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DIVING DEVELOPMENT AND BEHAVIOR OF A REHABILITATED MEDITERRANEAN MONK SEAL (*MONACHUS MONACHUS*)

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ABSTRACT

Among the priority actions identified for saving the critically endangered Mediterranean monk seal are gaining basic biological information on movements and behavior, and rescuing and rehabilitating wounded, stranded, and orphaned pups. On 22 May 2004 a rehabilitated monk seal juvenile was fitted with a satellite tag, released in the National Marine Park of Alonnisos, Northern Sporades, Greece, and monitored for 167 d. Postrelease, the seal remained close to the islands of the park and within the 200-m isobath. Throughout the monitoring period, the seal reduced time hauled out, while 95-percentile dive duration and depth gradually increased. The overall maximum depth of 123 m recorded in this study is the greatest depth ever recorded for the species. These results confirm the effectiveness of the rehabilitation program carried out on the particular animal and provide additional support for the continuation of the rehabilitation program as a conservation measure for the species. We demonstrate that satellite tracking of rehabilitated seals is a valuable research and conservation tool, even for a species that commonly uses shoreline caves for resting, molting, and parturition.

Key words: Mediterranean monk seal, *Monachus monachus*, satellite tracking, rehabilitation, diving development, conservation, Greece.

The Mediterranean monk seal (*Monachus monachus*) is one of the world's most endangered marine mammals and is considered as "critically endangered" by the World Conservation Union (IUCN) (Baillie *et al*. 2004). Several conferences have been held since 1978 in order to formulate guidelines and coordinate actions to promote its recovery (Johnson and Lavigne 1998).

The benefit of rehabilitation and release of marine mammals back to the wild is still a matter of debate (St. Aubin *et al*. 1996). In the case of the Mediterranean monk seal however, whose total world population is estimated to be fewer than 600 individuals (Johnson *et al*. 2006), rescuing and rehabilitating every single wounded, stranded, and orphaned pup is regarded as a priority conservation action for the survival of the species (Ronald and Duguy 1979, Israëls 1992, Johnson and Lavigne 1998).

Within the Mediterranean Sea, rescue and rehabilitation of Mediterranean monk seal pups is currently carried out only in Greece. The Hellenic Society for the Study and Protection of the Mediterranean Monk Seal (MOm) is a non-profit, non-governmental organization and is the coordinator of a Rescue and Information Network (RINT) that collects information on live and dead seals throughout Greece (Adamantopoulou *et al*. 1999). Seals requiring medical or other assistance are treated at the Mediterranean Monk Seal Rehabilitation Center (MSRC) at the island of Alonnisos, Greece, which has been established in cooperation with the Seal Rehabilitation and Research Center of Pieterburen (SRRC), The Netherlands. Since 1990, seventeen seals have been treated, of which seven survived to release (Androukaki *et al*. 2003). However the fates of these released seals, and thus the contribution of the rehabilitation procedure to the conservation of the wild population, have not been monitored with the exception of one study deploying VHF-radiotelemetry devices on two rehabilitated young monk seals (Reijnders and Ries 1989).

In 2004 MOm and the Sea Mammal Research Unit (SMRU) carried out the first satellite tracking of a rehabilitated Mediterranean monk seal in Greece. The aims of the study were to document the movements and behavior, infer the development of dive capability, and evaluate early survival of the released seal. The movements and behavior of Mediterranean monk seals are still poorly understood, due to the scarcity of the species, the inaccessibility of its habitat, and concerns about the consequences of intervention on its small and endangered population. Considering the general lack of knowledge regarding the species and despite the fact that we monitored only one individual, our study not only works toward the broader aim of assessing the efficacy of rehabilitation efforts, but also toward understanding the species' biology and thus guiding the development of more effective conservation management policies.

Methods

Pup Rehabilitation and Release

On 29 December 2003 a male Mediterranean monk seal pup approximately 2–3 wk old was found abandoned ashore on the island of Karpathos (35°37′N, 27°07′W) in the southeastern Aegean Sea. The pup was underweight (15 kg) and weak, and had superficial wounds on the flippers and lower jaw. It was therefore brought to the MSRC where it was treated according to standard operational procedures developed by MOm in collaboration with the SRRC Pieterburen, the Erasmus University of Rotterdam, and the Veterinary School of the Aristotle University of Thessaloniki (Androukaki *et al*. 2003). By the time of its release, on 22 May 2004, the juvenile had attained a weight of 58.5 kg, was feeding on live fish, and behaved aggressively toward humans.

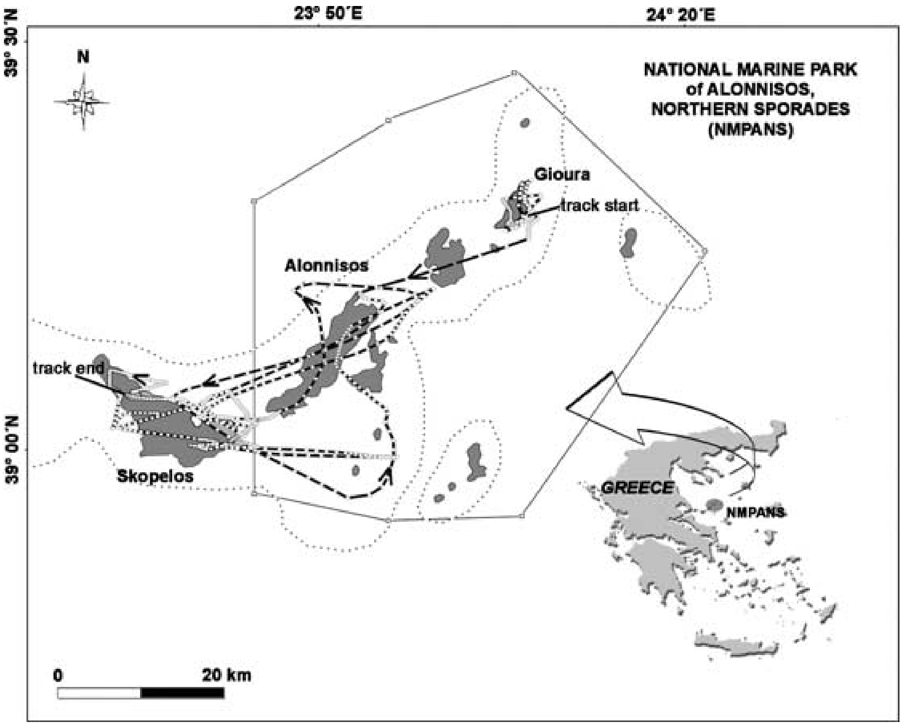

Figure 1. Map of the Northern Sporades showing the smoothed track of the tagged pup; the 200-depth isobath is shown as a dotted line, and park boundaries are shown as a continuous line.

Study Area

The seal was released at Gioura (Fig. 1), an uninhabited island in the archipelago of the Northern Sporades. The archipelago is located in the northwestern Aegean Sea and has been identified as being of crucial importance to the survival of the species (Schultze-Westrum 1977, Dendrinos *et al*. 1999). This was the main reason for designating the area as the National Marine Park of Alonnisos, Northern Sporades (NMPANS) in 1992. The NMPANS has an area of approximately 2,200 km^2 (Fig. 1).

Satellite Telemetry

Prior to release, the seal was physically restrained while a Satellite Relay Data Logger (SRDL; series 9000, SMRU, University of St. Andrews, Scotland) was glued to the dorsal fur with quick setting epoxy resin. Its detailed operation is described by McConnell *et al*. (1999) and Fedak *et al*. (2002) and is summarized here. A dive record started when the seal was submerged to at least 4 m for at least 6 s. The dive was terminated when the tag surfaced above 4 m. A haul-out record started when the tag became continuously dry for 600 s and ended when it became continuously wet for 120 s. In addition, the percentage of time spent diving and hauled out in

4-h summary periods was recorded. These records commenced at 0020, 0060, 1000, 1400, 1800, and 2200 Eastern European Time (EET). Data records were buffered and transmitted in a pseudo-random manner so that, while not all the data collected on board could be received through the limited Argos bandwidth at this latitude, the data that are received are unbiased by behavior when there is increased opportunity to transmit. In this study 66% of all summary periods and 9% of all dives were relayed. This difference in performance is expected because more importance (in terms of transmission allocation as scheduled by the tag software) is given to completeness in summary records rather than in dive records (see Fedak *et al*. 2002).

Data Processing and Analysis

Argos locations were filtered following McConnell *et al*. (1992) in order to eliminate unrealistic locations. The tracks were then smoothed with a two-dimensional general additive model (GAM) (Lonergan, SMRU unpublished) procedure and descretized to 6-h intervals.

In the analysis of dive behavior we attempt to distinguish physiological capability from observed behavior. We argue that over a certain period of time it is likely that a seal exerts itself to its physiological limit, in terms of both dive duration and the percentage of time spent diving in 4-h periods. We thus grouped the dive behavior data into 14-d bins and selected the upper 95th-percentile (U95pct) value within each bin as an index of capability. All times of day are given in Eastern European Time (EET = Universal Time Coordinated [UTC] + 2 h), and daylight saving time is ignored.

Results

The seal was tracked from 22 May 2004 to 5 November 2004, a total of 167 d. The number and daily rate of Argos locations acquired are shown in Table 1. During this time we received 1,075 dive records and 529 4-h summary records (52% of tracking duration). Of the 642 haul-out records logged by the SRDL, 187 (29%) were successfully relayed ashore.

Movements

The smoothed tracks of the pup are shown in Figure 1. Postrelease, the pup remained close to the coast of the island of Gioura for almost a month, until 14 June

Table 1. The number, daily rate, and percentage of Argos locations, grouped by location quality (LQ). LQ 3 provides the most accurate fix (*ca*. 66% of fixes within 150 m of truth). See Vincent *et al*. (2002) for a discussion of Argos errors.

Location quality	*n*	*n* per day	Location quality per day (%)
B	247	1.479	62.2
A	90	0.539	22.6
0	25	0.150	6.3
1	22	0.132	5.55
2	8	0.048	2.01
3	5	0.030	1.26
Total	397	2.378	100

when it traveled approximately 50 km over 10 d to the island of Skopelos. After a week there, it spent 11 d encircling Alonnisos before returning again to Skopelos. Two days later it made a similar trip over a 23-d period. For the remaining 97 d it remained close to the coast of Skopelos.

Haul-Out Behavior

Short-term trends in the haul-out behavior of the seal were evident. Individual records of this behavior are shown in Figure 2. In general, a tendency developed for haul-outs to occur mainly between dawn and dusk. This is also indicated in the histogram of the mean percentage of time hauled out within 4-h summary periods, as shown in Figure 3A. Although human activity may influence monk seal diurnal rhythm, there is no empirical data to support this assumption and this study was not designed to test this hypothesis.

A binomial GAM fitted to the 4-h percentage of time hauled-out records (Fig. 3B) also suggested long-term trends in the percentage of time hauled out. In the 2 wk following release the seal hauled out for an average of 65.5% of the time. This decreased to an average of 31.7 in the middle 2 wk of July, increased to 40.0% in the middle 2 wk of August, and thereafter declined to 25.6% in the month of October.

Diving Behavior and Capability

Diving behavior is summarized in Figure 4. The U95pct of dive duration increased over the first 2 mo and thereafter stabilized (Fig. 4A). The U95pct dive duration in the first 14-d bin was 1.8 min (mean duration = 1.6 min) whereas the average from mid-July onward was 4.7 min (mean duration = 3.4 min). The maximum duration, observed in mid-July, was 6.7 min (Fig. 4B).

To examine longer time scale dive capability we considered only those 4-h summary periods where there was no haul-out activity and thus only represented diving effort at sea. The percentage of time spent diving in these periods, and their U95pct values, are shown in Figure 4C. Similar to individual dive durations, the U95pct values of time spent diving initially rose steeply from an initial 34% to 73% in mid-July. Thereafter there was a slight increase, with a maximum of 80% in mid-October.

Maximum depth U95pct increased from an initial 14 m to 79 m at the beginning of August (Fig. 4D). Thereafter the mean maximum dive depth was 41 m. The overall maximum dive depth, observed in mid-July, was 123 m (Fig. 4E).

Discussion

Tracking Performance

In comparison with other Argos telemetry studies the rate and quality of locations were low (see Vincent *et al*. 2002). This was probably due to the lower latitudes in Greece (and thus lower satellite availability) and the use of shoreline caves for resting, molting, and parturition (Johnson *et al*. 2006). However, locations and the behavioral data received were sufficient to describe the gross behavior of the seal. Thus, we recommend that future rehabilitated seals should be fitted with tags to monitor the efficacy of rehabilitation. Special emphasis should be given to new telemetry

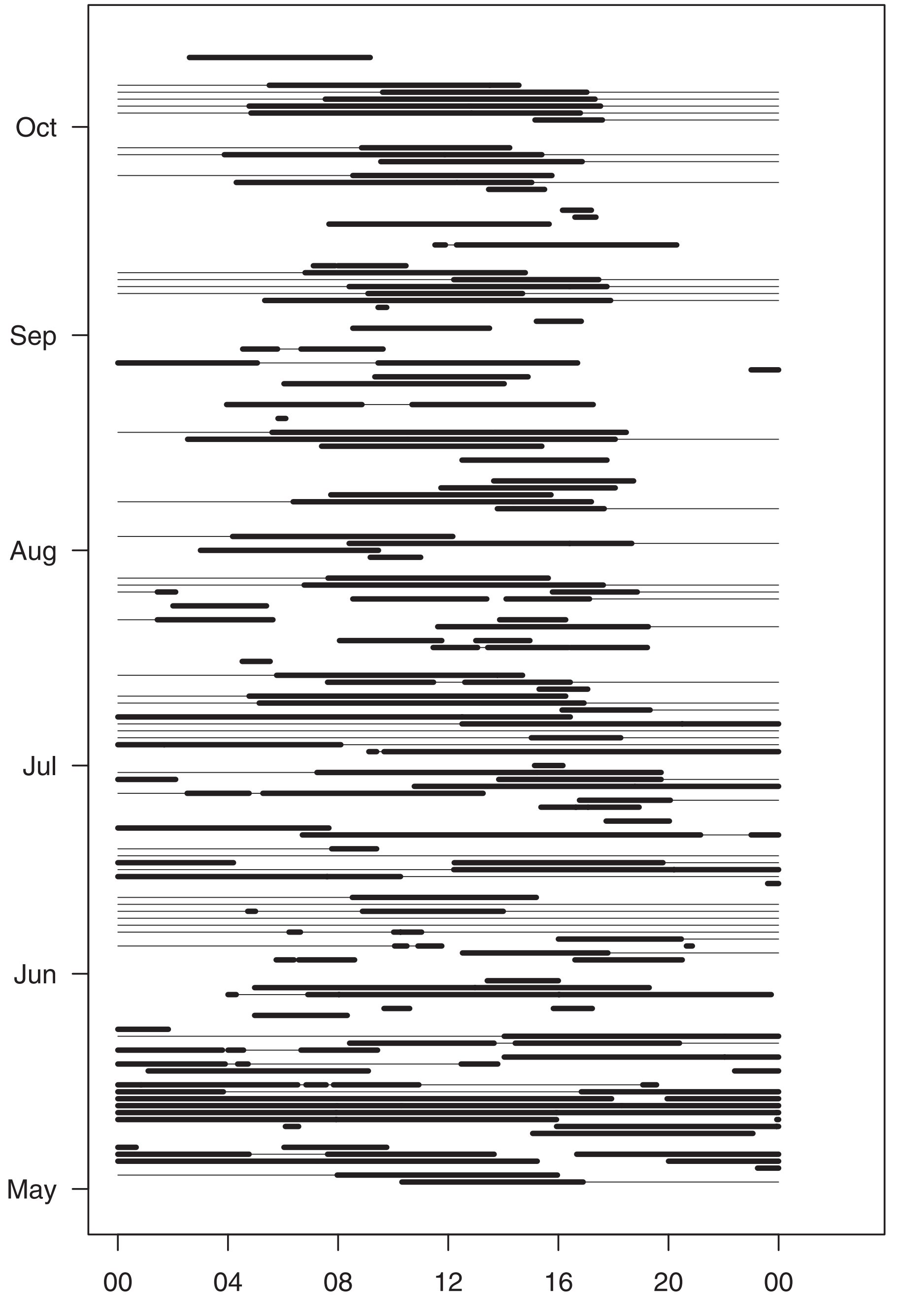

Figure 2. Haul-out records plotted as hour of day (EET) against date. The thick lines represent haul-out periods and the thin lines show the time when we are certain that the seal was not hauled out. In the remaining time the haul-out status (based on haul-out records rather than 4-h summary periods) is unknown.

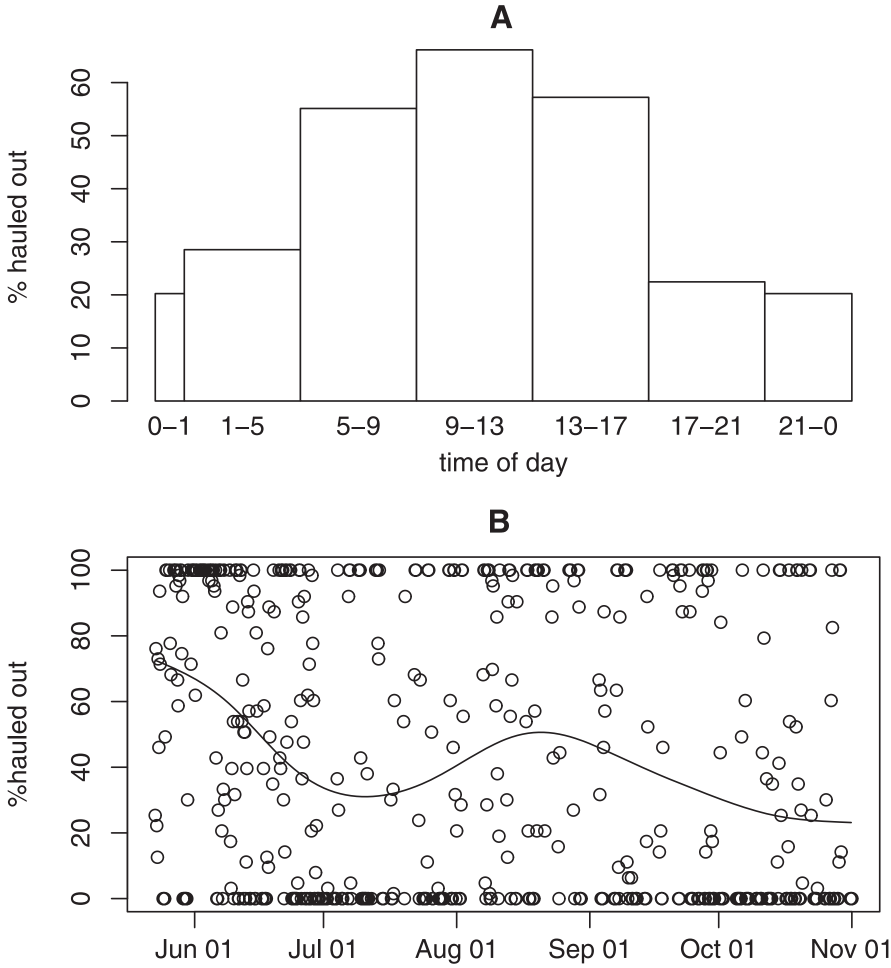

Figure 3. Haul-out behavior. The daily variability in the mean of the time hauled out within 4-h summary periods (A). The percentage of time hauled within each 4-h summary period through time with a GAM smoother (B).

technology incorporating global positioning system (GPS) fix determination and data relay over mobile phone networks as suggested by McConnell *et al*. (2004). Such systems can radically increase the accuracy and rate of locations and overcome the limited Argos data bandwidth at lower latitudes.

Development of Diving Capability

We considered two metrics which we suggest represent physiological dive capability—the upper 95 percentile of both dive duration and percentage of time spent diving while at sea. Both these metrics showed an increase in capability over the first 2 mo postrelease, which then leveled off. Comparison with other studies

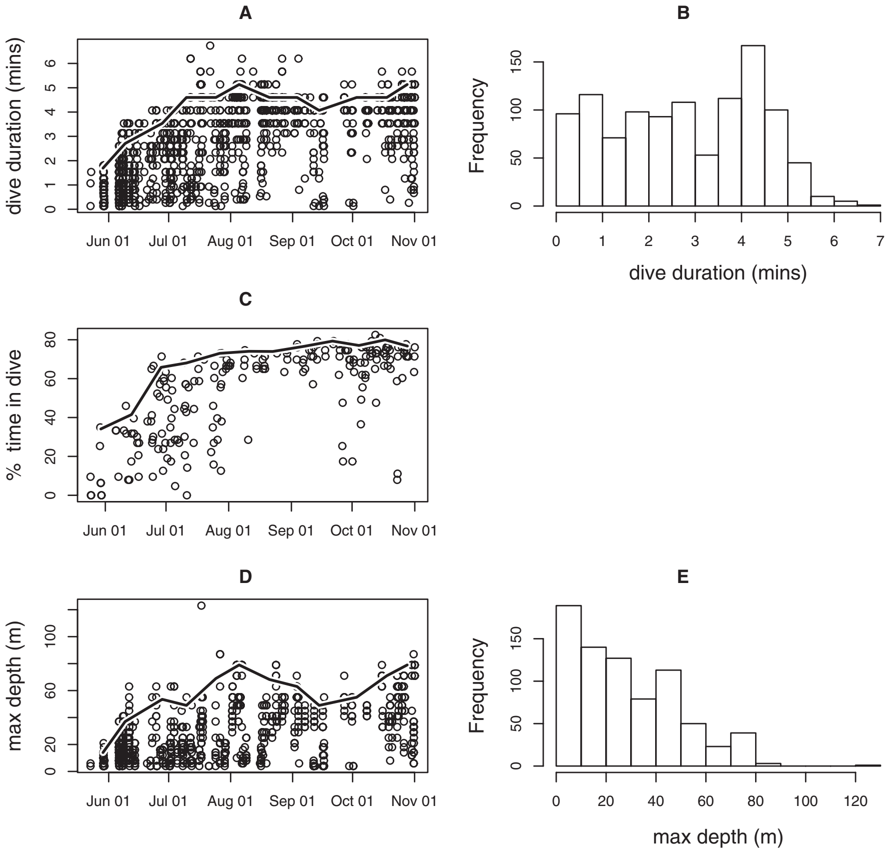

Figure 4. Dive behavior. Temporal changes (with upper 95-percentile limits) and frequency distribution of duration (A, B) and maximum depth (D, E) of individual dive records. Diving effort (expressed as the percentage of time spent diving) was determined from those 4-h summary periods where there was no haul-out activity (C).

from the eastern Mediterranean part of the species distribution is complex because our study did not use the methods reported by other researchers (Reijnders and Ries 1989, Kiraç *et al*. 2002). However, the results from Reijnders and Ries (1989) show that within 2 mo after release, the "diving capacity" of the tracked monk seal had nearly doubled. In addition, dive lengths increased in 2 mo as well, from 90% less than 2 min to 50% over 4 min. In a cross-sectional study carried out at the Cabo Blanco Peninsula, Western Sahara, Gazo *et al*. (2006) report a similar development of diving performance among pups. However, mean and maximum dive depths recorded in that study are much shallower than the ones obtained in the present study. In fact, the maximum depth of 123 m observed is three times deeper than the deepest dive recorded in the Cabo Blanco region and is the greatest depth recorded for any Mediterranean monk seal. Underwater topography in the Cabo Blanco region and in our study site differs markedly; in Cabo Blanco the continental platform is very wide and depths below 40 m are 30 km offshore. In contrast, the 200-m depth isobath in the Northern Sporades region lies usually within 5 km of the coastline (Fig. 1).

Haul-Out Behavior

In the first 2 wk postrelease the seal spent 65.5% of its time hauled out, but this decreased to about half this amount over the remainder of the tracking period. Over this latter time the seal developed a diurnal pattern, when hauling out was more common during daylight hours. This concurs with the study by Reijnders and Ries (1989) in which seals within 2 mo became more active during the evening and night. However, studies from Greece and Turkey indicate in contrast that hauling-out behavior increased during the night (Panou *et al.* 1993, Dendrinos *et al.* 1994, Güçlüsoy and Savaş 2003, Gucu *et al.* 2004). However, these studies monitored the overall haul-out activity and did not distinguish between sex and age classes. Such differences make it difficult to compare the two studies because of possible variability due to differences in the developmental stages of the seals or a seasonal effect (Dendrinos *et al.* 1994).

Movements

Throughout the tracking period the seal remained within the 200-m isobath around the islands of the Northern Sporades archipelago and its daily movements fell within the 40–50-km home range estimated for adult male monk seals (Berkes *et al.* 1979, Gucu *et al.* 2004). In addition, the maximum depth U95pct was only 79 m, confirming the coastal nature of the species. However, the individual in our study and in the study by Reijnders and Ries (1989) in the same area covered considerable distances that extended beyond the boundaries of the protected area of the NMPANS. This fact should be taken into consideration when designing marine protected areas for the species and conservation initiatives (such as education and mitigation of interactions with fisheries) should therefore be designed and implemented on a broader geographical scale.

Evaluation of the Rehabilitation Procedure

The primary objective of the rehabilitation program carried out by MOm is to provide treated individuals with the skills, or the ability to develop skills, required to live on their own in the wild without depending or interacting with humans. The individual in our study was tracked for 167 d, during which it appeared to gradually attain full diving behavior and capabilities. A monk seal monitoring program carried out at the same time in the area did not record any observations of the seal (MOm, unpublished data), indicating that the seal was not habituated to humans. These facts indicate the short-term success of the rehabilitation procedure carried out on this particular individual and offer strong support for its continuation. Rehabilitated seals are now also implanted with microtransponders for the potential identification of seals found dead. Future actions to monitor the long-term efficacy of rehabilitation include a genetic study in order to evaluate the reproductive input of rehabilitated animals to the wild population.

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Literature Cited

Adamantopoulou, S., E. Androukaki and S. Kotomatas. 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., E. Fatsea, L. T. Hart, T. Kuiken, A. D. M. E. Osterhaus, E. Tounta and N. Komnenou. 2003. Treating stranded Mediterranean monk seal pups in Greece. 15th Biennial Conference on the Biology of Marine Mammals, 14–19 December 2003, Greensboro, NC.

Baillie, J. E. M., C. Hilton-taylor and S. N. Stuart, eds. 2004. 2004 IUCN Red List of threatened species. A global species assessment. IUCN, Gland, Switzerland and Cambridge, UK.

Berkes, F., H. Anat, M. Esenel and M. Kislalioglu. 1979. Distribution and ecology of *Monachus monachus* on Turkish coasts. Pages 113–128 *in* K. Ronald and R. Duguy, eds. First international conference on the Mediterranean monk seal, Rhodes, Greece, 2–5 May 1978. UNEP Technical Series 1. Pergamon Press, Oxford, UK.

Dendrinos, P., E. Tounta, S. Kotomatas and A. Kottas. 1994. Recent data on the Mediterranean monk seal population of the Northern Sporades. Bios (Macedonia/Greece) 2:11–16.

Dendrinos, P., S. Kotomatas and E. Tounta. 1999. Monk seal pup production in the National Marine Park of Alonissos-N. Sporades. Contributions to the Zoogeography and Ecology of the Eastern Mediterranean Region 1:413–419.

Fedak, M., P. Lovell, B. J. McConnell and C. Hunter. 2002. Overcoming the constraints of long range radio telemetry from animals: Getting more useful data from smaller packages. Integrative and Comparative Biology 42:3–10.

Gazo, M., C. Lydersen and A. Aguilar. 2006. Diving behaviour of Mediterranean monk seal pups during lactation and post weaning. Marine Ecology Progress Series 308:303–309.

Güçlüsoy, H., and H. Savaş. 2003. Status of the Mediterranean monk seal (*Monachus monachus*) in the Foca Pilot Monk Seal Conservation Area, Turkey. Zoology in the Middle East 28:5–16.

Gucu, A. C., G. Gucu and H. Orek. 2004. Habitat use and preliminary demographic evaluation of the critically endangered Mediterranean monk seal (*Monachus monachus*) in the Cilician Basin (Eastern Mediterranean). Biological Conservation 16:417–431.

Israëls, L. D. E. 1992. Thirty years of Mediterranean monk seal protection—a review. Mededelingen 28:1–65.

Johnson, W. M., and D. M. Lavigne. 1998. The Mediterranean monk seal. Conservation guidelines. Multilingual edition. International Marine Mammal Association, Inc., Guelph, Ontario.

Johnson, W. M., A. A. Karamanlidis, P. Dendrinos, P. F. de Larrinoa, M. Gazo, L. M. Gonzalez, H. Güçlüsoy, R. Pires and M. Schnellmann. 2006. Monk seal fact files. Biology, behaviour, status and conservation of the Mediterranean monk seal, *Monachus monachus*. The Monachus Guardian. Available from http://www.monachus-guardian.org.htm (accessed 20 October 2006).

KIRAÇ, C. O., Y. SAVAS, H. GÜÇLÜSOY AND N. O. VERYERI. 2002. Observations on diving behaviour of free ranging Mediterranean monk seals *Monachus monachus* on Turkish coasts. The Monachus Guardian 5:37–42.

MCCONNELL, B. J., C. CHAMBERS AND M. A. FEDAK. 1992. Foraging ecology of southern elephant seals in relation to the bathymetry and productivity of the Southern Ocean. Antarctic Science 4:393–398.

MCCONNELL, B. J., M. A. FEDAK, P. LOVELL AND P. S. HAMMOND. 1999. Movements and foraging areas of grey seals in the North Sea. Journal of Applied Ecology 36:1–19.

MCCONNELL, B., E. BRYANT, C. HUNTER, P. LOVELL AND A. HALL. 2004. Phoning home—a new GSM mobile phone telemetry system to collect mark-recapture data. Marine Mammal Science 20:274–283.

PANOU, A., J. JACOBS AND D. PANOS. 1993. The endangered Mediterranean monk seal *Monachus monachus* in the Ionian Sea, Greece. Biological Conservation 64:129–140.

REIJNDERS, P. J. H., AND E. H. RIES. 1989. Release and radiotracking of two rehabilitated monk seals in the Marine Park 'Northern Sporades,' Greece. Research Institute for Nature Management, Texel, The Netherlands. 17 pp.

RONALD, K., AND R. DUGUY, eds. 1979. The Mediterranean monk seal. UNEP Technical Series 1. Pergamon Press, Oxford, UK.

SCHULTZE-WESTRUM, T. 1977. Mönchsrobben im Nord-Sporaden Gebiet. Oryx 13:421.

ST. AUBIN, D. J., J. R. GERACI AND V. J. LOUNSBURY. 1996. Rescue, rehabilitation, and release of marine mammals: An analysis of current views and practices. Proceedings of a workshop held in Des Plaines, Illinois, 3–5 December 1991. U.S. Department of Commerce, Silver Spring. NOAA Technical Memorandum NMFS-OPR-8. 65 pp.

VINCENT, C., B. J. MCCONNELL, V. RIDOUX AND M. A. FEDAK. 2002. Assessment of Argos location accuracy from satellite tags deployed on captive gray seals. Marine Mammal Science 18:156–166.

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