Nursing Behaviors of Beluga Calves (*Delphinapterus leucas*) Born in Captivity

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The nursing behaviors of two beluga whale calves were observed for the first 55 days postpartum. For both calves, the total time spent nursing in a given period peaked around 7–10 days postpartum and then declined over time. One calf, however, was found to have an unusual decline in nursing at day 35 postpartum. Ten days later, this calf was diagnosed as having a bacterial infection and given antibiotics. This suggests that early detection of health problems may be possible by observing calves' nursing behavior. For both calves, their general nursing patterns were similar, although one calf consistently nursed more than the other. Both calves nursed roughly every half hour, neither showed any signs of a circadian pattern, and carryover effects for both calves were found, indicating that there was a relationship in the overall nursing pattern from one interval to the next. That is, if nursing dropped off during one interval, it was typically made up in the next interval. Zoo Biol 16:247–262, 1997.

Key words: lactation; suckling; reproduction; cetacean; beluga

INTRODUCTION

The successful nursing of a beluga calf (*Delphinapterus leucas*) by its natural mother in captivity is an important concern for zoological parks and aquariums and for the continued survival of the captive beluga population. The birth of two beluga calves born within one week of each other at the same location presented a unique opportunity to study and directly compare the nursing events of two calves reared by two different cows almost simultaneously.

There have been other studies describing the nursing events of cetaceans, though it is difficult to find articles specific to beluga behavior. Drinnan and Sadleir (1981)

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described the nursing behavior of a captive-born beluga calf conceived in the wild for the first 111 days of life. Our study discusses in more detail the frequency of nursing bouts and the amount of time spent nursing. Information on the nursing behavior of other cetaceans is available for comparison: on bottle-nose dolphin (*Tursiops truncatus*) behavior [Eastcott and Dickinson, 1987; McBride and Kritzler, 1951; Tavolga and Essapian, 1957], on killer whales (*Orcinus orca*) [Asper et al., 1988], on common dolphins (*Delphinus delphis* L.) [Logan and Robson, 1971], and on Commerson's dolphins (*Cephalorhynchus commersonii*) [Joseph et al., 1987]. Such studies can be used to highlight similarities and differences in nursing behavior of the different cetacean species.

METHODS

A male beluga calf (Hudson) was born at The Aquarium for Wildlife Conservation in Brooklyn, New York on August 7, 1991 at 2:31 A.M. His mother, Natasha, an 11-year old, was captured at Manitoba, Canada on July 16, 1984 and had been at the Aquarium for Wildlife Conservation for 7 years. The male calf was her first offspring. Another male (Casey), was born a week later, on August 14, 1991 at 12:41 A.M. His mother, Kathy, a 20-year old, was captured at Manitoba, Canada on February 24, 1976 and had been with the aquarium for 16 years. Kathy had given birth 10 years prior (the calf never nursed and died 8 weeks later of enteritis).

The whales were housed in three interconnecting pools (A, B, and C) with gates that could be opened or closed. Pools A and C were 125,000-liters (50 ft. dia. × 12 ft. deep) and Pool B was 27,500-liters (25 ft. dia. × 10 ft. deep). The pools were supplied with ocean water filtered through a high rate sand filter in a semi-closed, chlorinated system with surface skimming. Coliform counts were maintained below 100 colonies/100 ml [Calle et al., 1993]. Pool A was connected to Pool B, which was connected to Pool C.

Originally, Natasha, Hudson, and Kathy were housed together in Pool A. Approximately 8 hours after Hudson's birth, Kathy ranked Hudson twice on the flank for unknown reasons (for more discussion see Cook et al., 1992). Although the injury was not severe, Kathy was moved to Pool B. Visual contact was permitted, allowing Kathy to observed the nursing behaviors of Hudson and Natasha. A week later Kathy was moved to Pool C where she gave birth to Casey, and Newfy was placed in Pool B.

Definition of Terms

Lockon. Occurs when the calf attaches to the nipple while presumably suckling milk from the mammary gland [Drinnan and Sadleir, 1981]. Drinnan and Sadleir classified a successful suckling as having occurred when milk was consumed by the calf. It should be noted that we could not confirm that milk was consumed during this time, only that the calf was observed to be locked onto the nipple. Frequently, however, when the nipple was released, milk was released into the tank, suggesting that at these times, milk was indeed consumed. In this study, the terms "lockon" and "nursing" are used interchangeably.

Bouts. A group of one or more lockons occurring within a 5 min interval [Drinnan and Sadleir, 1981]. A new bout occurred when there was a gap of 5 min or more between nursing events (1–10 sampling).

Period. A 6 hr time interval (a 24-hr day was divided into four periods).

Day/Night. Day was defined to be from 8 A.M. to 8 P.M.

Nursing. The total lockon or nursing event (recorded in sec). This was the total number of sec from lockon to lockoff, a calf was observed to be on his mother's mammary [Cowie et al., 1951].

Data Collection

The data examined here refer to roughly the first 55 days of life for each calf. Belugas are largely dependent upon nursing for the first year, until their teeth emerge [Katona et al., 1983]. Afterwards, they supplement their diet with shrimp and small fish [Haley, 1978]. Most calves nurse from 20–24 months [Noward, 1991], and some nurse for up to 2 years [Katona et al., 1983]. Following our study, Hudson died at age 2 1/2, on March 3, 1994. Casey is still alive.

Data sheets were designed to record the date, time, and duration of lockons. Whenever possible, three observers were stationed around the tank to provide the best possible viewing of the calf as it nursed. The sampling method constituted two focal-pair samplings [Altmann, 1974], where nursing activity was continuously observed during the sample periods. Each observer was given a stopwatch and a walkie-talkie used for inter-observer communication. Observations were made from two underwater windows and from the whale shed where a video camera allowed the observer to watch underwater activity. Once lockon was verified by an observer with the best view, the other observers timed the event and the time from lockon to lockoff was recorded. Although formal inter-observer reliability testing was not conducted, the observers were trained, the recorded values of each of the three observers were generally consistent with each other, and at least one aquarium employee was always present. Whale watches were conducted around the clock in 4-hr shifts. A total of 30 observers were used, and more than 50% of them were aquarium personnel. The information from the data sheets was entered on a personal computer using the spreadsheet package QuattroPro [Borland, 1993].

Statistical Methods

The observations took the form of time series data. It can be expected that neighboring observations may be correlated with each other and all analysis was done based on this expectation [Brown et al., 1990]. More detailed discussion of these data and the methods used to analyze them can be found in Chatterjee et al. [1995].

Due to a shortage of personnel, observations could not be made 24 hr per day for all 55 days. The pattern of incomplete and missing observations is as follows: the first 19 days of Hudson's data were complete, i.e., 24-hr per day. For the remaining 38 days of study, 40% of the periods had complete data, 30% had partial data, and 30% were without observation. The total percentage of periods with missing data was thus 19.3%, corresponding to 957 hr observed out of 1368 total hr. For Casey, the first 12 days of data collection were complete. The remaining 44 days of observations consisted of 17% complete periods, 40% partial periods, and 43% missing periods, for a total percentage of missing periods of data collection of 33.6%, corresponding to 713 hr observed out of 1338 total hr. When partial information was available, the data collected were used to proportionally account for the times with no data. If a period was completely unobserved, the values for that period were taken to be the linear interpolants from the two neighboring time periods. Comparisons using plots, t-tests, and regression analysis of the time periods with the adjusted data to those with the complete data gave no evidence of any biases introduced by using these adjustments (see the Appendix for more details). It was crucial to make adjustments of this type, because of the time series nature of the data. As the results of the next section demonstrate, ignoring the time ordering results in serious violations of the assumptions of the analysis and a severe loss of predictive power of the model.

All analyses are based on these adjusted data. Statistical and graphical analyses were performed using the BMDP [Brown et al., 1990], STATISTIX [Analytical Software, 1992] and S-PLUS [Statistical Sciences, 1993] statistical packages, with all figures here being produced using the last named package.

RESULTS

Nursing Times

The target variable of interest was the amount of time spent locked on per period (called nursing times) for each calf. Fig. 1 gives side-by-side boxplots of the nursing times for Hudson and Casey, separated by the number of days postpartum. The limits of the boxes are the upper and lower quartiles of the period nursing time values for each day, while the limits of the dotted lines correspond to the minimum and maximum values. The horizontal line in each box is the median period nursing time for that day. Several patterns are apparent from these plots:

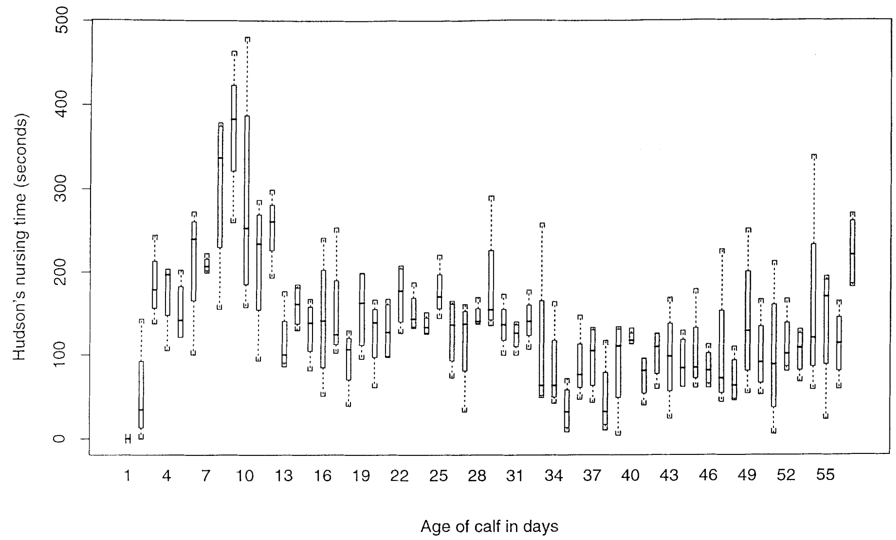
(1) The median nursing times for Casey are higher than those for Hudson, for virtually every day in the time studied, indicating that Casey was nursing on average more then Hudson. In fact, in almost 90% of the individual time periods Casey's nursing time exceeded Hudson's, far more than would be expected if the median nursing times were equal.

(2) Other than the higher values for Casey, the two nursing time series exhibit similar patterns in nursing behavior. In particular, both series start flat at zero, since each calf's first successful nursing episode occurred several periods postpartum (33 hr for Hudson, 18 hr for Casey). Then, each series rises rapidly, peaking at around 7–10 days postpartum, and then slowly declining.

(3) Casey's series exhibits a sudden increase in nursing between 20 and 40 days postpartum, which is not observed in Hudson's series.

(4) There is a good deal of variation in nursing times from period to period, with nursing times on any one day often varying by several hundred sec from one 6 hr time period to another. The variability is directly related to the level of nursing, with more nursing generally associated with a wider range of individual nursing times.

(5) There is a decline in Hudson's nursing times, starting at around 35 days postpartum. This is not easy to see in Fig. 1, because of large within-day and between-day variation, but is more apparent in Fig. 2. The latter figure is a three day (12 six-hr periods) centered moving average of Hudson's nursing times. So, for example, the value at Day 2 is the average of the nursing times for all periods in Days 1 through 3. This moving average smooths over random perturbations in the nursing times, leaving just two dominant features: the large peak around Day 10 (mentioned in (2) above), and a pronounced decline around Day 35. Note that the many small



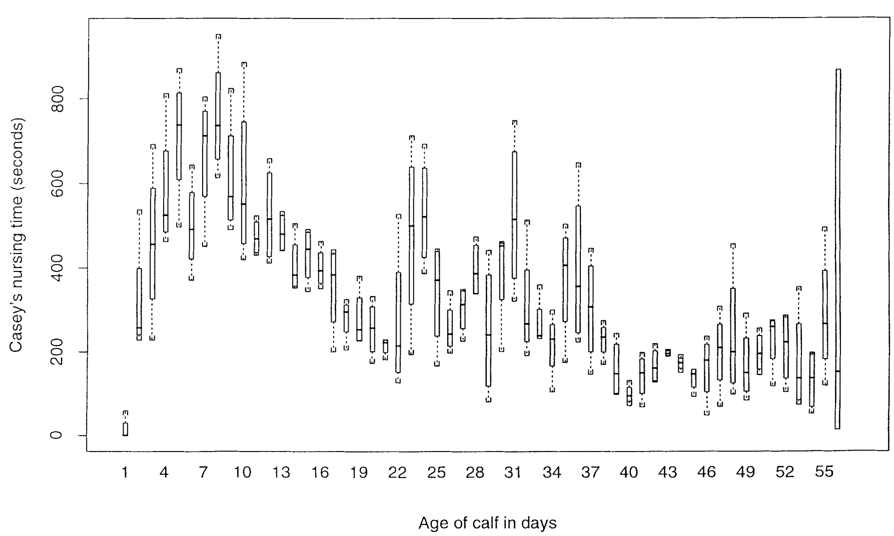


Fig. 1. Side-by-side boxplots of time period nursing times separated by number of days postpartum.

"jagged edges" of the curve represent random fluctuation in nursing times, but the Day 35 decline is far deeper than this general level of variability. More sophisticated smoothing methods can be used to highlight this pattern even more clearly (see Simonoff, 1996, Fig. 5.18 for details).

Number of Bouts

Fig. 3 gives side-by-side boxplots of the number of nursing bouts per period for each calf. This number is fairly stable at around 9–11 bouts per 6-hr time period separated by day for both calves, except around Day 35 for Hudson (corresponding

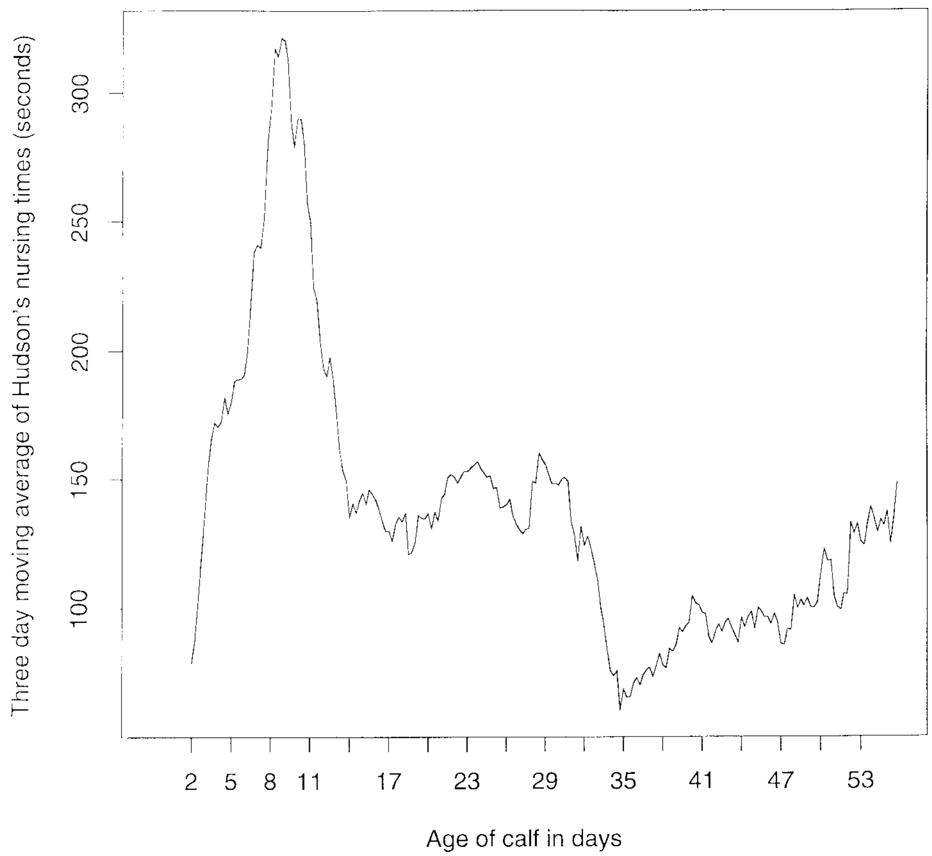


Fig. 2. Three day (12 six-hour periods) centered moving average plot of Hudson's nursing times.

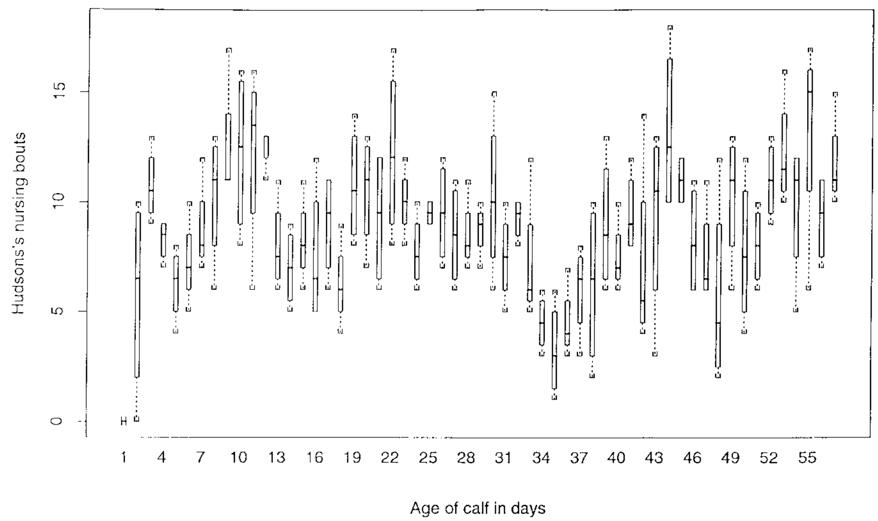
to the decline in nursing described earlier). That is, a nursing bout was occurring on average roughly 10 times per 6-hr time period, or every 36 min. This can be seen by observing the daily median bout per period values, which are represented by the solid lines inside the boxes.

Table 1 summarizes several aspects of the nursing experience for each calf, separated by number of weeks postpartum. The table gives average values per period of nursing time, lockons, and bouts, and of lockons per bout. The table reinforces the patterns noted earlier in the plots, including the general time trend of nursing levels and the higher levels of nursing time and lockons for Casey.

Prediction of Nursing Times

A least squares regression with the period, number of lockons and number of bouts as the predictors of Hudson's nursing time was performed, and had a Durbin-Watson statistic of 1.00, strongly rejecting the hypothesis of no autocorrelation ($P < .0001$). Due to autocorrelation of the residuals, the time series structure of the data makes analysis on the original data problematic.

We addressed this problem by differencing the data. That is, the target variable was to be the change in nursing time from the previous time period to the current



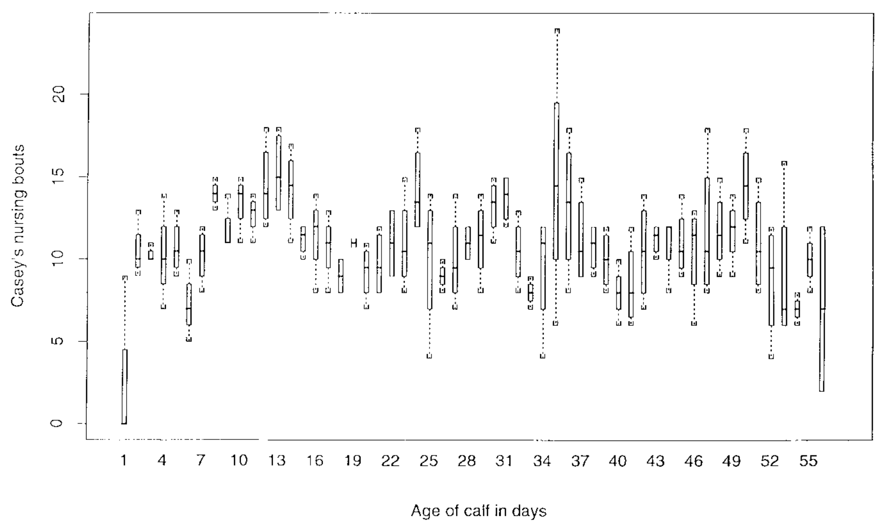


Fig. 3. Side-by side boxplots of time period nursing bouts separated by number of days postpartum.

time period: $NURSING_t - NURSING_{t-1}$. Using this as our target variable removes the autocorrelation problems, while still allowing direct prediction of nursing times using readily available information with no change in the analysis.

Fig. 4. gives scatter plots for Hudson's data of the change in nursing time vs (1) the number of lockons in the current period, (2) the number of lockons in the previous period, and (3) the amount of nursing in the previous period. Corresponding plots for Casey's data were very similar. As might be expected, a higher level of nursing activity, measured by the number of lockons, was associated with an increase in nursing time.

TABLE 1. Weekly summaries of average nursing patterns by number of weeks postpartum

HUDSON

Weeks Postpartum	Nursing Time (in secs)	Nursing Bouts	Lockons	Lockons per bout
1	140.6	6.7	17.9	2.64
2	252.6	10.7	23.5	2.15
3	132.9	8.8	11.9	1.34
4	146.4	9.4	12.9	1.37
5	116.0	7.3	10.6	1.45
6	88.1	7.1	10.7	1.48
7	98.5	9.3	18.8	2.18
8	118.5	10.2	19.2	1.85
9	223.3	11.8	23.0	2.03

CASEY

Weeks Postpartum	Nursing Time (in secs)	Nursing Bouts	Lockons	Lockons per bout
1	465.0	8.8	25.3	2.89
2	552.0	13.7	40.2	2.95
3	315.4	10.4	23.0	2.20
4	366.7	10.9	28.0	2.64
5	332.6	11.6	27.1	2.31
6	212.9	10.3	26.0	2.49
7	181.3	11.3	22.3	1.98
8	219.7	9.7	25.0	2.61

Carryover Effects

We examined the possibility of carryover effects, where the level of nursing activity in the previous time period (measured by number of lockons or nursing time itself) would be a predictor of activity in the current time period. If such effects existed, we should see a relationship between change in nursing time compared to the previous period's lockons and nursing times. The observed negative associations (Fig. 4) imply that an unusually high level of activity in the previous time period is associated with decreased activity in the next time period, and visa versa. Since the first few time periods where no feeding took place were clearly different from subsequent time periods, they were not used for this analysis.

For Hudson's data, a strong model ($R^2 = .76$, $F = 172.6$, $P < .0001$) was found to predict the change in nursing time from the current time period, the number of lockons in the current time period, the number of lockons in the previous time period, and the nursing time in the previous time period:

$$\text{NURSING}_t - \text{NURSING}_{t-1} = 43.53 - .205 \times t + 6.731 \times \text{LOCKONS}_t - 3.460 \times \text{LOCKONS}_{t-1} - .516 \times \text{NURSING}_{t-1}$$

or, equivalently,

$$\text{NURSING}_t = 43.53 + .484 \times \text{NURSING}_{t-1} - .205 \times t + 6.731 \times \text{LOCKONS}_t - 3.460 \times \text{LOCKONS}_{t-1}.$$

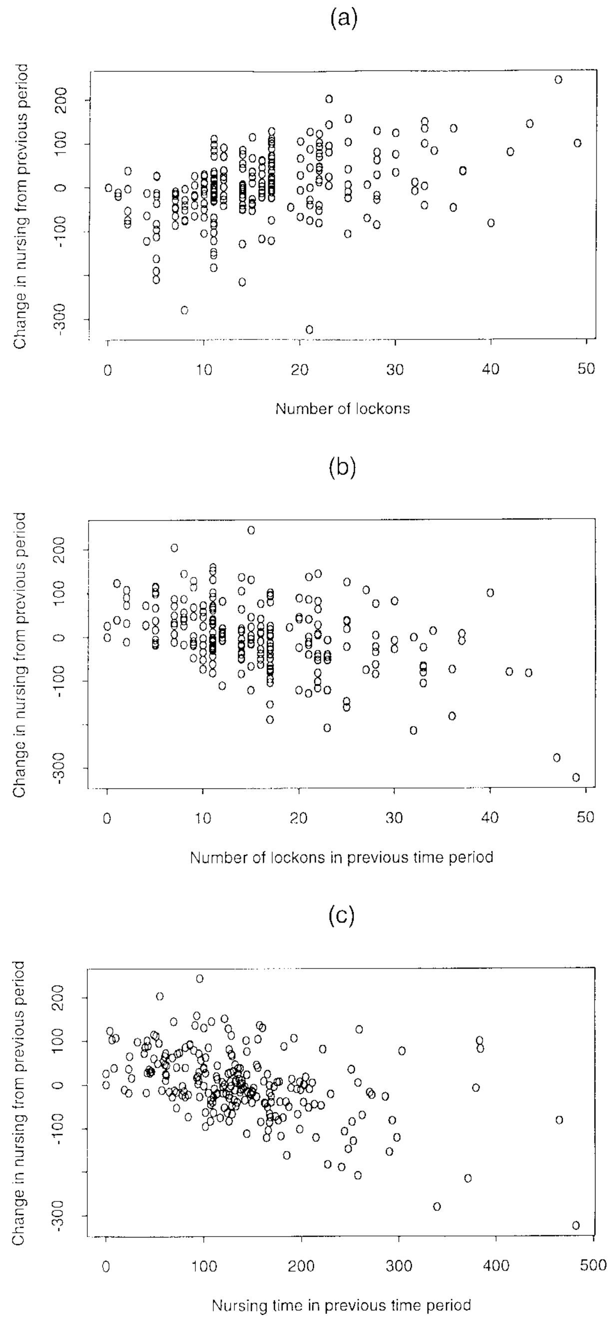


Fig. 4. Scatter plots relating the change in nursing time from the previous period to various predictors for Hudson's data. (a) Number of lockons in the current period as predictor. (b) Number of lockons in the previous period as predictor. (c) Nursing time in the previous period as predictor.

An indicator variable identifying whether or not the time period was during the day or night did not add significantly to the fit, implying that no circadian effect is apparent.

When this model was applied to Hudson's actual nursing times, the standard deviation of the predictions of nursing times per 6-hr time period after nursing began was 38.2 sec. Given that Hudson's nursing time reached as high as 480+ sec, this is a considerable gain in predictive power.

For Casey's data, the best model is somewhat weaker than for Hudson's data ($R^2 = .55$, $F = 52.9$, $P < .0001$), predicting the change in nursing time from the current time period, the number of lockons in the current time period, the number of nursing bouts in the current time period, the number of nursing bouts in the previous time period, and the nursing time in the previous time period:

$$\begin{aligned} \text{NURSING}_t - \text{NURSING}_{t-1} = {} & 139.05 - .835 \times t + 5.730 \times \text{LOCKONS}_t \\ & + 10.818 \times \text{BOUTS}_t - 11.048 \times \text{BOUTS}_{t-1} \\ & - .594 \times \text{NURSING}_{t-1} \end{aligned}$$

or, equivalently

$$\begin{aligned} \text{NURSING}_t = {} & 139.05 + .406 \times \text{NURSING}_{t-1} - .835 \times t + 5.630 \times \text{LOCKONS}_t \\ & + 10.818 \times \text{BOUTS}_t - 11.048 \times \text{BOUTS}_{t-1}. \end{aligned}$$

Once again, no circadian effect is apparent for these data.

When this model is applied to Casey's actual nursing times, the standard deviation of the predictions of nursing times per 6-hr time period after nursing began was 113.7 sec. This is considerably larger than for Hudson, but it should be recalled that Casey's nursing times exceeded 950 sec for one time period, so it still reflects a considerable gain in predictive power.

The similarity of the two models is noteworthy. Although Casey's model involves the nursing bouts variable, Hudson's model uses the lockon variable, both imply the same general decrease in change in nursing over time (given the other variables), positive association with measures of nursing intensity in the current period (given the other variables), and negative association with measures of nursing intensity in the previous period (given the other variables). From this, we see that it is possible to predict the amount of nursing from a few readily available variables.

A limitation of these models is that, despite their functional similarities, they are not able to account for the inherent difference in level of nursing times for the two calves. Fig. 5 (a) presents a time series plot of the actual nursing time for Hudson (solid line) and the predictions of Hudson's nursing time implied by the model built using Casey's data (dashed line). Fig. 5 (b) is a corresponding plot of Casey's nursing times (solid line) and times implied by the model built using Hudson's data (dashed line). Although the predicted times follow the general pattern of the observed times, the predictions of Hudson's nursing are consistently too high (a median error of 41.5 sec), while those of Casey are consistently too low (a median error of 40.6 sec).

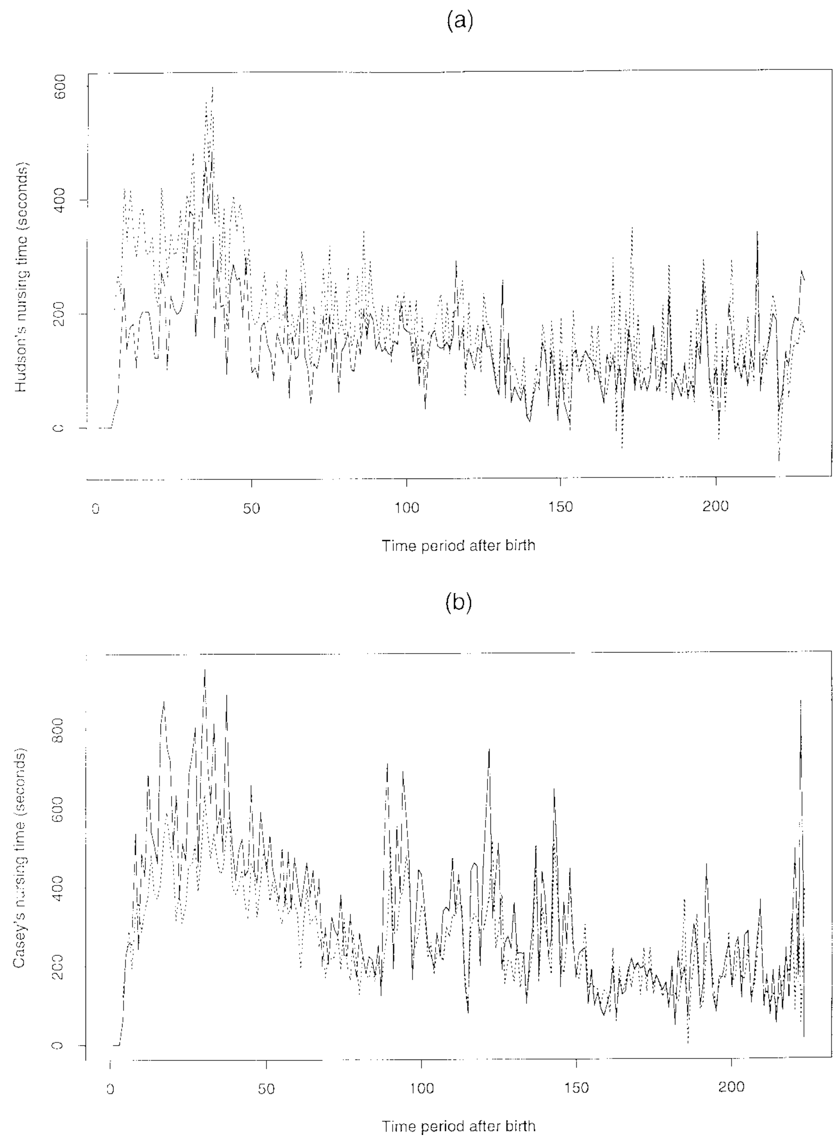


Fig. 5. Time series plots of actual and predicted nursing time per period. (a) Actual nursing time for Hudson (solid line) and predicted nursing time for Hudson based on Casey's data (dashed line). (b) Actual nursing time for Casey (solid line) and predicted nursing time for Casey based on Hudson's data (dashed line).

DISCUSSION

Casey's nursing times were substantially higher than Hudson's on average, given the other variables. We speculated on a number of factors that could have contributed to this: (1) Casey's mother, Kathy, had been more receptive to nursing than Hudson's mother. In fact, Casey's mother had presented her mammaries only 2 hr postpartum while Hudson's mother was reluctant to allow nursing; (2) Casey's mother was older and had previously had an offspring, and (3) the incident, mentioned earlier, where Kathy raked Hudson.

Although Casey's nursing times were consistently higher than Hudson's on average the two patterns were similar, i.e., peaking around 7–10 days postpartum, and then declining. This is not consistent with the report of Drinnan and Sadleir (1981), whose data were unavailable for the first few days. However, Asper et al. (1988) noted that 7 days after the birth of a killer whale, the nursing frequency decreased. McBride and Kritzler (1951) stated for a bottle-nosed dolphin that nursing was rather frequent as the calf grew. Eastcott and Dickinson (1987) and Cockcroft and Ross (1990) also stated that there was less nursing as the calf became older. It makes sense to us that the calves would have this initial "feast" to help in their development. A thick layer of blubber would withstand the cold temperatures in which they are usually found [Stewart and Stewart, 1989] and allow them enough energy to escape from predators. Harrison (1969) reports that cetaceans double their weight within the first week of life and continue to grow rapidly during the first postnatal year. Moreover, the reason for the decline in nursing over time may be due to the calf becoming more efficient at obtaining milk and/or requiring less nourishment, and the introduction of solid foods.

Our findings revealed a major advantage to observing nursing times for a newborn calf when predicting illness. Ten days before Hudson was diagnosed as having a bacterial infection, there was a clear decline in his nursing times (at around day 35), distinguishable from the general variability in nursing times. Antibiotics were administered starting at day 45 for 24 days [Cook et al., 1992], and the calf recovered. The fact that nursing declined 10 days before any distress was noted in the calf could have important implications for future newborns, since the observation of such a decline could be an "early warning sign" of potential problems. It would be easy for zoo personnel to identify such a decline in real time for any newborn calf by constructing a moving average plot of nursing times for the previous three days, as that only depends on already observed values. Other articles on cetaceans indicate how the frequency of nursing changed just prior to illness or death. With bottle-nosed dolphins, Tavolga and Essapian (1957) noted that the day before a calf's death, it nursed very few times. In contrast, Amunden (1986) noted that an off-spring that was nursing from a sick mother had tried to nurse more frequently in order to compensate for the mother's lack of milk production. For killer whales, it was reported by Marliave (1992) that a calf's frequency of nursing rapidly increased just prior to being hand-fed by aquarium personnel when it became obvious that the calf was not receiving adequate nutrition from its mother — suggesting that it was not satiated after each nursing bout. Drinnan and Sadleir (1981) recorded that toward the end of a calf's life, all nursing activity was considerably reduced.

Also, the number of nursing bouts per period was consistent for both calves, occurring on average roughly every 36 min. This is consistent with Drinnan and Sadleir's report (1981), who stated a beluga calf nursed 17–22 bouts per 12-hr period, or every 32–42 min. Logan and Robson (1971) stated that a common dolphin (*Delphinus delphis* L.) nursed about every half hour for a few days and then gradually the periods lengthened somewhat. Joseph et al. (1987) found that Commerson's dolphins (*Cephalorhynchus commersonii*) nursed every 40 min on average. Bottle-nosed dolphins (*Tursiops truncatus*) were reported to nurse every 26 min [McBride, 1951] or every 30 min [Eastcott and Dickinson, 1987].

For both Hudson and Casey, the day/night variable did not provide predictive power, indicating no circadian effect was found. Drinnan and Sadleir (1981), when studying belugas, did not find a clear circadian pattern either. Asper et al. (1988) noted that for killer whales, nursing activity was spread throughout the day and night, indicating that no circadian pattern was apparent. But for bottle-nosed dolphins, Eastcott and Dickinson (1987) mentioned that more suckling was done at night when there was minimal interruption and human intervention.

A carryover effect of the change in nursing time from the previous time period related to other properties of nursing was noted, and could perhaps be due to fatigue or to a fuller stomach.

The comparison of Hudson's or Casey's fitted model to the actual data for each indicated that general patterns were similar, but that the actual data for Casey were higher, from which we can conclude that calf-to-calf variation is high, but general patterns were similar between the two.

CONCLUSIONS

1. One calf's nursing times were higher than the other's on average, but the general patterns were similar.

2. Nursing times for both calves peaked around 7–10 days postpartum, and then steadily declined over time.

3. On average, the calves nursed roughly every 36 min.

4. There existed a carryover effect where the amount of nursing in the previous time period could be a predictor for the amount of nursing in the next period. If the amount of nursing was unusually high in the previous time period, we could predict the amount of nursing to decrease in the following time period.

5. For both calves, no circadian pattern in nursing activity was found.

6. In one calf, a drop off in nursing occurred approximately 10 days before an infection was discovered, suggesting that observing nursing times could help to predict problems related to the health of the calf.

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APPENDIX: EFFECT OF DATA IMPUTATION

As was noted in the Statistical Methods section, incomplete and missing data were imputed for the analyses described here. This was essential, given the time series nature of the data. The target variable in each regression is the change in nursing from the previous time period; if this differenced variable is not used, the basic assumptions of the regression model are violated, since the errors exhibit both autocorrelation and heteroscedasticity. Further, each regression model relies on variables such as nursing, lockons, and bouts from the previous time period to predict the change in nursing, with almost all predictive power lost if these variables are omitted. Thus, no analysis is possible without the imputations.

Incomplete and missing data did not occur randomly. As would be expected, incomplete and especially missing data were more common during the night than during the day. For Hudson, 80 of 114 periods during the day were complete, 28 had partial data, and 6 were missing, while 55 of 114 night periods were complete, 21 partial, and 38 missing. The corresponding figures for Casey were 37 of 112 complete, 58 partial, and 17 missing (Day) vs 40 of 111 complete, 13 partial, and 58 missing (Night). Data became less complete as the calves grew older. Figure 6 is a plot of the number of hours observed per day by age for Hudson (solid line) and Casey (dashed line).

A natural way to determine whether the data imputation methods used here have affected the analyses is to check whether group membership has predictive power for the nursing time, where "group" is defined by whether a time period's nursing time was based on complete observations, on partial information, or was originally missing (unobserved). If nursing time differs based on group membership, that indicates that a bias has been introduced into the model by the data imputation.

This assessment is not made on the nursing times themselves. Since the first 2–3 weeks of observations are complete, which corresponds to a period of high overall nursing level, the complete data periods have higher nursing levels on average than that of the incomplete ones. This does not indicate a problem with the regression analyses, however, since the higher level of nursing is accounted for by the predictors in the regression.

The correct approach is to fit an analysis of covariance (ANCOVA) model using regression models for $NURSING_t - NURSING_{t-1}$, determining if group mem-

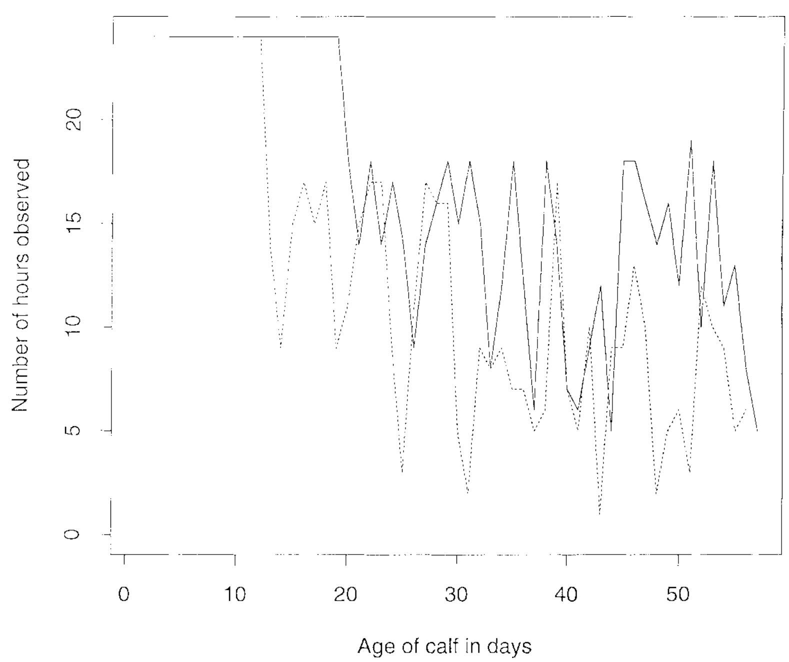

Fig. 6. Time series plots of number of hours spent observing calf per day by days postpartum for Hudson (solid line) and Casey (dashed line).

bership adds any predictive power to the fit using the appropriate partial *f*-test (see, for example, Bowerman et al., 1986, Chapter 7, for a discussion of ANCOVA partial *F*-tests). The resultant *F*-tests (for Hudson, $F = 1.23$ on (2,216) degrees of freedom, for a tail probability of .29, while for Casey $F = 1.27$ on (2,212) degrees of freedom, for a tail probability of .28) show that group membership does not add significant predictive power to either regression, and that the change in nursing time is not related to whether the time period originally had complete, partial, or no information. Thus, the estimates of the regression coefficients and resulting nursing time predictions are apparently not biased because of the data adjustments.

The imputation for missing data does have one effect on the analyses that should be noted. Since the nursing time values are set to be exactly on the straight line connecting the adjacent nursing times, they are less variable than the other values. For both Hudson's and Casey's data, the estimated standard deviation of the regression error term was roughly one-third smaller for the periods with imputed missing values than for the other periods. This leads to underestimation of the standard deviation of the errors, and inflation of the *F*-statistic that tests the overall significance of the regression.

Based on the proportions of periods with imputed missing data (19.3% for Hudson and 33.6% for Casey, respectively), we estimate that the overall *F*-statistic has been inflated by roughly 10% for Hudson and 20% for Casey, which still leaves both tests highly significant. That is, each model provides highly significant predictive power for nursing times. Simonoff (1988) described more complex imputation schemes that can be used in some circumstances to try to avoid this possible overestimation of the strength of the regression.