

Application of acceleration data loggers to classify the behavior of captive Amazonian manatees (*Trichechus inunguis*)

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Abstract—The *Trichechus inunguis* is endemic to the Amazon region. Observation is nearly impossible because of the turbid water, which consequently hinders study of their behaviour. In this study, we deployed the acceleration data loggers to 9 captive Amazonian manatees to classify their behaviour at INPA, Brazil. The experiments were also recorded by video camera. We classified four types of behaviours: inactive on the bottom, walking on the bottom, surfacing and swimming. Inactive and walking on the bottom were classified using standard deviation (SD) of dive depth and longitudinal acceleration. The SD of dive depth shows the low variability in inactive and walking on the bottom (ranged from 0.0 to 0.1 m), the SD of longitudinal acceleration shows the low variability in inactive (from 0.00 to 0.01 ms⁻²), high variability in walking on the bottom (from 0.01 to 0.15 ms⁻²). Mean classification accuracy was 87.1% and 84.9% during inactive and walking on the bottom, respectively. 6 manatees were fed floating vegetables during experiment, and they showed a characteristic of long surfacing during feeding time. This characteristic was probably a fair reflection of their natural behavior, as wild Amazonian manatees prefer floating and emergent aquatic plants.

Key words: acceleration data logger, Amazonian manatee, behaviour, classification, time budget, *Trichechus inunguis*

Introduction

The Amazonian manatee (*Trichechus inunguis*) is the only herbivorous mammal that inhabits strictly fresh water, and is endemic to the Amazon region. They are distributed throughout the Amazon basin, from the heads of rivers in Colombia, Peru and Ecuador, to the Marajo Island, Brazil (Domning 1981, Rosas 1994). To date, the only studies on sirenian diving and feeding behaviours have been based on visual observations (Domning 1980, Gomes et al. 2008, Hartman 1979, Horikoshi-Beckett and Schulte 2006, Marshall et al. 2000, Marshall et al. 2003). Hartman (1979) described the gross swimming movements of the wild Florida manatee (*Trichechus manatus latirostris*) that uses its tail and pectoral flippers for movement. The manatee's pectoral flipper is a highly maneuverable appendage, with the elbow allowing remarkable flexion. In addition, the flippers were usually used in conjunction with the tail in wild Florida manatees, as the main source of motion on the bottom. They

walked on the bottom with alternate movements of the flippers. This behaviour was reported in captive West Indian manatees: Florida and Antillean manatees (*Trichechus manatus manatus*) (Gomes et al. 2008, Horikoshi-Beckett and Schulte 2006). Only one breath is taken during a surfacing, manatees open their nostrils for air at the surface and closes them on submersion with equally precise timing (Gallivan et al. 1986, Hartman 1979). When resting, wild Florida manatees showed two basic postures: hanging suspended near the surface and lying on the bottom. This is the same posture observed with captive West Indian manatees (Gomes et al. 2008, Horikoshi-Beckett and Schulte 2006), but there are no reports about surface resting behaviour in wild Amazonian manatees. Captive Amazonian manatees were inactive on the bottom (Mukhametov et al. 1992). Regarding their feeding behaviour, dugongs (*Dugong dugon*) showed a benthic-feeding pattern (Aragones and Marsh 2000, Marsh et al. 1982), while the Florida manatees fed in a variety of manners depending on the food source (Hartman, 1979). Amazonian manatees preferred to eat floating or emergent plants (Best

1981, Colares and Colares 2002, Domning 1980, Rosas 1994), similarly to West African manatees (*Trichechus senegalensis*) (Marshall et al. 2003). Sirenians possess a short muscular snout that is covered by short sinus hairs, used to bring plants into the mouth (Hartman 1979, Marshall et al. 2003). In relation to the feeding behaviour, the degree of snout deflection was calculated by Domning (1978). Amazonian manatees and West African manatees have the least deflected snouts presumably an adaptation for feeding on floating vegetation. The dugongs possess the most deflected snout, which is advantageous for a benthic feeder, while West Indian manatees present intermediate deflection.

Although the behavioural characteristics were reported by observation in some sirenians, it was difficult to obtain temporal behavioural information, in particular of Amazonian manatees, as visual observation is made nearly impossible because of the very turbid water and the specie's naturally cryptic behaviour (Colares and Colares 2002, Rosas 1994, Rosas and Pimentel 2001). Time-depth recorder (TDR) was used to measure the dive depth in dugong, but its activity was undetermined (Chilvers et al. 2004). In the present study, we attached acceleration data logger to captive Amazonian manatees at National Institute of Amazonian Research (INPA), to classify and investigate the behavioural characteristics from dive depth and acceleration data. Behaviours were recorded using a video camera for a given length of time, in order to investigate the classification accuracy. After classification, we compared the proportion of each behavioural category during the day and at night to investigate the diurnal activity.

Materials and Methods

1. Study sites and manatees

Experiments were conducted from August 18 to 26, 2007 at INPA in Manaus, Brazil (Table 1). Data loggers were mounted on 9 manatees with a total recording time for each

individual of about 22.4–46.0 h. Study animals were kept outdoors in three outdoor circular pools (with 10 m in diameter and about 2.5 m depth). Five trials were conducted using 1–3 individuals (Table 1). The behaviours were recorded using a video camera (FVM100, Canon, Japan). Total video recording duration was from 2 to 4 h for each experiment. Based on reports that Amazonian manatees prefer to eat floating or emergent plants (Best 1981, Colares and Colares 2002, Domning 1980), all manatees at INPA are given food that floats on the surface of the water. In order to record feeding behaviour, during the experimental period, we offered customary food, such as para grass and lettuce, to 6 manatees (individuals 4–9) just once in the morning (Table 1).

2. Instruments

A W380L-PD2GT (22 mm in diameter, 132 mm in length, 79 g in air: Little Leonardo Ltd, Tokyo, Japan) and a W190L-PD2GT (20 mm in diameter, 117 mm in length, 60 g in air: Little Leonardo Ltd, Tokyo, Japan) were used in this study. Dive depth was recorded at 1 sec intervals, and longitudinal acceleration at 1/32 sec or 1/16 sec intervals by each data logger. The data loggers were attached to the dorsal surface of the manatee's body using a polypropylene belt. On four manatees (individuals 1–3, 7), the data logger was attached by a single belt fitted to the animals' girth, while on the other five manatees (individuals 4–6, 8, 9), the data logger was attached by two belts also fitted to the animals' girth. In one manatee (individual 7), the single belt arrangement was moved forward by the animal's movement during the experiment and was fitted slightly looser in comparison to the other seven individuals.

3. Data analysis

We analyzed the recorded logger-data using "Ethographer" (Sakamoto et al. 2009), which is available at no cost for academic use (<http://bre.soc.i.kyoto-u.ac.jp/bls/index.php?Ethographer>) and works with Igor Pro (WaveMetrics

Table 1. Amazonian manatee individuals used in this study. Body length (BL) and body mass (BM). Feed time is from the start of offering the foods and the end of experiment.

Individual no.	Sex	Duration of captivity (year)	Deployment duration (h)	Experiment date (mm-dd/ mm-dd)	Feed time (mm-dd hh:mm/hh:mm)	BL (m)	BM (kg)
1	F	23	45.6	08-18/08-20	NA	2.5	373
2	M	2	46.0	08-18/08-20	NA	1.2	46
3	M	3	22.4	08-19/08-20	NA	1.8	117
4	F	3	25.4	08-21/08-22	08-22 08:26/09:44	1.4	55
5	F	5	25.1	08-21/08-22	08-22 08:26/09:44	1.6	87
6	M	4	24.5	08-21/08-22	08-22 08:26/09:44	1.4	53
7	M	4	24.3	08-23/08-24	08-24 11:16/12:28	1.5	70
8	M	12	25.4	08-23/08-24	08-24 11:16/12:28	1.5	66
9	F	33	25.3	08-25/08-26	08-26 09:20/10:13	2.1	208

Inc., Lake Oswego, OR, USA). Dives were defined as manatee movements to depth greater than 0.2 m. We only used dives with a maximum depth greater than 0.5 m for exclusion of intricate movement. The longitudinal acceleration included both dynamic acceleration (such as strokes) and static acceleration (such as body angle). From visual analysis of the videos, we classified the manatee's behaviour into four categories: inactive on the bottom, walking on the bottom (using pectoral flippers), surfacing and swimming. During resting, unlike Florida manatees, captive Amazonian manatees were inactive on the bottom (Mukhametov et al. 1992). As there are no reports of surface resting in wild Amazonian manatees, we only classified inactive on the bottom (Fig. 1a). Walking on the bottom has been frequently observed in captive Amazonian manatees at INPA. We considered that this behaviour is presumably an important form of movement for Amazonian manatees, therefore it was categorized (Fig. 1b). When breathing, a manatee surfaces and exposes its nostrils. We categorized the surfacing as the time between the end of a dive period and the start of a new dive (Fig. 1c). Finally, we considered swimming to be the behaviour performed in the absence of inactive, walking on the bottom, and surfacing behaviour (Fig. 1d). To investigate the characteristic of feeding behaviour, we extracted the data during feeding periods (Table 1).

We used the standard deviation (SD) to detect the manatee's activity. The SD shows the variability of data. The SD of dive depth shows the low variability in staying the same depth, while high variability in changing the depth such as descending or ascending. The SD of longitudinal acceleration shows the low variability in inactive, while high variability in active behaviour. Because the inactive and walking on the bottom showed a very similar time-depth profile (Fig. 1a, b), we developed the classification methods using SD of dive depth and longitudinal acceleration. Using the data during inactive and walking on the bottom confirmed by video data, we calculated the SD of dive depth and longitudinal acceleration at 5 sec intervals. To classify two behaviours (inactive and walking on the bottom), the characteristics of SD were used as definitions. The accuracy of classifying inactive and walking behaviours was also calculated. These two behaviours were extracted from the video data, and the percentage of fit (misclassification) duration was calculated between the data categorized from the video and logger-data. After classifying behaviour, we calculated the proportion of each behaviour during the day and at night to investigate differences in each behaviour between these periods. We defined daytime as the period from sunrise to sunset, and nighttime as the period from sunset to sunrise (Star Date online; <http://stardate.org/>). In order to determine these calculations, the feeding period

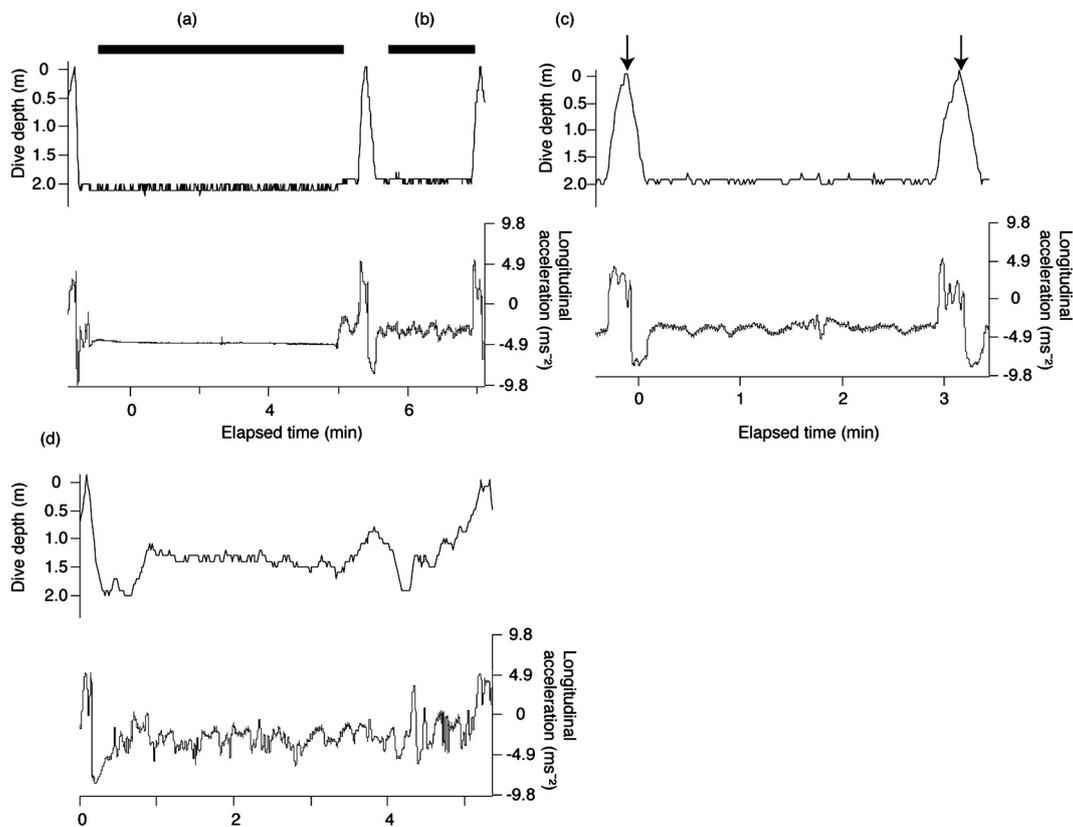


Fig. 1. Diagrams showing an example of four types of categorized behaviour: inactive (a), walking on the bottom (b), surfacing (c), swimming (d). Arrows indicate the surfacing points.

was not taken into consideration.

The differences of inactive duration between day and nighttime were analyzed using the Generalized Linear Mixed Models (GLMM) with including individual manatee as a random effect, or Generalized Linear Model (GLM) with Gamma error distributions. The surface duration was compared between feed time and the other time by analyzing the GLMM, with Gamma error distributions and individual manatee was included as random effect. The most parsimonious model was selected on the basis of AIC. For statistical analyses, we used software “R”. GLM and GLMM analyses were performed in the “R” package, GLMM was analyzed using package lme4 and function lmer.

Results

The SD of dive depth showed the same range during walking and inactive on the bottom (Fig. 2a). While the SD of longitudinal acceleration was higher during walking, it was lower during inactive on the bottom (Fig. 2b). For example, in individual 6, the SD of dive depth was from 0.05 to 0.06 m (from upper to lower quartiles of box plot) between inactive and walking on the bottom (Fig. 2a), the SD of longitudinal acceleration was from 0.00 to 0.01 ms^{-2} during inactive on the bottom, from 0.02 to 0.04 ms^{-2} during walking on the bottom (Fig. 2b). For classification of inactive on the bottom, we used the SD of dive depth from 0.0 to 0.1 m, the

SD of longitudinal acceleration from 0.00 to 0.01 ms^{-2} as definitions in 8 individuals (individual 1–6, 8–9). For classification of walking on the bottom, we used the SD of dive depth from 0.0 to 0.1 m, the SD of longitudinal acceleration from 0.01 to 0.15 ms^{-2} as definitions in 8 individuals (individual 1–6, 8–9). In individual 7, the belt was slightly looser, therefore the calculated SD was higher than the other manatees. In individual 7, we used the SD of dive depth from 0.0 to 0.2 m and longitudinal acceleration from 0.0 to 0.2 ms^{-2} as definitions for classification of inactive on the bottom, the SD of dive depth from 0.0 to 0.2 m and the SD of longitudinal acceleration from 0.2 to 1.1 ms^{-2} as definitions for classification of walking on the bottom. In order to extract only the bottom behaviour, we calculated the frequency of dive depth matching the definitions of inactive on the bottom given above, and considered the start point of peak value as bottom depth in each manatee. During walking, the length of the pectoral flippers (from 0.28 to 0.44 m in each manatee) was subtracted from the defined bottom depth for each individual to estimate the actual bottom depth during walking. We considered an individual to be inactive or walking when the categorized behaviour continued for more than 5 s (inactive: range 99–100%, walking: range 96–100% of categorized data for each manatee). Classification accuracy was from 78.6 to 100.0% during inactive on the bottom, from 76.1 to 95.7% during walking on the bottom (Table 2). We categorized the surfacing as the time between the end of a dive period and the start of a new dive, and swimming to be the be-

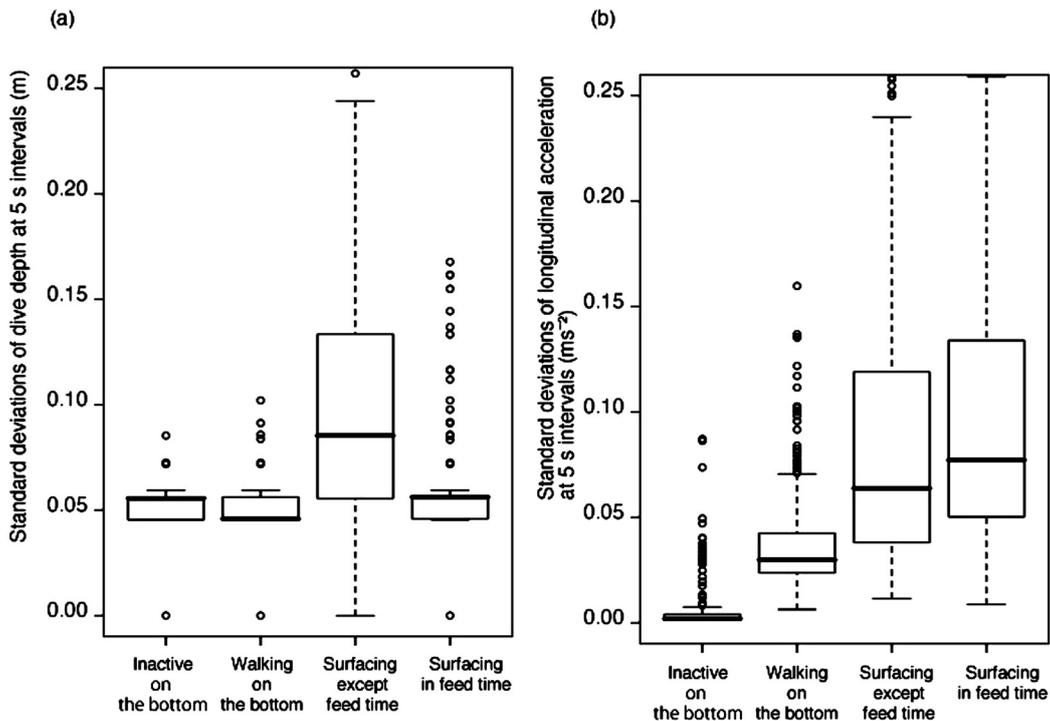
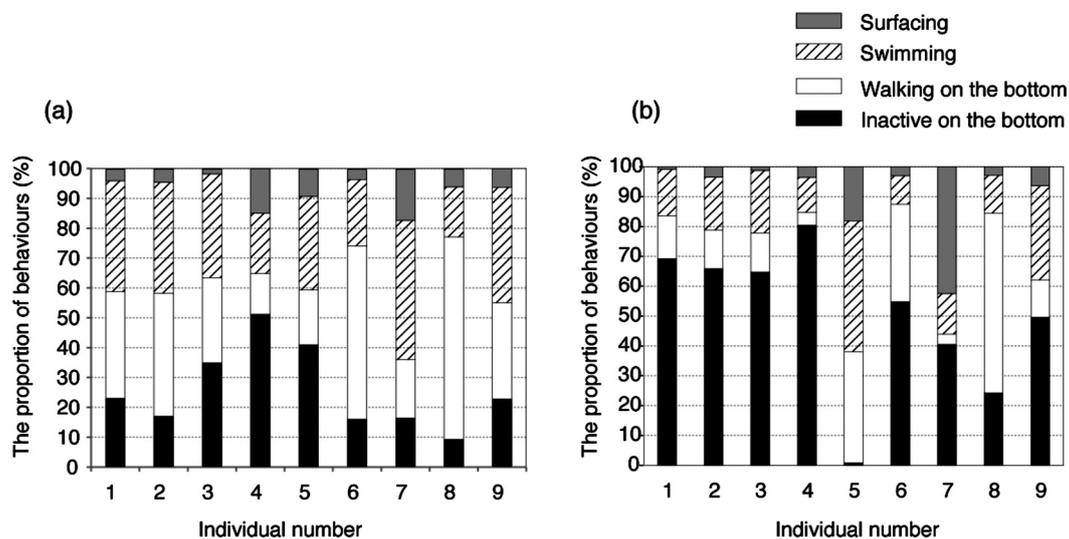


Fig. 2. Example of box plots for the standard deviations of dive depth (a) and longitudinal acceleration (b) during inactive, walking on the bottom, surfacing except feeding time, and surfacing in feeding time in individual 6. The box plots show the median (center line), the upper and lower quartiles (edges of the box), and 10% and 90% percentiles (ends of whiskers). Open circles show the outlier.

Table 2. Results for classification of inactive and walking behaviour in captive Amazonian manatees.

individual no.	Fitted duration between video and categorization (s)		Classification accuracy (%)		Percentage of misclassification			
	Inactive	Walking	Inactive	Walking	Waking	Swimming	Inactive	Swimming
1	1656	164	79.5	77.7	7.3	13.1	1.4	20.9
2	1307	3891	95.4	86.9	0.1	4.5	0.0	13.1
3	1861	416	78.6	84.4	8.7	14.2	0.0	15.6
4	2519	215	89.4	88.5	3.2	7.3	0.0	11.5
5	1408	169	82.8	76.1	7.5	9.9	0.0	24.3
6	773	1694	82.2	95.7	7.8	10.0	0.0	5.0
7	618	324	84.2	79.2	6.8	9.7	1.5	20.8
8	9	2574	100.0	94.1	0.0	0.0	0.3	5.5
9	1603	237	92.1	81.7	2.2	5.6	1.0	17.2

**Fig. 3.** The proportion of inactive, walking on the bottom, surfacing and swimming behaviour were calculated in day (a) and night (b). The behaviour during feeding time was removed from these calculations.

haviour being performed in the absence of inactive, walking on the bottom, and surfacing behaviour.

All manatees, except individual 5, were more inactive at night than during the day (Fig. 3). Only individual 5 was more inactive during the day than at night (Fig. 3). To test the effect of phase (day and night) on inactive duration, we used a GLMM with Gamma errors and all manatees except individual 5 was included as a random factor. In individual 5, to test the effect of phase (day and night) on inactive duration, we used GLM with Gamma errors. In all manatees except individual 5, the GLMM for inactive duration including phase (day and night) as explanatory variable was the best model with lowest AIC. The model had an AIC value 245.0 lower than the second best model, which included random effect only. The GLMM for inactive duration revealed that it was affected by phase, and inactive duration during the day was shorter than at night (GLMM; phase, estimate value \pm SE in day = 85.11 ± 7.06 s, at night = 19.61 ± 8.78 s). In individual

5, the GLM for inactive duration including phase as explanatory variable was the best model with lowest AIC. The model had an AIC value 18.7 lower than the second best model, which included dependent variable only. The GLM for inactive duration in individual 5 revealed that it was affected by phase (day and night), and the inactive duration during the day was longer than at night (GLM; phase, estimate value \pm SE in day = 85.11 ± 7.06 s, at night = 19.61 ± 8.78 s). During feeding time, the duration of surfacing increased compared with the other surfacing behaviour (Fig. 4). To test the effect of states (feeding time and the other time) and phase (day and night) on the duration of surfacing, we used GLMM with Gamma errors. The GLMM for the surface duration including states (feeding time and the other time) as explanatory variable was the best model with lowest AIC. The model had an AIC value 722.0 lower than the second best model, which included phase (day and night). The GLMM for the surface duration revealed that it was affected

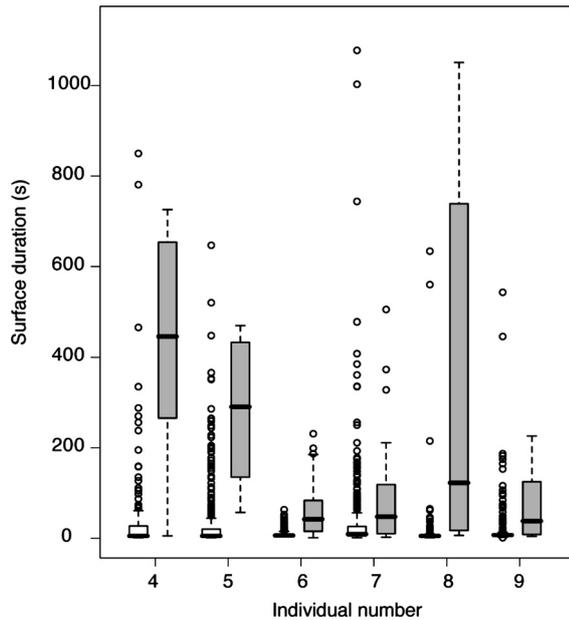


Fig. 4. Box plots for the surface duration in feed time and the other time. White bar shows the surface duration except feeding time and gray bar shows the surface duration during feeding time. The box plots show the median (center line), the upper and lower quartiles (edges of the box), and 10% and 90% percentiles (ends of whiskers). Open circles show the outlier.

by states (feed time and the other time), and the surface duration during feeding time was longer than the surface duration during the other time (GLMM; states, estimate value \pm SE in feed time = 169.30 ± 60.29 s, in the other time = 29.81 ± 30.74 s). However, there were not clearly differences of the SD of dive depth or longitudinal acceleration between surfacing in feeding and other behaviours (Fig. 2). For example, the SD of dive depth was from 0.05 to 0.06 m (from upper to lower quartiles of box plot) during surfacing in feeding, from 0.06 to 0.14 m during surfacing in other behaviour (Fig. 2a), longitudinal acceleration was from 0.04 to 0.12 ms^{-2} during surfacing in feeding, from 0.05 to 0.14 ms^{-2} during surfacing in other behaviour (Fig. 2b). In individual 7, the percentage of surfacing at night was exceedingly longer than in the other manatees we observed (Fig. 3b). To investigate the difference between surfacing duration in nighttime and feed time in individual 7, we analyzed the GLM, surface duration as dependent variable, phase 2 (nighttime and feed time) as explanatory variable, with Gamma error distributions. The GLM for surface duration including only dependent variable was the best model with lowest AIC. The model had an AIC value 1.3 lower than the second best model, which included phase 2 (nighttime and feed time). The GLM for surface duration revealed that it was not affected by phase 2 (GLM; dependent variable only, estimate value \pm SE = 128.74 ± 44.74 s), indicating that the surface duration at night was the same with the surface duration during feeding time in individual 7.

Discussion

By calculating the SD of dive depth and longitudinal acceleration, it is possible to automatically categorize inactive and walking on the bottom. During feeding, manatees tended to stay longer near the surface compared with the surface duration during other surfacing behaviours. However, there were not clearly differences of the SD of dive depth or longitudinal acceleration between surfacing in feeding and other behaviours. These results indicate that manatees surfaced and ate foods with the same movements (such as stroking and changing body angle) with short surfacing. These characteristics were probably a fair reflection of their natural behavior given that the captive animals were fed floating vegetables in order to simulate their natural foraging conditions, as wild Amazonian manatees prefer floating and emergent aquatic plants (Best 1981, Colares and Colares 2002, Domning 1980). Although manatees were not fed at night, the proportion of surfacing increased in individual 7 (Fig. 3b). During the course of our observations, we confirmed that individual 7 tried to eat fallen leaves floating on water surface several times. There was no difference in surface duration between nighttime and feeding time in individual 7, which allows us to presume that feeding also took place at night.

Calculation of activity budgets for captive Amazonian manatees showed that most individuals were inactive at night except for individual 5 (Fig. 3). In addition, the duration of inactive periods at night was longer than during the day except in individual 5. Therefore, we concluded that these eight individuals rested primarily at night but that individual 5 rested primarily during the day. It's not known exactly why individual 5 showed the nocturnally active. The time that individual 5 was kept in captivity was not much different from the other individuals (Table 1), therefore, this behaviour is apparently not related to the time spent in captivity. There are reports that indicate changes in the behaviour of dolphins in captivity, such as performance shows, training and feeding, whereby they shift their typical activity rhythms to become more diurnally active (Gnone et al. 2001, Lyamin et al. 2000, Renjun et al. 1994). Although captive Amazonian manatees do not engage in public performances or any training exercises, they are fed in the mornings. There is a possibility that feeding time affected the circadian variations. Captive Amazonian manatees showed greater diurnal or nocturnal activity, different from wild Amazonian manatees, which were equally active during the day and at night (Montgomery et al. 1981). Captive Amazonian manatees also differed from wild Florida manatees (*Trichechus manatus*), which were essentially arrhythmic, and the frequency of resting, feeding and other activities showed no consistent differences related to the time of day (Hartman 1979).

This is the first report of the detailed behavioural infor-

mation by using acceleration data loggers to sirenia. The classification methods using SD of dive depth and longitudinal acceleration will be applicable to other animals. And we expect that there will be even broader application of acceleration data loggers to sirenians in their natural environment.

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