Chilvers & Meyer (2017), Hamilton & Baker (2019)
Northern elephant seal *Mirounga angustirostris*					4.40	Lowry et al. (2014)
Northern fur seal *Callorhinus ursinus*					4.47	Muto et al. (2022)
South African fur seal *A. pusillus pusillus*					4.77–5.40	Butterworth et al. (1988), Butterworth & Wickens (1990), Wickens & Shelton (1992)
South American fur seal *A. australis*					3.16–4.97	Baylis et al. (2019)
Steller sea lion *Eumetopias jubatus*					4.20–5.20	Calkins & Pitcher (1982), Trites & Larkin (1996), Pitcher et al. (2007)

[a]Unpublished reports. See footnotes 1 & 2 in text

(Table 1). Based on these results, the following pup multipliers were arbitrarily proposed:

• Mature multipliers recorded for the Mediterranean monk seal were similar to mature multipliers inferred in 2 other seal species, i.e. the closest relative of the Mediterranean monk seal, the Hawaiian monk seal and the New Zealand sea lion, that have population trajectories that are very similar to that of the Mediterranean monk seal (Chilvers 2015, Littnan et

al. 2015). We consider the mature multipliers inferred for the reproductive nuclei in Astakida and Gyaros in Greece and in the subpopulation in the archipelago of Madeira not to be representative of the situation throughout the eastern Mediterranean Sea. The multipliers in the reproductive nuclei in Astakida and Gyaros, according to unpublished reports by MOm[1] and Karamanlidis & Dendrinos[2], respectively, are likely underestimates, because a part of the popula-

Table 2. Estimates of mature individuals and total population size of Mediterranean monk seals in the eastern Mediterranean Sea using the proposed pup multipliers. A: minimum estimate of total N of mature individuals; B: maximum estimate of total N of mature individuals; C: minimum estimate of total N of individuals; D: maximum estimate of total N of individuals

Country	N_{pup}	A	B	C	D	Data source of N_{pup}
Greece	75	187	262	337	450	Karamanlidis & Dendrinos (2023); MOm (unpubl. data) in Karamanlidis et al. (2023)
Türkiye	17	42	59	76	102	M. Ok & C. O. Kiraç (pers. comm.) and SAD-AFAG (unpubl. data) in Karamanlidis et al. (2023)
Cyprus	3	7	10	13	18	H. Nicolaou (pers. comm.); Department of Fisheries and Marine Research Cyprus (unpubl. data) in Karamanlidis et al. (2023)
Remainder	2	10	10	12	12	Present study
Total	97	246	341	438	582	

Table 3. Global estimates of mature individuals and population size of the Mediterranean monk seal using the proposed pup multipliers. A: minimum estimate of total N of mature individuals; B: maximum estimate of total N of mature individuals; C: minimum estimate of total N of individuals; D: maximum estimate of total N of individuals

Subpopulation	N_{pup}	A	B	C	D	Data source
Madeira	3.5	13	13	27	27	Pires et al. (2023); R. Pires (pers. comm.) and IFCN (unpubl. data) in Karamanlidis et al. (2023)
Cabo Blanco	70	184	184	350	350	Fernández de Larrinoa et al. (2021); Fernández de Larrinoa (pers. comm.) and CBD Habitat (unpubl. data) in Karamanlidis et al. (2023)
Eastern Mediterranean	97	246	341	438	582	Present study
Total	170.5	443	538	815	959	

tion (i.e. adult males) did not frequent the reproductive caves monitored, whereas the multiplier in the subpopulation in the archipelago of Madeira is likely an overestimate that is related to the current demographic situation of the species in the region (i.e. very low pup survival, very low reproductive rates; Pires et al. 2023). The mature multiplier inferred for the recovering Mediterranean monk seal subpopulation in Cabo Blanco (which has the most robust dataset) is the one most likely to reflect the actual situation throughout the eastern Mediterranean Sea. Considering the previous, a conservative mature multiplier of 2.5 is proposed, which is even lower than the one calculated for the subpopulation in Cabo Blanco (i.e.

2.63); the more optimistic mature multiplier is set at 3.5.

• Total population multipliers recorded for the Mediterranean monk seal were similar to the multipliers recorded in other pinnipeds, with the exception of the multiplier for the archipelago of Madeira. As in the case of the mature multiplier, the total population multiplier inferred for the archipelago of Madeira is likely an outlier, and the respective multiplier for the subpopulation in Cabo Blanco should be considered the one that most likely reflects the current demographic situation in the eastern Mediterranean Sea. Considering the previous, a conservative total population multiplier of 4.5 is proposed, which is even lower than the one inferred for the Mediterranean monk seal subpopulation in Cabo Blanco (i.e. 5.0); the more optimistic total population multiplier is set at 6.0.

Using the multipliers proposed in the previous step (i.e. mature multiplier: 2.5—3.5; total population multiplier: 4.5—6.0), the basic demographic parameters of the Mediterranean monk seal subpopulation in the eastern Mediterranean and in the global population of the species were calculated. These calculations resulted in a total estimate of 438—582 (including 246—341 mature individuals) (Table 2) and 815—959

[1]MOm (2008) Unpublished final report on the monitoring of the status of the population of the monk seal, in Karpathos and Saria. MOm/Hellenic Society for the Study and Protection of the Monk Seal, Athens

[2]Karamanlidis AA, Dendrinos D (2012) A glimpse into the past, a prospect for the future: studying the status and behavior and promoting conservation of Mediterranean monk seals at the island of Gyaros. Unpublished final report to the National Geographic Grant #W178-11. MOm/Hellenic Society for the Study and Protection of the Monk Seal, Athens

(including 443–538 mature individuals) (Table 3) for the eastern Mediterranean and the global population of the Mediterranean monk seal respectively.

4. DISCUSSION

Mediterranean monk seals have been recently making a notable recovery that has created a new conservation reality for the species (Karamanlidis 2024), which requires reliable demographic data in order to plan and evaluate management and conservation actions. The present study introduces a new approach to estimating basic demographic parameters of the Mediterranean monk seal in the eastern Mediterranean Sea using arbitrarily proposed pup multipliers.

The pup multipliers have been proposed considering data from other subpopulations of the species, but also data from other pinnipeds. Considering data from other seal species has been necessary, especially in cases, such as in the Mediterranean monk seal, where detailed demographic data are missing (e.g. Trites & Larkin 1996, Lowry et al. 2014, Punt et al. 2020). While caution is generally needed when using multipliers that are not species-specific (Frie et al. 2012), in the case of the Mediterranean monk seal it is not unreasonable to consider multipliers from other species and/or taxa, even from otariids, since Mediterranean monk seals exhibit a maternal care system and population structure that lies between the phocid and otariid patterns, perhaps being closer to the latter (Pastor et al. 2011).

While proposing these Mediterranean monk seal-specific pup multipliers, it is acknowledged that, in their present form, they have certain caveats, limitations and/or points of concern, including:

• Extrapolating from pups to total population and creating pup multipliers requires the calculation of life tables (Pitcher et al. 2007, Lowry et al. 2014) that need detailed information on demographic parameters (e.g. age-specific survival and fecundity rates) that should be representative of the population to which the pup counts are being extrapolated (Russell et al. 2019). Such information is not available yet for the Mediterranean monk seal in the eastern Mediterranean Sea.

• Pup counts can be good indicators of abundance in populations with stable age distributions. If age distributions are shifting due to ecosystem changes or other factors, pup counts will not be a good indicator until the population reaches a new stable age distribution (Berkson & DeMaster 1985). In the case of the Mediterranean monk seal in the eastern Mediterran-

ean Sea, too little information is available on the age distribution in order to evaluate if and how the proposed pup multipliers might be affected. Unstable age distribution might have been an issue for the Mediterranean monk seal subpopulation in Cabo Blanco during the mass die-off in 1997, when a rapid change (i.e. within a couple of months almost two-thirds of the adult population died) in demographic parameters took place. However, as this subpopulation has now recovered to its pre mass die-off levels (Fernández de Larrinoa et al. 2021), there is little reason to suspect such an effect in this subpopulation. We speculate that the same applies to the subpopulation in the eastern Mediterranean, but extensive research is still necessary in order to verify this assumption.

• Changes in population demography and exchanges with other populations nearby might affect the number of animals present in a way which is not deducible from pup counts alone (Härkönen & Harding 2001). While this is not a major issue in the isolated Mediterranean monk seal subpopulations in the archipelago of Madeira and Cabo Blanco, it should be considered a problem in the eastern Mediterranean, where evidence from genetic (Karamanlidis et al. 2021b) and photoidentification efforts indicates that mature Mediterranean monk seals move extensively throughout the region (Karamanlidis 2024).

On the other hand, counting pups and using pup multipliers as an approach to estimate basic demographic parameters of Mediterranean monk seals in the eastern Mediterranean Sea also has several strengths, including:

• Newborn pups (i.e. pups until approximately the age of 2 mo that have not undergone the first molt) are the easiest age class in Mediterranean monk seals to count: newborn pups spend the most time of all age classes on land (Karamanlidis et al. 2021a), at the easiest-to-predict locations (i.e. pupping caves; Dendrinos et al. 2007) and are among the easiest to identify because of their unique, external appearance (i.e. sexually dimorphic patch on the ventral side; Samaranch & González 2000). All these facts, in combination with the limited mobility of newborn pups, reduce significantly the possibilities of double-counting individuals in geographically overlapping population nuclei, while reducing at the same time monitoring and logistic efforts.

• In contrast to photoidentification studies aiming at monitoring the adult segment of a population that need to be carried out year-round in order to be accurate, counting newborn pups in the eastern Mediterranean can focus on the pupping season, which

extends mainly during the months September—December (Karamanlidis 2024), thus, reducing considerably monitoring and logistic efforts.

• When using pup multipliers, one should always keep in mind that the maximum number of pups counted during a survey is always an underestimate of the total annual pup production. At the time of a survey, some pups are yet to be born, while others are not counted, as they may have already left the colony, or died (Boveng et al. 1998). In the case of the Mediterranean monk seal, monitoring efforts throughout the range of the species have tried to minimize this error in order to obtain an unbiased estimate of total pup production, by carrying out multiple field surveys to the main pupping sites throughout the entire pupping season, combined with the deployment of camera traps and photoidentification techniques (for similar adaptations in monitoring techniques, see Russell et al. 2019). Compared to other pinnipeds, the number of newborn Mediterranean monk seal pups going undetected in closely monitored populations should be considered small.

Considering the caveats, limitations and/or points of concern, but also their strengths, the proposed pup multipliers should not be considered, in their present form, a panacea for Mediterranean monk seal management and conservation, but merely a starting point for further research and improvement.

In contrast to the archipelago of Madeira (Pires et al. 2023) and Cabo Blanco (Forcada & Aguilar 2000, Martínez-Jauregui et al. 2012, Fernández de Larrinoa et al. 2021), Mediterranean monk seals in the eastern Mediterranean Sea have been notoriously difficult to count. Population estimates in the region have been based primarily on expert judgement (Karamanlidis et al. 2019) that relied on data of questionable quality, which has led previously to false predictions of the species' trajectory (Goedicke 1981). The development of pup multipliers for the Mediterranean monk seal subpopulation in the eastern Mediterranean Sea, although necessary to be treated with caution, is the first step in estimating in a formal way Mediterranean monk seal population demographics in the region.

The demographic parameters calculated in the present study show some notable differences from the demographic parameters currently associated with the species. More specifically, the number of mature individuals estimated in the eastern Mediterranean Sea (i.e. 246—341) is slightly higher than the number of mature individuals estimated during the last assessment of the conservation status of the eastern Mediterranean subpopulation of the species by the IUCN (i.e. 187—240; Karamanlidis et al. 2019). It is

also slightly higher than the cut-off value of 250 mature individuals of criterion D (IUCN Standards and Petitions Committee 2022), by which the Mediterranean monk seal subpopulation in the region was listed as Endangered. This fact might warrant a reassessment of the conservation status of the Mediterranean monk seal subpopulation in the eastern Mediterranean Sea. Similarly, the global estimate of mature individuals of the present study (i.e. 443—538) is higher than the number of mature individuals estimated during the previous global assessment of the Mediterranean monk seal by the IUCN (i.e. 350—450; Karamanlidis & Dendrinos 2015). Furthermore, the demographic parameters of the study for Türkiye differ from the ones used to evaluate the species in the current global assessment (Karamanlidis et al. 2023); the reason for this is that population demographics for the species in Türkiye in the current global IUCN species assessment are based on a combination of expert judgement and the use of the pup multipliers (Karamanlidis 2024), which slightly increased estimates. Finally, the global abundance estimate of the study is considerably higher than the total population estimate often associated with the species currently (i.e. 600—700 individuals; e.g. Pietroluongo et al. 2022, Panou et al. 2023). Even by this new estimate, with a global population of <1000 individuals, the Mediterranean monk seal should be considered, by population size standards, the most endangered seal species on Earth.

5. CONCLUSIONS

Quantifying trends in the abundance of animal populations is a central tenet in ecology that underpins animal management and conservation (Caughley & Gunn 1996). The conservation and management implications of the present study are profound: the pup multipliers proposed in the study provide for the first time a formal way to estimate basic demographic parameters of Mediterranean monk seals in the eastern Mediterranean Sea. The use of the study's multipliers is understandably very general, particularly considering that multipliers vary according to (sub)population growth rate (Lalas & Bradshaw 2001), and the fact that the proposed multipliers have been proposed based on data from other seals and other Mediterranean monk seal subpopulations. They should be considered therefore merely a starting point of efforts for further improving this monitoring approach. These efforts should include a formal assessment of the accuracy of the proposed multipliers using demographic data

from the Cabo Blanco Mediterranean monk seal sub-population (Lowry et al. 2014), while collecting at the same time the necessary population-specific data. The efforts should ultimately aim at establishing a robust (i.e. standardized) monitoring approach that includes coordination between various research groups and countries and the collection of newborn pup count data across the species' range in the eastern Mediterranean Sea (Pitcher et al. 2007).

LITERATURE CITED

Adamantopoulou S, Karamanlidis AA, Dendrinos D, Olivier J (2022) Citizen science indicates significant range recovery and defines new conservation priorities for Earth's most endangered pinniped in Greece. Anim Conserv 26: 115–125

Baylis AM, Orben RA, Arkhipkin AA, Barton J, Brownell RL Jr, Staniland IJ, Brickle P (2019) Re-evaluating the population size of South American fur seals and conservation implications. Aquat Conserv 29:1988–1995

Berkson JM, DeMaster DP (1985) Use of pup counts in indexing population changes in pinnipeds. Can J Fish Aquat Sci 42:873–879

Boveng PL, Hiruki LM, Schwartz MK, Bengtson JL (1998) Population growth of Antarctic fur seals: limitation by a top predator, the leopard seal? Ecology 79:2863–2877

Brasseur SM, van Polanen Petel TD, Gerrodette T, Meesters EH, Reijnders PJ, Aarts G (2015) Rapid recovery of Dutch gray seal colonies fueled by immigration. Mar Mamm Sci 31:405–426

Bundone L, Panou A (2022) Improvement of knowledge on the Mediterranean monk seal sub-population in the central Ionian Sea, Greece, using photo-identification. In: Marine mammal research and conservation effort — Are we on the right path? Proc 33rd Annu Conf Eur Cetacean Soc, Ashdod, 5–7 April 2022. European Cetacean Society, Liège, p 106 (Abstract)

Butterworth DS, Wickens PA (1990) Annex 2. Modelling the dynamics of the South African fur seal population. In: Report of the subcommittee of the Sea Fisheries Advisory Committee appointed at the request of the Minister of Environment Affairs and of Water Affairs, to advise the Minister on scientific aspects of sealing. Southern African Nature Foundation, Stellenbosch, p 33–57

Butterworth DS, Duffy DC, Best PB, Bergh MO (1988) On the scientific basis for reducing the South African seal population. S Afr J Sci 84:179–188

Calkins DG, Pitcher KW (1982) Population assessment, ecology and trophic relationships of Steller sea lions in the Gulf of Alaska. In: Environmental assessment of the Alaskan continental shelf. Final Report of Principal Investigators 19. Outer Continental Shelf Environmental Assessment Program, US Department of Commerce and US Department of Interior, Anchorage, AK

Carretta JV, Oleson EM, Baker J, Weller DW and others (2016) U.S. Pacific marine mammal stock assessments: 2015. NOAA Tech Memo NOAA-TM-NMFS-SWFSC-561. https://repository.library.noaa.gov/view/noaa/11987

Caughley G, Gunn A (1996) Conservation biology in theory and practice. Blackwell, Cambridge, MA

Ceriani SA, Brost B, Meylan AB, Meylan PA, Casale P (2021) Bias in sea turtle productivity estimates: error and factors involved. Mar Biol 168:1–10

Chapron G, Legendre S, Ferrière R, Clobert J, Haight RG (2003) Conservation and control strategies for the wolf (*Canis lupus*) in western Europe based on demographic models. C R Biol 326:575–587

Chilvers BL (2015) *Phocarctos hookeri.* The IUCN Red List of Threatened Species 2015:e.T17026A1306343, doi:10.2305/IUCN.UK.2015-2.RLTS.T17026A1306343.en (accessed 18 Sep 2023)

Chilvers BL (2021) Pup numbers, estimated population size, and monitoring of New Zealand fur seals in Doubtful/Pateā, Dusky and Breaksea Sounds, and Chalky Inlet, Fiordland, New Zealand 2021. NZ J Mar Freshw Res 57: 75–87

Chilvers BL, Meyer S (2017) Conservation needs for the endangered New Zealand sea lion, *Phocarctos hookeri.* Aquat Conserv 27:846–855

Demerdzhiev D, Stoychev S, Dobrev D, Spasov S, Oppel S (2015) Studying the demographic drivers of an increasing imperial eagle population to inform conservation management. Biodivers Conserv 24:627–639

Dendrinos P, Karamanlidis AA, Kotomatas S, Legakis A, Tounta E, Matthiopoulos J (2007) Pupping habitat use in the Mediterranean monk seal: a long-term study. Mar Mamm Sci 23:615–628

Dendrinos D, Adamantopoulou S, Koemtzopoulos K, Mpatzios P and others (2022) Anecdotal observations of the use of open beaches by female Mediterranean monk seals *Monachus monachus* and their pups in Greece: implications for conservation. Aquat Mamm 48:602–609

Duck CD, Thompson D (2007) The status of grey seals in Britain. NAMMCO Sci Publ 6:69–78

Fernández de Larrinoa P, Baker JD, Cedenilla MA, Harting AL and others (2021) Age-specific survival and reproductive rates of Mediterranean monk seals at the Cabo Blanco Peninsula, West Africa. Endang Species Res 45: 315–329

Forcada J, Aguilar A (2000) Use of photographic identification in capture-recapture studies of Mediterranean monk seals. Mar Mamm Sci 16:767–793

Forcada J, Robinson SL (2006) Population abundance, structure and turnover estimates for leopard seals during winter dispersal combining tagging and photo-identification data. Polar Biol 29:1052–1062

Frie AK, Stenson GB, Haug T (2012) Long-term trends in reproductive and demographic parameters of female Northwest Atlantic hooded seals (*Cystophora cristata*): population responses to ecosystem change? Can J Zool 90:376–392

Gales NJ, Fletcher DJ (1999) Abundance, distribution and status of the New Zealand sea lion, *Phocarctos hookeri.* Wildl Res 26:35–52

Gales NJ, Shaughnessy PD, Dennis TE (1994) Distribution, abundance and breeding cycle of the Australian sea lion *Neophoca cinerea* (Mammalia: Pinnipedia). J Zool 234: 353—370

Gibbens J, Arnould JPY (2009) Age-specific growth, survival and population dynamics of female Australian fur seals. Can J Zool 87:902—911

Goedicke TR (1981) Life expectancy of monk seal colonies in Greece. Biol Conserv 20:173—181

Goldsworthy SD, Page B (2007) A risk-assessment approach to evaluating the significance of seal bycatch in two Australian fisheries. Biol Conserv 139:269—285

Goldsworthy SD, Bulman C, He X, Larcombe J, Littnan C (2003) Trophic interactions between marine mammals and Australian fisheries: an ecosystem approach. In: Gales N, Hindell M, Kirkwood R (eds) Marine mammals: fisheries, tourism and management issues. CSIRO Publishing, Melbourne, p 62—99

Goldsworthy SD, Page B, Shaughnessy PD, Linnane A (2010) Mitigating seal interactions in the SRLF and the gillnet sector SESSF in South Australia. SARDI Res Rep Ser No. 405

Goodman S (2016) *Pusa sibirica.* The IUCN Red List of Threatened Species 2016:e.T41676A45231738, doi:10.2305/IUCN.UK.2016-1.RLTS.T41676A45231738.en (accessed 18 Sep 2023)

Gülce S, Gücü AC, Ok M, Sakinan S, Sahin E, Tutar O, Mertkan T (2014) Population viability analysis of Mediterranean monk seal (*Monachus monachus*) and significance of dispersal in survival (Northeast Mediterranean Sea). In: ECS abstract book — marine mammals as sentinels of a changing environment. Proc 28th Conf Eur Cetacean Soc, Liege, 5—9 April 2014. European Cetacean Society, Liège, p 53 (Abstract)

Hamilton S, Baker GB (2019) Population growth of an endangered pinniped—the New Zealand sea lion (*Phocarctos hookeri*)—is limited more by high pup mortality than fisheries bycatch. ICES J Mar Sci 76:1794—1806

Hammill MO, Stenson GB, Myers RA, Stobo WT (1998) Pup production and population trends of the grey seal (*Halichoerus grypus*) in the Gulf of St Lawrence. Can J Fish Aquat Sci 55:423—430

Hammill MO, Stenson GB, Mosnier A, Doniol-Valcroze T (2021) Trends in abundance of harp seals, *Pagophilus groenlandicus*, in the Northwest Atlantic, 1952-2019. DFO Can Sci Advis Sec Res Doc 2021/006

Härkönen T, Harding KC (2001) Spatial structure of harbour seal populations and the implications thereof. Can J Zool 79:2115—2127

Harwood J, Prime JH (1978) Some factors affecting the size of British grey seal populations. J Appl Ecol 15: 401—411

Haug T, Henriksen G, Kondakov A, Mishin V, Nilssen KT, Rov N (1994) The status of grey seals *Halichoerus grypus* in North Norway and on the Murman Coast, Russia. Biol Conserv 70:59—67

Hauksson E (2007) Abundance of grey seals in Icelandic waters, based on trends of pup-counts from aerial surveys. NAMMCO Sci Publ 6:85—97

Hernández-Camacho CJ, Trites AW (2018) Population viability analysis of Guadalupe fur seals *Arctocephalus townsendi.* Endang Species Res 37:255—267

Hewer HR (1964) The determination of age, sexual maturity, longevity and a life-table in the grey seal (*Halichoerus grypus*). Proc Zool Soc Lond 142:593—624

Isaac NJB, Turvey ST, Collen B, Waterman C, Baillie JEM (2007) Mammals on the EDGE: conservation priorities based on threat and phylogeny. PLOS ONE 2: e296

IUCN Standards and Petitions Committee (2022) Guidelines for using the IUCN Red List categories and criteria, version 15.1. The International Union for Conservation of Nature (IUCN). https://www.iucnredlist.org/resources/redlistguidelines

Karamanlidis AA (2024) Current status, biology, threats and conservation priorities of the vulnerable Mediterranean monk seal. Endang Species Res 53:341—361

Karamanlidis AA, Dendrinos P (2015) *Monachus monachus.* The IUCN Red List of Threatened Species 2015:e.T13653A45227543. www.iucnredlist.org/species/13653/117647375#errata (accessed 18 Sep 2023)

Karamanlidis AA, Dendrinos P (2023) Mediterranean monk seal *Monachus monachus* (Hermann, 1779). In: Hackländer K, Zachos FE (eds) Handbook of the mammals of Europe. Springer, Cham

Karamanlidis AA, Lyamin O, Adamantopoulou S, Dendrinos P (2017) First observations of aquatic sleep in the Mediterranean monk seal (*Monachus monachus*). Aquat Mamm 43:82—86

Karamanlidis AA, Adamantopoulou S, Tounta E, Dendrinos D (2019) *Monachus monachus* Eastern Mediterranean subpopulation. The IUCN Red List of Threatened Species 2019:e.T120868935A120869697. www.iucnredlist.org/species/120868935/120869697 (accessed 18 Sep 2023)

Karamanlidis AA, Dendrinos P, Trillmich F (2021a) Maternal behavior and early behavioral ontogeny of the Mediterranean monk seal *Monachus monachus* in Greece. Endang Species Res 45:13—20

Karamanlidis AA, Skrbinšek T, Amato G, Dendrinos D and others (2021b) Genetic and demographic history define a conservation strategy for Earth's most endangered pinniped, the Mediterranean monk seal *Monachus monachus.* Sci Rep 11:373

Karamanlidis AA, Dendrinos D, Fernández de Larrinoa P, Kiraç CO, Nicolaou H, Pires R (2023) *Monachus monachus.* The IUCN Red List of Threatened Species 2023:e.T13653A238637039, doi:10.2305/IUCN.UK.2023-1.RLTS.T13653A238637039.en

Kıraç CO, Savaş Y (2019) Assessments for threats and ecological needs of monk seal populations in Turkish Aegean and the Sea of Marmara. In: Proc 5th Int Conf Marine Mammal Protected Areas, Costa Navarino, 8—12 April 2019. International Committee on Marine Mammal Protected Areas

Kirkwood R, Gales R, Terauds A, Arnould JP, Pemberton D, Shaughnessy PD, Gibbens J (2005) Pup production and population trends of the Australian fur seal (*Arctocephalus pusillus doriferus*). Mar Mamm Sci 21:260—282

Kirkwood R, Pemberton D, Gales R, Hoskins AJ, Mitchell T, Shaughnessy PD, Arnould JP (2010) Continued population recovery by Australian fur seals. Mar Freshw Res 61:695—701

Kurt M, Gücü AC (2021) Demography and population structure of Northeastern Mediterranean monk seal population. Mediterr Mar Sci 22:79—87

Laake JL, Lowry MS, DeLong RL, Melin SR, Carretta JV (2018) Population growth and status of California sea lions. J Wildl Manag 82:583—595

Lalas C, Bradshaw CJA (2001) Folklore and chimerical numbers: review of a millennium of interaction between fur seals and humans in the New Zealand region. NZ J Mar Freshw Res 35:477—497

Littnan C, Harting A, Baker J (2015) *Neomonachus schauinslandi.* The IUCN Red List of Threatened Species 2015:e. T13654A45227978, doi:10.2305/IUCN.UK.2015-2.RLTS. T13654A45227978.en (accessed 18 Sep 2023)

Lowry MS, Condit R, Hatfield B, Allen SG and others (2014) Abundance, distribution, and population growth of the northern elephant seal (*Mirounga angustirostris*) in the United States from 1991 to 2010. Aquat Mamm 40:20–31

Mace GM, Collar NJ, Gaston KJ, Hilton-Taylor C and others (2008) Quantification of extinction risk: IUCN's system for classifying threatened species. Conserv Biol 22: 1424–1442

Mansfield AW, Beck B (1977) The grey seal in eastern Canada. Rep No. 704. Arctic Biological Station, Fisheries and Marine Service, Department of Fisheries and the Environment, Sainte-Anne-de-Bellevue

Martínez-Jauregui M, Tavecchia G, Cedenilla MA, Coulson T, Fernández de Larrinoa P, Muñoz M, González LM (2012) Population resilience of the Mediterranean monk seal *Monachus monachus* at Cabo Blanco peninsula. Mar Ecol Prog Ser 461:273–281

Morgan JW (1999) Effects of population size on seed production and germinability in an endangered, fragmented grassland plant. Conserv Biol 13:266–273

Muto MM, Helker VT, Delean BJ, Young NC and others (2022) Alaska marine mammal stock assessments, 2021. NOAA Tech Memo NOAA-TM-AFSC-441

Nicolaou H, Dendrinos D, Marcou M, Michaelides S, Karamanlidis AA (2019) Re-establishment of the Mediterranean monk seal *Monachus monachus* in Cyprus: priorities for conservation. Oryx 55:526–528

Nilssen KT, Haug T (2007) Status of grey seals (*Halichoerus grypus*) in Norway. NAMMCO Sci Publ 6:23–31

Page B, Welling A, Chambellant M, Goldsworthy SD, Dorr T, van Veen R (2003) Population status and breeding season chronology of Heard Island fur seals. Polar Biol 26: 219–224

Panou A, Bundone L, Aravantinos P, Kokkolis T, Chaldas X (2022) Mediterranean monk seal, a sign of hope: increased birth numbers and enlarged terrestrial habitat. In: Marine mammal research and conservation efforts — Are we on the right path? Proc 33rd Annu Conf Eur Cetacean Soc, Ashdod, 5–7 April 2022. European Cetacean Society, Liège, p 95 (Abstract)

Panou A, Giannoulaki M, Varda D, Lazaj L, Pojana G, Bundone L (2023) Towards a strategy for the recovering of the Mediterranean monk seal in the Adriatic-Ionian Basin. Front Mar Sci 10:1034124

Pastor T, Cappozzo HL, Grau E, Amos W, Aguilar A (2011) The mating system of the Mediterranean monk seal in the Western Sahara. Mar Mamm Sci 27:E302–E320

Payne MR (1979) Growth in the Antarctic fur seal *Arctocephalus gazella.* J Zool 187:1–20

Pietroluongo G, Martín-Montalvo BQ, Ashok K, Miliou A and others (2022) Combining monitoring approaches as a tool to assess the occurrence of the Mediterranean monk seal in Samos Island, Greece. Hydrobiology 1: 440–450

Pires R, Aparicio F, Baker J, Pereira S and others (2023) First demographic parameter estimates for the Mediterranean monk seal population at Madeira, Portugal. Endang Species Res 51:269–283

Pitcher KW, Brown PF, Brown RF, Lowry MS and others (2007) Abundance and distribution of the eastern North Pacific Steller sea lion (*Eumetopias jubatus*) population. Fish Bull 107:102–115

Punt AE, Siple M, Sigurgsson GM, Víkingsson G and others (2020) Evaluating management strategies for marine mammal populations: an example for multiple species and multiple fishing sectors in Iceland. Can J Fish Aquat Sci 77:1316–1331

Regan HM, Ben-Haim Y, Langford B, Wilson WG, Lundberg P, Andelman SJ, Burgman MA (2005) Robust decision-making under severe uncertainty for conservation management. Ecol Appl 15:1471–1477

Rey-Iglesia A, Gaubert P, Themudo GE, Pires R and others (2021) Mitogenomics of the endangered Mediterranean monk seal (*Monachus monachus*) reveals dramatic loss of diversity and supports historical gene-flow between Atlantic and eastern Mediterranean populations. Zool J Linn Soc 191:1147–1159

Russell DJF, Morris CD, Duck CD, Thompson D, Hiby L (2019) Monitoring long-term changes in UK grey seal pup production. Aquat Conserv 29:24–39

Samaranch R, González LM (2000) Changes in morphology with age in Mediterranean monk seals (*Monachus monachus*). Mar Mamm Sci 16:141–157

Shaughnessy PD, Stirling I, Dennis TE (1997) Changes in the abundance of New Zealand fur seals, *Arctocephalus forsteri*, on the Neptune Islands, South Australia. Wildl Res 23:697–709

Stobo WT, Zwanenburg KCT (1990) Grey seal (*Halichoerus grypus*) pup production of Sable Island and estimates of recent production in the Northwest Atlantic. Can Bull Fish Aquat Sci 222:171–184

Taylor RH (1982) New Zealand fur seals at the bounty islands. NZ J Mar Freshw Res 16:1–9

Triantis K, Mylonas M (2009) Greek Islands, biology. In: Gillespie R, Clague D (eds) Encyclopedia of islands. Encyclopedias of the natural world, Vol 2. University of California Press, Oakland, CA, p 388–392

Trites AW, Larkin PA (1996) Changes in the abundance of Steller sea lions (*Eumetopias jubatus*) in Alaska from 1956 to 1992: How many were there? Aquat Mamm 22: 153–166

Wickens PA, Shelton PA (1992) Seal pup counts as indicators of population size. S Afr J Wildl Res 22:65–69