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Activity Patterns of the Mediterranean Monk Seal (*Monachus monachus*) in the Archipelago of Madeira

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Abstract

Activity patterns of the critically endangered Mediterranean monk seal (*Monachus monachus*) were examined in the Desertas Islands Nature Reserve in the archipelago of Madeira. Activity of seals at sea was recorded from 25 lookout sites positioned along the reserve's coastline and correlated to site location, season, time of day, and state of tide. From 1994 to 2005, monk seal activity, related mainly to the reproductive behaviour of the species, was recorded primarily at the three pupping sites within the reserve. Activity was influenced by site location, season, and state of tide but not by the time of day. Activity was highest during the autumn and winter months and was related to the pupping and post-parturition necessities of the species, and during high tide, when the incoming action of the sea led monk seals to move out of coastal caves, which are used for resting and breeding. Differences in activity among the three sites monitored were attributed to the level of protection offered by these locations against wind and wave action. The findings of this study, the most extensive study of its kind, have enabled the identification of priority research, and conservation actions for the species in the area.

Key Words: Mediterranean monk seal, *Monachus monachus*, population estimates, pupping sites, seasonal activity, species conservation, tidal influence, Desertas Islands Nature Reserve

Introduction

Activity patterns of several pinnipeds have been the subject of intense scientific research and have provided valuable insights into their life strategies while promoting their effective monitoring and protection (Costa & Williams, 1999; Dendrinos et al., 2007a). Seal activity has been related to various factors such as season (e.g., elephant seals [*Mirounga leonina*] [Hindell & Burton, 1988] and Hooker's sea lions [*Phocarctos hookeri*] [Beentjes, 1989]), time of day (e.g., Weddell seals [*Leptonychotes weddelli*] [Lake et al., 1997]), lunar cycle (e.g., harbour seals [*Phoca vitulina*] [Watts, 1993] and Galápagos fur seals [*Arctocephallus galapagoensis*] [Horning & Trillmich, 1999]), ambient temperature (e.g., New Zealand fur seals [*Arctocephalus forsteri*] [Johnstone & Davis, 1987]), and state of tide (e.g., Weddell seals [Bornemann et al., 1998] and harbour seals [van Parijs et al., 1999]).

By contrast, very little is known on the activity patterns of the Mediterranean monk seal (*Monachus monachus*). With fewer than 600 individuals surviving nowadays (Johnson et al., 2006), the Mediterranean monk seal is considered to be critically endangered, with a high risk of extinction over the next three generations (Baillie et al., 2004). Its distribution range contracted severely in the past century, and Mediterranean monk seals survive now only in small, isolated colonies distributed over the archipelago of Madeira, the Cabo Blanco region in the Western Sahara, and the Mediterranean Sea where they occupy remote, coastal caves (Johnson et al., 2006). The species' endangered status, cryptic nature, and the inaccessibility of its habitat have prevented long-term research efforts and the wide-scale application of effective but invasive research methods such as radio-telemetry to study its activity patterns, either at sea or at land. Short-term studies have indicated that the activity of Mediterranean monk seals in Greece, Turkey, and the Western Sahara is influenced by the season (Dendrinos et al., 1994, 1999), the state of the sea and tide (Marchessaux & Muller, 1987; González et al., 1997, 2002), and/or the time of day (Dendrinos et al., 1994; Güçlüsoy & Savas, 2003; Gucu et al., 2004).

The Desertas Islands are the last stronghold of the Mediterranean monk seal in the archipelago of Madeira (Reiner & dos Santos, 1984; Pires et al., in press). In order to protect the species, the islands were declared the Desertas Islands Nature Reserve (DINR) in 1990, and are managed by the Parque Natural da Madeira Service (PNMS). The present study was carried out within the framework of the Monk Seal Conservation and Monitoring Programme (MSCMP), carried out by PNMS in the area (Pires et al., in press), and quantified Mediterranean monk seal activity at sea (i.e., the occurrence of a seal at sea) in the DINR and examined its relationship to a number of environmental factors. We hypothesized that activity of monk seals would be influenced by site location, seasonality, state of tide, and time of day. The aim of the study was to identify which of these factors influence monk seal activity and determine the effect their different levels have on it.

Materials and Methods

Study Area
The Desertas sub-archipelago comprises three islands (Ilhéu Chão, Deserta Grande, and Bugio) located 11 miles southeast of the island of Madeira (16° 28' to 16° 33' longitude west, 32° 24' to 32° 35' latitude north) (Figure 1). The 37-km long coastline is composed mainly of steep, inaccessible cliffs with several beaches and caves. The islands are uninhabited, with the exception of the PNMS station at Doca, where the park personnel reside. The reserve boundary is defined by the 100-m depth isobath. The entire northern half of the protected area has the status of a partial reserve, where human activity, including fishing, is controlled; whereas, the southern half has the status of a strict reserve, where all human activities, except scientific research, park management actions, and traditional tuna fishing, which is not considered to present a threat to monk seals, are prohibited.

Data Collection
This study was part of a strictly non-invasive monitoring project carried out by PNMS and includes data collected by the research personnel and wardens of the PNMS from 1992 to 2005. Seal activity was recorded only at sea from 25 lookout sites where the inspection of potential pupping and/or feeding sites (i.e., areas with caves and/or rocky bottoms, shoals) was possible (Figure 1). From the lookout sites, and aided by binoculars, the surrounding marine area was surveyed and the number of individual seals sighted at sea was recorded. Access to these lookout sites was only possible by sea. Due to the remoteness of the study area and in order to guarantee the security of the wardens and research personnel, monitoring efforts were carried out only under favourable weather conditions (i.e., below a Beaufort scale of three or four).

In our study, we examined the relationship between monk seal activity and location, season, tidal state, and time of day. Seasonal activity was classified as winter (W: 21 December to 20 March), spring (S: 21 March to 20 June), summer (Sm: 21 June to 22 September), or autumn (A: 23 September to 20 December). Tidal state was classified as high (HT) or low (LT) if the time was one and a half hours before or after the peak of the respective tide, whereas intermediate periods were classified as flood (FT) or ebb (ET) tide. Activity could be recorded systematically only during daytime, which was classified as morning (M: 08:00 to 11:59 h), midday (MD: 12:00 to 15:59 h) or afternoon (A: 16:00 to 19:59 h). Each individual seal sighted within an hour of monitoring effort was counted as one sighting, and monk seal activity was evaluated based on the sighting rate (SR = total number of sightings/total hours of effort). Individual identification was based on external morphological features such as pelage colouration, scars, and wounds. Age class and gender of individual monk seals were determined based on morphological characteristics described by Badosa et al. (1998), Dendrinos et al. (1999b), and Samaranch & González (2000). In the statistical analysis, only the minimum number of positively identified individuals was used.

Data Analysis
General Linear Model (GLM) fitting techniques were used in order to understand the relationship between the sighting rates of Mediterranean monk seals in relation to the variables recorded. A logarithmic transformation was applied to the dependent variable in order to homogenize variances and site location, season, state of tide, and time of day were entered as fixed effect factors to the analysis. Observation effort was used as a weight, hence accounting for variations in the duration of observation effort throughout time. A custom forward stepwise method, starting with the null model with a single intercept, was used to produce candidate models. At the first step, each of the four factors recorded was added to the null model. If its p value was less than 0.05, then the model with the additional variable was considered to explain more of the variability in the dependent variable than a model without the variable. The factor causing the highest deviance reduction was kept. At each following step, a factor was added, and its main effects and two-way interactions were tested. Again, the combination of significant factors and interactions causing the highest deviance reduction was kept. The process was terminated when the addition of a factor and possibly its interactions was no longer significant.

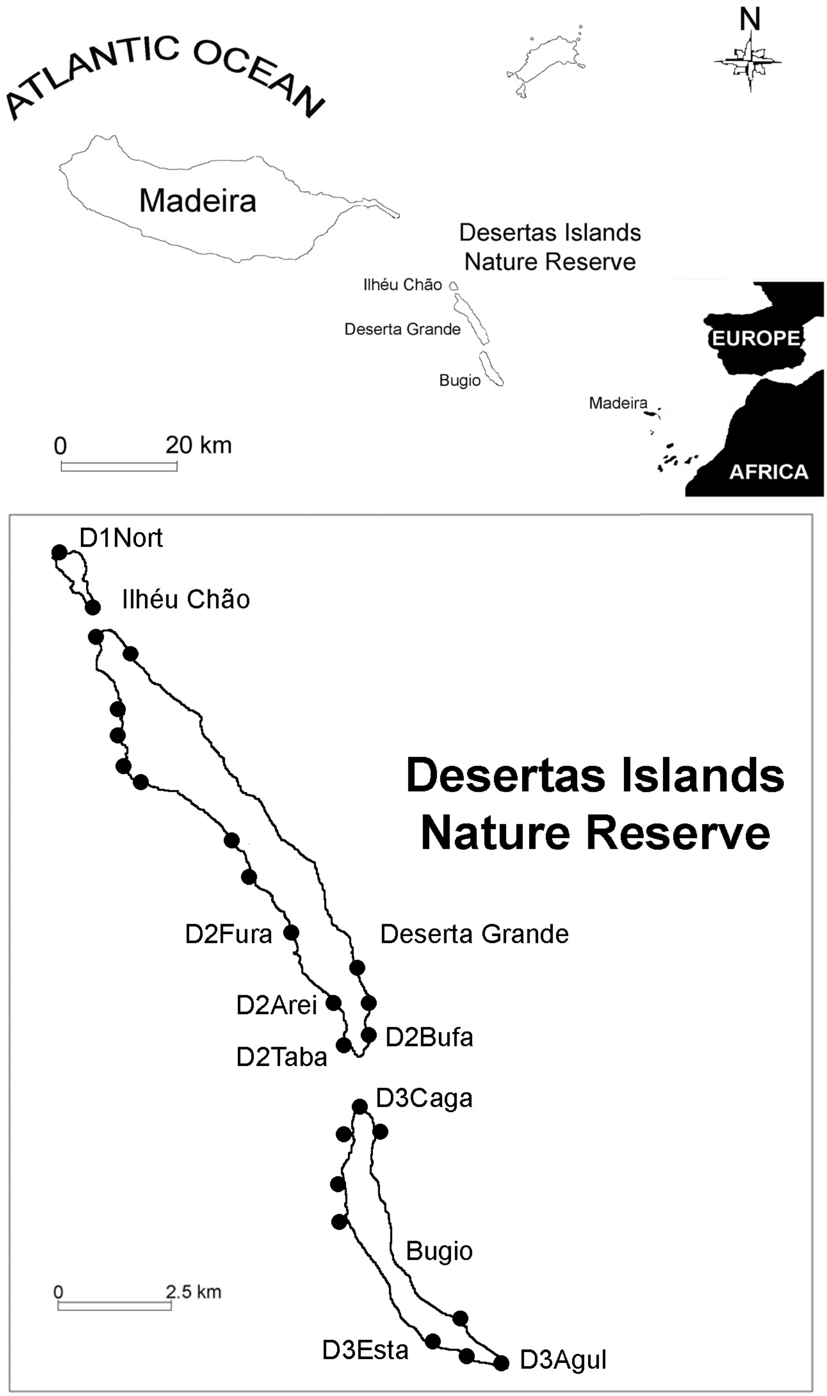

Figure 1. Map of the Desertas Islands Nature Reserve (DINR), indicating the names and locations of the lookout sites mentioned in the text

Each candidate model was compared against each other by using an information-theoretic approach. Competing models with different combinations of predictor variables were compared based on their ability to explain the observed phenomenon. For this, we calculated for each candidate model the second order Akaike Information Criterion (AIC_c), the delta AIC_c (ΔAIC_c), and Akaike weights (w_i). We identified the best model from the candidate set by selecting the model with the lowest AIC_c score (Burnham & Anderson, 2002). For this model, we carried out Tukey's HSD *post hoc* tests in order to identify differences in the means for each pair of factor levels. Differences in the means of pairs of factor levels were significant and consequently reported when the significance level was less than 0.05 ($p < 0.05$). All analyses were carried out using *SPSS*, Version 12.0 for Windows (SPSS Inc., 1989-2003).

Results

Observation Effort

During our study (1992 to 2005), the 25 lookout sites were occupied for 8,821 h, while a total of 2,266 monk seal sightings were recorded during 1,378 successful hours of observation. Sampling efforts were affected by adverse sea conditions and other priorities of the reserve management and were therefore heterogeneous (Table 1).

Significant monk seal activity (i.e., sighting rate > 0.150) within the DINR was recorded only at four locations (Lookout Sites D2Arei, D2Taba, D2Bufa, and D3Caga) (Table 1). We carried out the analysis in this study on the pooled data collected from 1994 to 2005 at the first three sites because previous research on habitat suitability identified them as being among the best potential pupping locations within the reserve (Silva, 1999; Karamanlidis et al., 2004). Lookout Sites D2Arei, D2Taba, and D2Bufa accounted for 90% of all monk seals sighted during the study. From the 35 pups born from 1990 to 2005 in the reserve, 34 were seen for the first time at these three sites (Pires et al., in press). In addition, the open beach at D2Taba is the only place within the archipelago where lactating females have been observed to take care of their newborn pups (Neves & Pires, 1999; Pires & Neves 2000).

These three sites accounted for 95% of all sightings of seals in groups (35.3% pre-weaned individuals, 7.2% juveniles/immature individuals, 27.7% adult females, 8.8% adult males, and 20.6% non-identified individuals), while all five adult females and three out of the five males identified during the MSCMP in the DINR were observed and identified for the first time at these locations (Pires et al., in press). Social behaviour in these areas consisted of behaviour relative to pup to pup and mother to pup interactions (i.e., playing and nursing), and mating behaviour. In fact, mating behaviour within the DINR has been recorded only at D2Arei and D2Taba (Pires, unpub.).

Description of Lookout Sites D2Arei, D2Bufa, and D2Taba

D2Arei—Lookout Site D2Arei overlooks a 600-m bay with a long sandy/stony beach and two caves on the southwestern side of Deserta Grande (Figure 1). Due to its location, the entire area is considered to offer the best protection against the prevailing winds, which originate from north-northeastern directions (Instituto Hidrográfico, 1979). One of the caves and the beach are considered to offer good conditions for resting and/or pupping. Another cave 200 m north of the lookout site is used by the seals and also is considered to offer good conditions for resting (Silva, 1999).

Table 1. Observation effort in hours, successful observation hours, monk seal sightings recorded, and sighting rate from 25 lookout sites at the Desertas Islands Nature Reserve (DINR)

Lookout site code	Observation effort (e)	Successful observation effort (s)	Number of sightings (*n*)	Sighting rate (*n*/e)
D2Arei	2,048	686	1,259	0.614
D2Taba	1,584	412	663	0.418
D2Bufa	602	74	112	0.186
D3Caga	480	73	81	0.168
D2Fura	427	9	10	0.023
D3Agul	360	4	4	0.011
D1Nort	294	4	4	0.013
D3Esta	286	1	1	0.003
All other lookout sites	2,740	115	132	0.048
Total	8,821	1,378	2,266	0.256

D2Taba—Lookout Site D2Taba is located 600 m south of Lookout Site D2Arei (Figure 1) and overlooks a bay and a cave as well. The stony beach was classified as offering medium conditions for pupping (Silva, 1999) and has been used since 1997 for this purpose. The cave was classified as offering good conditions for pupping (Silva, 1999; Karamanlidis et al., 2004) and has been identified as the main pupping site in the archipelago (Neves & Pires, 1999). The bay in this lookout site is much smaller and not as well-protected against the prevailing winds in the area as the one at Lookout Site D2Arei.

D2Bufa—Lookout Site D2Bufa is located at the southeastern side of Deserta Grande (Figure 1) and overlooks a cliffy area with a cave, which is considered to offer good pupping conditions (Silva, 1999; Karamanlidis et al., 2004). The area is highly exposed to the prevailing northeastern winds.

General Linear Model (GLM)

The GLM with the lowest AIC_c value was Model Number 10, which was considered as the "best" model (Table 2). The relationship between predicted and observed values of sighting rates ($r^2 = 0.695$) indicated that the predictions from the model fitted the data well, while inspection of the delta AIC_c values and Akaike weights for the other candidate models indicated that it was unlikely that any of them represented the best model (i.e., $\Delta AIC_c > 10$; $w_i < 0.10$) (Burnham & Anderson, 2002). We drew inferences regarding the relationship between the variables recorded and monk seal activity by using just the best model. Factors affecting Mediterranean monk seal sighting rate were site location, season, state of tide, and the interaction between site location and season (Partial eta square values: site location: 0.327; season: SF:0.292; state of tide: 0.269; site location–season interaction: 0.257).

Site-Specific Differences in Activity

The number of seals sighted at sea differed among the three lookout sites. *Post hoc* tests indicated that sighting rates were low at D2Bufa (Mean = 0.134; SD = 0.182) and D2Taba (Mean = 0.280; SD = 0.255) and high at D2Arei (Mean = 0.539; SD = 0.366) (Figure 2). Sighting rates at D2Arei were 1.55 and 0.63 times higher than those at D2Bufa and D2Taba, respectively.

Seasonal Changes in Activity

Post hoc tests indicated that sighting rates of Mediterranean monk seals changed in relation to season. Sighting rates were low in spring (Mean = 0.278; SD = 0.267) and summer (Mean = 0.167; SD = 0.237) and high in autumn (Mean = 0.362; SD = 0.279) and winter (Mean = 0.474; SD = 0.412) (Figure 2). Sighting rates in autumn and winter were 0.53 and 0.79 times higher than in spring.

Tidal Pattern in Activity

Sighting rates differed according to the state of the tide. Sighting rates were low at low tide (Mean = 0.170; SD = 0.218) and high during ebb (Mean = 0.323; SD = 0.295), flow (Mean = 0.323; SD = 0.317), and high tide (Mean = 0.462; SD = 0.385) (Figure 2). Sighting rates were 0.82, 0.84, and

Table 2. Akaike information statistics for General Linear Model (GLM) analysis relating sighting rates of Mediterranean monk seals in the DINR to environmental variables

Model number	Model type	K[1]	RSS[2]	AIC_c[3]	ΔAIC_c[4]	w_i[5]
1	Null model only		14.791			
2	Null + site	3	12.838	-223.778	69.043	1.017E-15
3	Null + season	3	12.790	-224.183	68.638	1.246E-15
4	Null + tide	3	13.799	-215.982	76.839	2.064E-17
5	Null + Pday	3	13.961	-214.722	78.099	1.099E-17
6	Null + season + site	4	10.651	-241.791	51.030	8.297E-12
7	Null + season + site+ season* site	4	8.740	-261.147	31.674	1.324E-07
8	Null + season + tide	4	11.592	-232.648	60.173	8.581E-14
9	Null + season + tide + season* tide	4	10.377	-242.606	50.215	1.247E-11
10	Null + season + site+ season* site + tide	5	6.387	-292.821	0.000	0.999

[1]K: Number of parameters in the model; [2]RSS: Residual Sum of Squares; [3]AIC_c: Akaike's information criterion adjusted for small sample sizes; [4]ΔAIC_c indicates the amount of support for the model relative to the top-ranking one (higher values show less support); [5]w_i: Akaike weight is the ratio of the ΔAIC_c of the target model relative to all other models. It is another index of the strength of evidence of each model and can be interpreted, heuristically and according to the given data, as the probability of the model being correct.

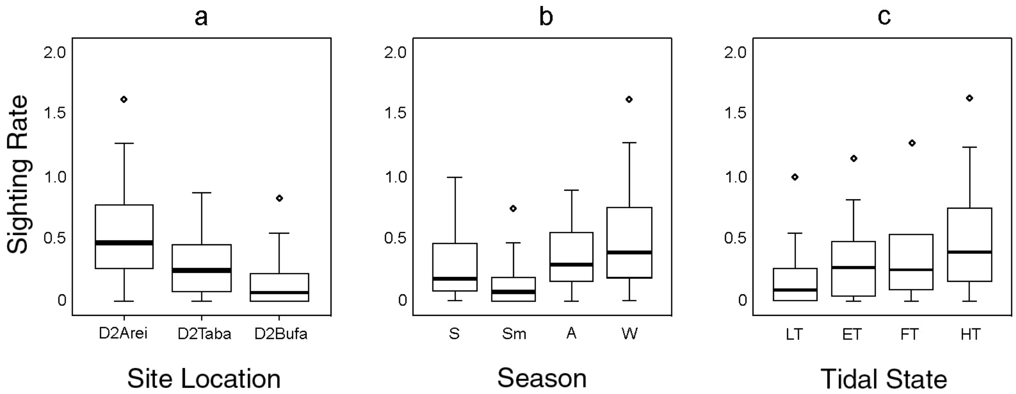

Figure 2. Sighting rates of Mediterranean monk seals in the DINR according to site location (a), season (b), and tidal state (c); plots show median, inter-quartile range, total range, and outliers (see "Materials and Methods" section for season and tidal state abbreviations).

1.5 times higher during ebb, flow, and high tide, respectively, than during low tide.

Interaction Effect Between Site Location and Season
Modelling results indicated a significant interaction effect between site location and season. Minimum sighting rates at Lookout Sites D2Taba and D2Bufa were recorded in summer, and at D2Arei in autumn. Maximum sighting rates at D2Arei and D2Bufa were recorded in winter, and in the autumn at D2Taba (Figure 3).

Discussion

Several aspects of the life history of the Mediterranean monk seal are still poorly understood. This lack of knowledge has hampered the formulation and consequent implementation of effective protection measures for the species (Brasseur et al., 1997) and has led conservationists to regard scientific research that will shed light on aspects of the species' biology among the priority actions for the conservation of the species (Johnson & Lavigne, 1998; Anonymous, 2005). This study, which is the most extensive of its kind, has worked effectively towards this direction. It has quantified the activity of the species at sea in the DINR and identified factors that affect it.

Over a 12-y monitoring period, significant activity and social interactions among Mediterranean monk seals were detected primarily at the coastal areas close to the pupping sites of the DINR, which is in accordance with results of previous short-term monitoring efforts (Pires, 1997; Pires

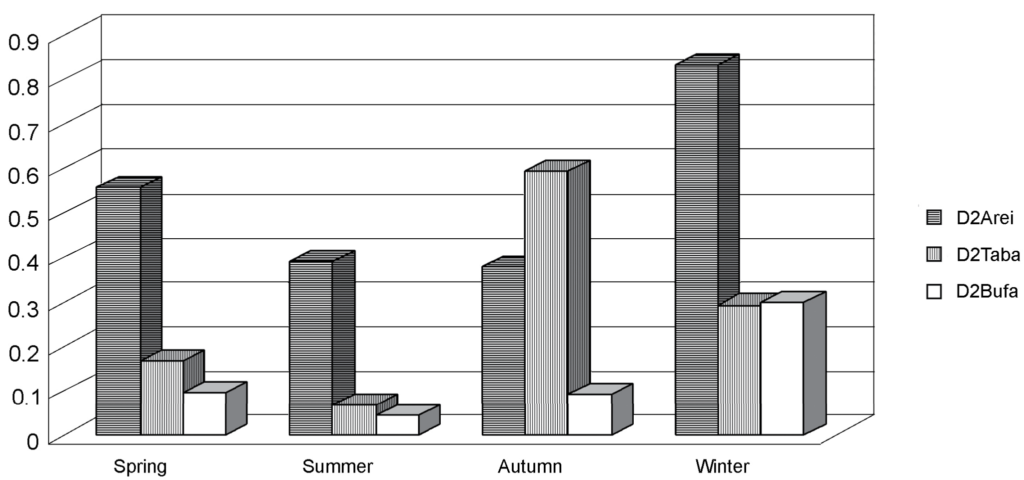

Figure 3. Sighting rates of Mediterranean monk seals in the DINR throughout the year according to site location

& Neves, 2001). These areas were used primarily by lactating mothers and their pups.

Effects of Environmental Variables on Mediterranean Monk Seal Activity

Annual activity was highest during the autumn and winter months, which is in accordance with previous observations from the area (Pires & Neves, 2001) and with observations from Greece and Turkey (Dendrinos et al., 1994, 1999a; Gucu et al., 2004). Activity in these months was determined by the timing of pupping events and post-parturition activity of the species. Pupping season in the DINR starts in September and reaches a peak in the beginning of November. Births also have occurred outside this 3-mo period as late as March (Pires et al., in press). The prolonged pupping season and lactation period of this species (Gazo et al., 2006) are responsible for the increased activity near pupping/breeding sites in the archipelago during the autumn and winter months. Once pups are weaned, seal activity in the area decreases and remains at low levels until the next pupping season. During this time, seals might change their behaviour and turn more solitary and/or spend longer periods of time in the open sea in order to cover dietary needs or in caves resting.

Mediterranean monk seal activity at sea throughout the day was influenced by the state of the tide, with low levels of activity occurring during low tide and increasing levels of activity occurring towards high tide. This is in accordance with results of previous short-term studies from the area (Pires, 1997; Neves, 1998) and observations of hauling out behaviour at the Cabo Blanco region (Marchessaux & Muller, 1987; Jurado et al., 1993; González et al., 2002). This shift in activity could be due to the decrease of available haulout space within caves when sea levels rise, which leads seals to move out of them. This assumption is supported by the fact that from the 53 caves that have been surveyed, so far only eight are steep enough to provide a dry surface throughout the entire tidal cycle (Silva, 1999; Karamanlidis et al., 2004), and by anecdotal behavioural observations from the beach at D2Taba (Neves & Pires, 1999). Increased activity at sea among seals during high tide has been attributed also to increased food availability and, accordingly, adjusted foraging behaviour in other species (Zamon, 2001). There is still too little information available on Mediterranean monk seal diet and food availability to substantiate this hypothesis for the DINR.

Results indicate that monk seal activity at the Desertas Islands was not influenced by the time of day, confirming previous short-term studies from the area (Pires, 1997; Matono, 1999; Silva, 1999). These results are in sharp contrast, however, to areas where tide amplitude is very small, such as the Mediterranean Sea, where the daylight period appears to have an important effect on monk seal activity (Dendrinos et al., 1994; Güçlüsoy & Savas, 2003; Gucu et al., 2004). It appears that in the archipelago of Madeira, tide has a stronger effect on daily activity patterns of the species than time of day.

Although it was not possible to directly record monk seal activity in relation to the state of the sea in the DINR, we speculate that bad sea and wind conditions have a similar effect as high tide—that is, they reduce available haulout space and disturb seals by splashing them and thus lead them to move out of some caves. Observations from the interior of caves at the Cabo Blanco colony indicate that parturient females move towards the furthest end of caves in order to protect themselves and potentially their pups from wind and wave action (Layna et al., 1999). In Greece, lactating females actively seek out caves that offer the best protection against wind and wave action (Dendrinos et al., 2007b). Considering the direction of the predominantly northeastern winds in the area (Instituto Hidrográfico, 1979), the effect of sea state offers a possible explanation for the differences in activity levels observed throughout the year among the three pupping sites. D2Arei, which offers the best protection against wind, and D2Bufa, which provides the worst, had the highest and lowest activity rates respectively.

A significant interaction effect between site location and season was observed in the area. D2Taba, which was identified as the main pupping location in the DINR, had highest activity rates in autumn, which coincides with the peak of the pupping season in the area (Pires et al., in press). Thereafter, activity rates at D2Taba decreased and increased in D2Arei and D2Bufa—locations that offer the best protection against wind and wave action but from opposite directions. We provide two possible explanations for this interaction effect. We speculate that during extremely bad weather and high tide, lactating females reduce the risk of their newborns being washed out of the caves by changing shelters. Thus, depending on wind and wave direction, D2Arei and D2Bufa receive an influx of animals from D2Taba. This assumption is supported by the fact that individuals detected at D2Taba have been regularly observed at the other two sites (Pires, unpub.) and the fact that both of them are located within swimming distance of newborn Mediterranean monk seal pups (Dendrinos et al., 1999a). A similar behaviour has been observed at the monk seal colony in the Northern Sporades, Greece (Dendrinos et al., 2007b), where the habitat is very similar to that in the archipelago of Madeira (Karamanlidis et al., 2004). Considering, however, the fact that the evaluation of the caves in the three locations indicated that they generally offered suitable protection against wind and wave action (Silva, 1999; Karamanlidis et al., 2004) and would therefore usually not be forced to leave caves during bad weather, we doubt that the effort of lactating females to protect their newborns is solely responsible for the differences in activity rates observed at the three lookout sites during autumn and winter. We suspect that the increase in activity at D2Arei and D2Bufa during winter is due to the effort of females to provide their pups with first experiences in diving and foraging. More behavioural observations are required to substantiate this claim.

Conservation Implications

The results of this study have outlined the importance of pupping sites in the archipelago of Madeira and described in detail activity patterns of Mediterranean monk seals at them. These findings have enabled us to identify actions towards the more effective monitoring and protection of the species in the area.

Accurately estimating seal populations involves the detailed understanding of their activity patterns (Erickson et al., 1989; Southwell, 2004). In the case of the endangered Mediterranean monk seal, conservation guidelines regard this task as a research priority and an essential prerequisite for the effective protection and management of the species (Israëls, 1992; Johnson & Lavigne, 1998; Anonymous, 2005). The findings of the study suggest that in the DINR, monitoring that would focus efforts in autumn at D2Taba and winter months at D2Taba and D2Arei, during high tide, would maximize success in collecting information on the demographic composition of the population in the area while prioritizing at the same time conservation and management actions and making use of available human and logistic resources in the most efficient way. Accurate population estimates for the population in the area also will require an understanding of activity patterns and habitat use of the species during the spring and summer months, especially those of adult males. Further research towards this direction should be considered.

Effective protection of the critical pupping habitat of the species is considered a conservation priority throughout the species' range (Israëls, 1992; Johnson & Lavigne, 1998; Anonymous, 2005). The findings of the study underline the importance of the three pupping sites in the archipelago of Madeira and justify the decision of the local authorities to include them in the strictly protected part of the Desertas Islands Nature Reserve. With the Mediterranean monk seal population in the area showing signs of expansion towards the main island of Madeira (Pires et al., in press), priority conservation actions should focus on identifying and effectively protecting such habitat at Madeira in order to promote the establishment of a resident colony there and the survival of the species in the archipelago.

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