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Meteorological influences on harbour seal haul-out

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Harbour seal (*Phoca vitulina concolor*) haul-out behaviour was studied during the spring and summer of two consecutive years to examine whether local environmental conditions influenced the number of seals on land in predictable ways. The study was conducted in an estuarine area with a large tidal amplitude. Tidal level and time of day were previously reported to be the predominant factors influencing the haul-out pattern in this area. Few of the meteorological variables recorded in the present study influenced seal haul-out numbers significantly and no single factor predominated. Increased numbers of seals on land were associated with weather conditions leading to warmer air temperatures, less cloud and less precipitation. This behaviour might be associated with moulting. High waves offshore were also related to more seals hauled out; the seals may be hauling out to meet a rest requirement. The number of seals on land was diminished by increased surf splash at the haul-out site, precipitation and human-related disturbance. Some differences in haul-out behaviour between the pupping and post-pupping period were noted. Regression analysis followed by a prediction experiment helped assess those variables considered important in influencing seal numbers on land.

Introduction

Harbour seals (*Phoca vitulina*) haul-out onto intertidal ledges, mudbanks, beaches and ice floes in all seasons of the year. Counts of seals on land will provide an estimate of the minimum seal population in an area, but are biased by factors influencing the number of animals hauled-out (Summers *et al.*, 1978). Several factors influence harbour seal haul-out behaviour (Boulva & McLaren, 1979; Pitcher & McAllister, 1981; Schneider & Payne, 1983; Terhune & Almon, 1983; Krieber & Barrette, 1984; Stewart, 1984; Pauli & Terhune, 1987). We examined the influence of meteorological variables previously reported to influence harbour seal haul-out behaviour and tested the importance of these variables over two seasons. With a regression model, we examined whether the effect of these influential factors remained consistent over the years. This model allowed us to test whether the relationships between haul-out behaviour and weather factors are consistent over time and it also helps reveal common patterns in harbour seal haul-out behaviour.

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Study Area and Methods

The study was conducted at Passamaquoddy Bay, New Brunswick, Canada. Passamaquoddy Bay is an inlet of the Bay of Fundy at the Maine-New Brunswick border (45° N 67° W). Average annual water temperature is less than 7°C and maximum tidal range is 9.1 m. The semi-diurnal tides expose rocky ledges and cobble flats at each ebb. Seals haul out onto tidal ledges that are adjacent to deep water channels. In Passamaquoddy Bay, 5 main landing sites (including a group of ledges surrounding Saint Croix Island) are used; none of the ledges are contiguous with the mainland. Seals are occasionally hunted in this area because of their supposed nuisance value to commercial fisheries.

Observations were made at Saint Croix Island. This small island (approximately 12 ha) has 2 sets of ledges which are used as haul-out sites. Seals hauled out onto ledges to the north of the island in 1983 and ledges to the south of the island in 1984. The tide exposed the ledges to the south earlier than the northern ledges. Behavioural observations and counts of the number of seals hauled out were made from the mainland, across the Saint Croix River, (to the east of the island) at a distance of approximately 1 km. A 20–45X telescope was used. All seals hauled out onto the eastern (offshore) side of the ledges or onto very low profile ledges. Thus, all hauled animals could be seen from the observation site. Visits to and around Saint Croix Island confirmed this observation. Counts were made almost every day that visibility permitted. The study was conducted from May 10–Sept. 1 (1983 (65 observation days) and April 15–Sept. 1, 1984 (94 observation days). The counts were made at 10 minute intervals over a four to six hour period centred on low tide. On a few days, observations were made on both morning and evening low tides.

Environmental variables measured at or near the study site included:

(1) the date of observation (converted to an observation number, with the first day of observation being day one)
(2) time of day at ten-minute intervals
(3) human disturbance scored as one for presence or zero for absence
(4) precipitation similarly scored
(5) air temperature measured in an unshaded condition
(6) wind speed (km/h) measured with an 'Airguide' hand-held anemometer
(7) wave height in the estuary based on the Beaufort scale
(8) the height of surf hitting the haul-out in seal body 'thicknesses'
(9) cloud cover measured as percent of sky covered
(10) time of each count from low tide
(11) time from first light of each count
(12) wind direction
(13) wave direction classified into one of eight 45° sectors with true north to 45° east designated as sector one
(14) water temperature at St. Andrews, N.B. (3 km distant)
(15) air-water temperature difference (variable 5 minus 14)
(16) windchill factor as per Boulva and McLaren (1979)
(17) solar radiation at St. Andrews, as measured on an Eppley radiometer (1984 only)
(18) black globe temperature (1984 only)
(19) surface temperature of seaweed covered rock (1984 only)

Data were analysed with the SAS statistical packages (SAS Inst. 1982). After the data had been examined with correlation analyses, stepwise regressions were run with a significance level for entry into the model of $P<0.05$.

Results

At St. Croix Island there was more accessible ledge space available than was used by the seals. The preferred ledges were large and flat, with a gently sloping profile. In 1984, the seals consistently hauled out onto one set of ledges near the south end of the island, then moved to lower profile ledges farther from the island as the latter were exposed by the falling tide. The maximum number of seals counted during one low tide was 94 in 1983 and 75 in 1984. These maximum counts occurred in May of each year. The numbers of seals counted varied significantly with month in each year ($\chi^2=535.2$, 1983; $\chi^2=299.9$, 1984; $P<0.001$). There was a mid-summer decline in attendance at the haul-out site during both years.

The numbers of seals on land were often not constant on a minute-by-minute basis. Numbers on land could change rapidly and always decreased as a result of human disturbance (usually in the form of a boat approaching the haul-out site). Sometimes seals rushed to the water without apparent cause. At any time during the low tide cycle, seal numbers on land could range from zero to 100% of the maximum daily count.

Correlation matrices were produced for all recorded variables for both years to examine independence and multicollinearity of the data. No single variable, or combination of several variables, had significant predictive power to explain the variation in the data. This decision was tested with a principal component analysis (SAS Inst., 1982); of 17 variables that could be entered in the analysis, 9 components were required to explain 90% of the variation, the first 2 components explained less than 50% of the variation, and the relationships revealed were not necessarily meaningful.

Based on the results of these latter tests, relationships between the maximum daily counts and all recorded environmental variables were examined with multiple linear regression analysis using stepwise and maximum R^2 procedures (SAS Inst. 1982). Regressions were run on raw data and data that had been subjected to a time-series analysis (Pauli, 1985). Only the maximum daily counts were used in the regression analysis to eliminate autocorrelation among the counts on a minute-by-minute basis. The mid-summer decline in the numbers of seals observed was smoothed by using the square of the observation number as a variable in the regressions.

Few of the recorded meteorological variables alone exerted a significant influence on the maximum number of seals hauled out on a daily basis (Table 1). The strong influence of the tide was diminished by using only the maximum daily count in the regressions; as the highest count usually occurred near low tide, time to low tide was often an insignificant or barely significantly variable in the equations. Those variables that were significant could be found in the equations for each year or in one year and in the pooled data for both years (Table 1). Meteorological variables related to fewer seals on land were those subjectively associated with inclement weather conditions. Wind speed and wave size, however, were associated with an increased number of seals in 1983 and 1984 respectively. These variables were correlated with each other (Spearman rank correlations $r_s=0.6$, 1983; $r_s=0.76$, 1984; $P<0.0001$). In addition, both wind speed (1983) and wave size (1984) were related to wave direction ($F=25.79$, $R^2=0.43$ and $F=58.89$, $R^2=0.56$ respectively; $P<0.0001$). This suggests an indirect positive correlation of wave direction and the number of seals on land, although the direct correlation is not significant. The positive influence of wind speed and wave size in the regression equations might be explained by

Table 1. Summary of a stepwise multiple regression analysis of maximum daily counts on environmental variables; 1983, 1984 and combined. Only those variables significant at $P<0.05$ are included. Variables are listed in approximate order of significance.

Variable	Nature of Influence on Seal Numbers 1983	1984	Both years
1. Precipitation	−ve	−ve	−ve
2. Square of date (observation)	+ve	+ve	+ve
3. Height of surf at haul-out	−ve	−ve	−ve
4. Date (observation)	−ve	—	−ve
5. Time since dawn	+ve	—	+ve
6. Height of waves offshore	—	+ve	+ve
7. Time to low tide	—	—	−ve
8. Wind speed	+ve	—	—
9. Disturbance	−ve	—	—
n	71	97	168
F	25.91	11.42	11.70
R^2	0.73	0.34	0.34

the association of these variables with waves from the west (when the hauling grounds were in the lee of the waves). No other significant correlations were found between wind speed and wave size and any of the other variables.

The best regression line resulting from analysis of the 1983 data was used in an attempt to predict the number of seals that would haul out given the meteorological conditions recorded during observation days in 1984. The equation used was $Y=53.61-2.1\ (\text{date})+0.02\ (\text{date squared})+1.0\ (\text{wind speed})+0.02\ (\text{time since dawn})-8.27\ (\text{precipitation})-8.54\ (\text{disturbance})-0.75\ (\text{surf})$. The fit of the predicted values to the observed counts was examined with a χ^2 goodness-of-fit test. We found that the equation produced by the maximum r^2 procedure was the best predictor of the number of seals that could be seen one year later (average deviation about ten seals). however, because this equation contained 15 variables, equations from other stepwise regressions were also tested (Table 1). Although the predictive power was diminished (deviation of over 25 seals), the relationships that had been revealed among the environmental factors and haul-out behaviour were supported.

As the counts spanned the pupping and later post-pupping (mating and early moult) periods, the data were divided into two groups and analysed separately. The period deemed the 'pupping season' commenced with the start of observations and ended on June 14. This is the period of whelping in the study area (Boulva & McLaren, 1979). The post-pupping period continued until the end of August. Several new relationships emerged as a result of the separate analyses. During the 1983 pupping season, wind speed and hour of day were the only variables significantly positively correlated with numbers of seals on land ($F=20{\cdot}98$, $R^2=0{\cdot}75$, $P<0.0001$). Variables that were negatively correlated with the number of seals hauled out were precipitation, surf height and disturbance. During the 1984 pupping season, both wave size and solar radiation (data for which were collected only in 1984) were positively correlated with numbers of seals on land ($F=11.54$, $R^2=0.45$, $P<0.0001$), while precipitation showed a negative correlation. Neither wave size nor wind speed was significantly associated with seal numbers on land during the post-pupping season of either year. During the post-pupping season of 1984 however, there was a positive relationship of seal numbers on land with solar radiation until July 15, after which there was also a positive correlation with the air-water temperature difference.

Discussion

There was a great deal of variability in the number of harbour seals hauled out at Saint Croix Island during any low tide. While the most important factor influencing haul-out behaviour was the tide, time of day was also important with a greater number of seals hauling out in the early afternoon (Pauli & Terhune, 1987). A negative correlation between harbour seal numbers on land and tide height has been noted in a number of studies (Pitcher & McAllister, 1981; Sullivan, 1980; Schneider & Payne, 1983; Terhune & Almon, 1983; Stewart, 1984). Yet when the tidal influence is removed (for example by observing the hauling grounds only at low tide), there is still much variability in the counts. The sources of this variability include the local environmental conditions, human-related disturbances to the hauled-out group, and individual differences in seal behaviour. Other researchers have concluded either that harbour seal haul-out behaviour is difficult to predict unless meteorological conditions are inclement (e.g. Loughlin, 1978) or that, because the behaviour of individual seals varies extensively, conclusions regarding numbers of seals on land versus meteorological conditions are unreliable (Brown & Mate, 1983).

Examination of a number of studies, however, reveals common patterns in harbour seal haul-out behaviour. Recently, Schneider and Payne (1983) and Krieber and Barrette (1984) have found patterns consistent with those described in the present study. Almost identical variables were found to exert a similar influence on haul-out behaviour in all three of these studies except for the positive relationship with wind speed and wave height that we observed at Saint

Croix Island (the Krieber and Barrette (1984) study did not examine wave height). The general conclusion from these studies is that increased numbers of harbour seals will be found on land with meteorological conditions that lead to warmer air temperatures, less cloud and no rainfall. Conversely, haul-out counts will diminish under inclement weather conditions. The unique exception we found to this latter statement is the sea state. The explanation for this lies in that fact that because the hauling grounds were sheltered and often in the lee of the island, the height of waves in the estuary and the height of surf at the haul-out site were not necessarily related. We found that with increased surf height at the haul-out, the number of seals on land was always diminished. This supports Sullivan's (1980) suggestion that surf at the hauling grounds may physically interfere with the animals hauling out. Increased wind speed and wave height in the estuary, on the other hand, were related to larger numbers of seals on land (Table 1). This relationship may be related to the waves making it more difficult for seals to rest or perform other activities in the water, resulting in their coming ashore. As this negative relationship was also particularly apparent in the 'pupping season' data, it might be related to the animals hauling out to whelp or nurse their pups.

The numbers of seals hauled out at Saint Croix Island appeared to be related to factors which would generate warmer air temperatures (e.g. solar radiation during the early 1984 season and air-water temperature differences late in the 1984 season). The relationship was not strong enough for air temperature to appear in the stepwise multiple regression analysis of both seasons (Table 1). The reason for this is that the highest haul-out counts occurred during the colder spring whelping period of both years; later, increased counts occurred during the warmer afternoon hours (Pauli & Terhune, 1987) which nullified the earlier trend. The relationship with solar radiation may be a result of the seals leaving the water to increase surface temperatures for epidermal maintenance and repair. This behaviour would be particularly important in Passamaquoddy Bay where water temperatures are cold throughout the year. By hauling out, the seals can increase their pelt surface temperatures, (and presumably their skin surface temperatures by vasodilation of the peripheral blubber layers), from an ambient water temperature of 9°–12°C to well over 30°C on sunny days (Pauli, unpublished data). Thus, hauling out may be important during the late summer and fall moulting period when the seals may come ashore in order to warm their skin for epidermal maintenance and for the moult (Ling *et al.*, 1974). Support for this comes from the finding that harbour seals spend more time on land during the moult (Boulva & McLaren, 1979; Pitcher & Calkins, 1979; Brown & Mate, 1983). At other times of the year, seals may haul out to conserve energy or to rest. The increased numbers of seals on land as a result of increased wave height in the estuary suggests that factors other than temperature may also be important.

One consequence stemming from the variable influence of meteorological factors on the number of seals hauling out is that the proportion of seals remaining in the water will be similarly influenced. This would be important when the size of a local harbour seal population is estimated from haul-out counts. While a regression equation similar to the one reported in this study may be used as a crude guide to estimating 'correction factors' which might be applied during or after a harbour seal haul-out count, the accuracy of such an approch remains to be evaluated. The equations may simply be used as a guide to the variables that could be assessed before an aerial census for harbour seals is conducted. This would help ensure that the censuses are conducted during optimal conditions for haul-out. Such censuses might return to the highest estimate of the local seal populations.

Even if this were to be attempted, however, sufficient ground truthing would have to be undertaken to ensure that factors such as human disturbance, local wind and surf conditions and/or seals moving to another, nearby haul-out site were considered.

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