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SOUTHWEST FISHERIES SCIENCE CENTER

NATIONAL MARINE FISHERIES SERVICE - SOUTHWEST FISHERIES SCIENCE CENTER P.O. BOX 271 LA JOLLA, CA 92038

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MEASURING SURFACE AND DEEP BODY TEMPERATURES OF DOLPHINS IN THE EASTERN TROPICAL PACIFIC: IS THERMAL STRESS ASSOCIATED WITH CHASE AND CAPTURE IN THE ETP-TUNA PURSE-SEINE FISHERY?

by

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ADMINISTRATIVE REPORT LJ-00-13C

FINAL REPORT

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Explanatory Note

This final report summarizes the objectives and work accomplished by Dr. Ann Pabst and colleagues under P.O. 40JGNF800331, " Report on prototype of thermosensor tag and feasibility of use on ETP dolphins ", awarded by NMFS in September 1998. The work was undertaken as part of the research program conducted by the National Marine Fisheries Service as mandated by the International Dolphin Conservation Act (IDCPA).

Although most of the scientists who contributed to the work described herein are not directly affiliated with the National Marine Fisheries Service, the Service has published this report as an Administrative Report in order to contribute to creating an easily-accessible permanent record of IDCPA-related research.

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Abstract

A stated goal of the Workshop on the **Investigation of the Potential Influence of Fishery-Induced Stress on Dolphins in the Eastern Tropical Pacific Ocean** was "to identify physiological and morphological indices that can be practically measured to quantify the effects of stress on dolphins that are chased and captured in the ETP-tuna purse-seine fishery." We hypothesized that dolphins undergoing a prolonged (20 minute-2 hour), high-speed chase in the warm surface waters of the ETP may be experiencing hyperthermic stress. Our goal was to develop an understanding of the relationships between surface body temperature at the dorsal fin, heat-flux across the dorsal fin, and deep body temperatures. An understanding of these relationships may permit an assessment of the thermal status of a wild dolphin at sea by quantifying the temperature profile of its dorsal fin alone. Such measurements could be made remotely by using a high-resolution, infrared, thermographic camera and more directly by using time-depth recorders (TDRs) equipped with temperature and heat-flux sensors. We proposed three objectives for Year 1:

(1) *Begin laboratory work to design short-term, non-invasive, dorsal fin tag to monitor temperature and heat-flux at the fin in tagged and released dolphins.* We surpassed our objectives - we designed, built, and deployed thermal trac-pacs on 11 wild bottlenose dolphins (*Tursiops truncatus*) in Sarasota, FL in June 1999 and June 2000. These deployments represent the first measurements of dynamic heat-fluxes and skin temperatures that have been taken on dolphins swimming in the wild.

(2) *Carry out necropsies of ETP dolphins to establish relative positions of reproductive organs, circulatory pathways and CCHE to design multi-thermocouple colonic probe. And* (3) *Based upon these necropsies, develop colonic probe for ETP dolphins, for a range of species and size classes of animals.* Neither objectives 2 or 3 have been met because of lack of access to carcasses of dolphins from the ETP. We plan to carry out necropsies if carcasses become available.

Additional Accomplishments: Significant progress has been made in field-testing an infrared, thermographic camera, the DTIS 500, from Emerge Interactive. First year results demonstrated that infrared images illuminated a number of key features of the thermal profiles of dolphin dorsal fins: (1) the areas of highest temperature tended to be along superficial vessels and near the distal tip, (2) the hottest areas of the fin could change over time – that is, the thermal profile is dynamic, and (3) lesions on the fin were easily detected. Limitations of the soft- and hardware systems, though, resulted in a re-built camera and development of new image analysis software. These changes have resulted in a quantitative research-grade camera that was field-tested in June 2000. June 2000 experiments included thermal imaging dolphins as soon as possible after capture; continuous monitoring of heat-flux and skin temperatures at three positions at the dorsal fin, associated with simultaneous measurements of heart and respirations rates; and six successful deployments of the thermal trac-pac.

Introduction

A stated goal of the Workshop on the **Investigation of the Potential Influence of Fishery-Induced Stress on Dolphins in the Eastern Tropical Pacific Ocean** was "to identify physiological and morphological indices that can be practically measured to quantify the effects of stress on dolphins that are chased and captured in the ETP-tuna purse-seine fishery."

Thermal stress can be associated with chase and capture in terrestrial mammals (*e.g.* Antognini *et al.* 1996, Beringer *et al.* 1996, Curry 1999). Increased core temperatures in terrestrial mammals can cause maladaptive physiological changes and in extreme cases, even death (*e.g.* Taylor *et al.* 1972). Hyperthermia may be most severe in pregnant mammals where blood flow to the uterus - required for adequate thermoregulation of the developing fetus - may be compromised by shunting arterial blood flow to either (1) exercising locomotory muscles and/or (2) skin to dump excess heat at the body surface (reviewed in Bell and Hales 1986). Decreased blood flow to, and concomitant increased temperatures at the fetus cause detrimental effects including low birth weight, retarded growth, skeletal and neurological developmental anomalies, and ultimately acute fetal stress and death (reviewed in Rommel *et al.* 1993).

Based on observations on terrestrial mammals, it is possible that dolphins undergoing a prolonged (20 minute- 2 hour), high-speed chase in the warm surface waters of the ETP may be experiencing hyperthermic stress (Curry 1999). Like other mammals, dolphins can regulate their body temperature by controlling the flow of blood to the body surface (*e.g.* Scholander and Schevill 1955). The dolphin's uninsulated dorsal fin and flukes function as "thermal windows" across which excess body heat is dumped to the environment. Blood routed through veins on the surfaces of these extremities is cooled by heat transfer to the surrounding water and, when returned to the body core, can be used to achieve whole body cooling (Scholander and Schevill 1955). We have recently discovered that most of the blood routed through these superficial veins, though, is returned to the deep body via a venous plexus that is, in turn, juxtaposed to the arterial supply to the reproductive tissues (Rommel *et al.* 1992). Thus, dolphins possess a reproductive countercurrent heat exchanger (CCHE) that is in a position to cool the uterus and, hence, the developing fetus in females (Rommel *et al.* 1993, Pabst *et al.* 1998, Rommel *et al.* 1998) and the cryptic testes in males (Rommel *et al.* 1992).

Deep body temperatures of male bottlenose dolphins (taken with a custom-built colonic probe housing a linear array of thermocouples) demonstrate that temperatures in the region of the colon flanked by the CCHE are generally cooler than temperatures measured in front of or behind it (Rommel *et al.* 1994). Manipulation of the surfaces of the dorsal fin and flukes causes increases in body temperature at the region of the CCHE. Controlled and moderate surface swimming causes decreases in deep body temperatures in the region of the CCHE, but increases in body temperatures at other positions along the colon (Pabst *et al.* 1995). We hypothesize that these temperature changes are caused by changes in the temperature and/or the flow rate of blood returning from the dorsal fin and flukes (Pabst *et al.* 1995). Thus, the vascular design of the dorsal fin and flukes contributes to thermoregulation of both the whole body and the reproductive systems.

Although the CCHE in bottlenose dolphins has an increased ability to regulate the temperature of the testes during controlled and moderate exercise, we do not understand the effects of a prolonged, high-speed chase and subsequent capture on any aspect of thermoregulation in dolphins (reviewed by Curry 1999). In terrestrial mammals, high temperatures at the testis can block sperm production and maturation, and elevated temperatures at the uterus can cause fetal distress. Thus, comparative studies demonstrate that severe hyperthermia can negatively impact both the health of the individual and its reproductive success. Thus, we suggest that (1) surface and deep body temperatures and (2) heat-flux measurements should be considered as potential indices of stress associated with chase and capture of dolphins in the ETP-tuna purse-seine fishery.

Goals

In our initial proposal, we offered a research plan to investigate the thermal biology of ETP dolphins. Our goal was to develop an understanding of the relationships between surface body temperature at the dorsal fin, heat-flux across the dorsal fin, and deep body temperatures. An understanding of these relationships may permit an assessment of the thermal status of a wild dolphin at sea by quantifying the temperature profile of its dorsal fin alone. Such measurements could be made remotely by using a high-resolution, infrared, thermographic camera and more directly by using time-depth recorders (TDRs) equipped with temperature and heat-flux sensors.

We list below the proposed activities for Year 1, and our achievements towards those goals (please also see Preliminary Report, September 1999). We made significantly more progress towards Objective 1 - designing a thermal dorsal fin tag - than we had anticipated. To date, we have deployed thermal trac-pacs on 11 wild bottlenose dolphins (*Tursiops truncatus*). Objectives 2 and 3 – designing a colonic probe for ETP dolphins - required access to carcasses from the Necropsy Program. Thus, these objectives have not been met. Additional accomplishments, not included in the Year 1 proposal, include extensive field-testing of an infrared, thermographic camera, the DTIS 500, from Emerge Interactive. Our first field season demonstrated both software and hardware improvements that were required if we were to use the infrared thermal camera as a quantitative research tool. Because of generous donations of technical assistance from Emerge Interactive, Inc., generous logistical support from the Dolphin Biology Research Institute, Sarasota, FL, and efficient use of funds, we were able to extend the proposed Year 1 funds to help supplement a second field season in Sarasota in June 2000. Thus, our final report will include a brief outline of the improvements realized during that second field season.

RESEARCH PLAN: YEAR 1

OBJECTIVE 1: Begin laboratory work to design short-term, non-invasive, dorsal fin tag to monitor temperature and heat-flux at the fin in tagged and released dolphins.

Accomplishments to date:

Our progress on Objective 1 far surpassed what we proposed to accomplish - we have, in consultation with Dr. Michael Scott (IATTC) designed and deployed a dorsal fin thermal tag. We utilized the trac-pac, which uses a series of small suction cups to attach to the fin, to provide a design-flexible and non-invasive platform for our thermal tag. The thermal trac-pacs were built to fit an "average" size fin, vacuum-fitted on a mold of a dorsal fin of a wild Sarasota dolphin. Each trac-pac was fitted with a Mark 7 time-depth recorder from Wildlife Computers. Vatell B-episensor heat-flux discs were incorporated into the left side of the tag. These discs had a virtually instantaneous response to changes in heat-flux – a feature we thought critical to track real-time changes in heat flow across the surface of the dorsal fin. The heat-flux disc was attached to the tag by a spring system that permitted both a firm application to the dolphin's skin and a free flow of water across the back surface of the disc. An off-the-shelf thermistor was embedded under one of the suction cups, and customized mini-circuit boards, which were potted into the tag, were built to amplify the voltage signals from the heat-flux disc and thermistor. The thermal sensor in the Mark 7 TDR measured water temperature, although its response time was slower than that of the thermistor measuring skin temperature.

The tag was bench-tested using a Lauda Eco Line high precision water-circulating bath. These tests demonstrated that we could get accurate and precise heat flow data in the very controlled thermal environment of a water bath. To ensure that the tag could be successfully attached to a dolphin's fin, we live-tested the thermal trac-pac with a captive dolphin at Long Marine Lab, UCSC. The success of this portion of the research project relied heavily upon the unique research opportunities with captive bottlenose dolphins at Long Marine Lab. The iterative tests of the tag that were possible in this captive situation permitted us to make subtle design changes to the heat-flux disk attachment, thus, ensuring the collection of high-quality data in Sarasota.

In June 1999, we field-tested the thermal trac-pac in Sarasota, FL. We had five successful deployments that permitted us to gather, for the very first time, heat-flux data from free-ranging wild bottlenose dolphins (see Table 1). These deployments demonstrated that the thermal trac-pac remained attached for time periods sufficient to encompass changes in behavior that might influence the thermal status of the animal. Our two longest deployments, those of FB 117 and FB 192 illustrated the widest range of thermal responses we measured (see Figures 1 and 2). FB 117, a young female, had the highest initial deep body temperature (37.7°C) of any animal we recorded in June 1999, and had extremely high dorsal fin temperature and heat flow across the fin. FB 192, a large sexually mature male, had the lowest deep body temperature we have recorded in a male dolphin (in over a five year study period), and had, similarly, low fin temperature and heat-flux. These data are the first to demonstrate the importance of the dorsal fin as a dynamic thermal window in free-swimming dolphins.

While we considered our first year a success, it was clear that we could make improvements on the tag design, and on the data recording post-release. Both changes were made for the June 2000 dolphin captures. We replaced the thermistor with a more responsive copper-constantan thermocouple – this thermal sensor is the same design we use for taking deep body temperatures. This design change required building a new circuit board. We also improved our focal follow techniques so that we can more accurately describe locomotor and respiratory activities.

In June 2000, we deployed six thermal tags. Analysis of tracking data is on-going. Our observational data techniques have been improved, so that we have virtually continuous respiration records for the tagged animals. These data will help us determine how surfacing events are manifest within the heat-flux data record, and whether there is a relationship between respiration rates, skin temperature and heat-flux, in wild dolphins.

If a thermal tag were to be deployed on dolphins in the ETP, the addition of a sensor for directly measuring velocity would improve our abilities to relate thermal changes at the dorsal fin with locomotor activity. We would wish to work in consultation with Dr. Michael Scott to determine the feasibility of deploying a non-invasively attached tag. We suspect, though, that ETP deployments will require more invasive attachment mechanisms, which will require design modifications of the current thermal tag.

The design of the tag, and results from the June 1999 field season, were presented at **13th Biennial Conference of the Society for Marine Mammalogy,** held in Maui in December 1999 (see Appendix 1). Pabst and Westgate also made separate presentations at the evening Tagging Workshop held on the first day of the SMM meetings. This informal workshop permitted each of us to discuss the importance of considering tag designs that minimize impacts on vascular structures within the fin and fin coverage.

OBJECTIVE 2: Carry out necropsies of ETP dolphins to establish relative positions of reproductive organs, circulatory pathways and CCHE to design multi-thermocouple colonic probe.

Accomplishments to date:

We have not carried out necropsies of ETP dolphins to date, because of lack of access to carcasses. We plan to carry out necropsies if carcasses become available.

OBJECTIVE 3: Based upon these necropsies, develop colonic probe for ETP dolphins, for a range of species and size classes of animals.

Accomplishments to date:

Probe design and fabrication for ETP dolphins is dependent upon gathering these morphological data. If carcasses from the necropsy program are not available, we will require access to fresh, frozen carcasses from strandings.

ADDITIONAL ACCOMPLISHMENTS

Although Objectives 1-3 were the only ones explicitly stated in our first year contract, we also made significant progress on field-testing an infrared, thermographic camera, and we investigated deep-body temperatures and heat-flux rates on temporarily-held dolphins in Sarasota, FL.

The camera we used was the DTIS 500 infrared, thermographic camera from Emerge Vision (now EmergeInteractive). This camera uses non-cooled technology (*i.e.* the infrared thermal sensor functions at ambient temperature, rather than having to be cooled with liquid nitrogen). Thus, the DTIS 500 provided a small, extremely portable infrared camera. The other attractive feature of the DTIS 500 was the extensive image analysis software that supported the camera and provided quantitative measurement of thermal topographies.

In May 1999, we tank-tested the DTIS 500 at Long Marine Lab on two captive bottlenose dolphins and learned logistical techniques that would be used successfully in Sarasota. We also had the opportunity to take thermal images of sea lions at the Marine Mammal Center and sea otters at the Monterey Aquarium, which showed promise of using the camera as a clinical diagnostic tool for these marine mammals.

In June 1999, we field-tested the DTIS 500 in Sarasota, FL. We investigated the thermal biology of ten wild bottlenose dolphins (Table 2). For seven individuals, deep body temperatures were taken multiple times to determine how dolphin temperatures changed in the period after initial capture. Although we need to improve this aspect of the study we found that deep body temperatures tended to be higher closer to the time of the initial capture event (Table 3). Increased body temperatures were also associated with relatively high heat-flux rates.

In June 1999, heat-flux data were collected opportunistically using a customized "wand" containing a Vatell B episensor heat-flux disc, mounted on a stiff spring system. Our data indicated that heat-flux across the appendages was highly variable, and dependent upon location on the fin and the time of the measurement. These data suggested that single point measurements of heat-flux were insufficient to assess the thermal status of a dolphin, at least under the conditions of the capture event. We have subsequently improved our heat-flux measurement system, to measure heat-flux continuously, to make it more comparable to thermal dorsal fin tag data.

We used the DTIS 500 to capture 332 thermal images of animals, under multiple conditions – just after capture, held in the water, held on the boat (see examples in Figures 3 and 4). Of these, 249 were of sufficient quality to analyze quantitatively and qualitatively (Table 2). We also used the camera to systematically survey the dolphin's body surface, to look for "hot spots", injuries, etc. The DTIS 500 was an excellent diagnostic, tool in near-field conditions. The camera was also useful as a field detection device, because the relatively hot dorsal fins were easily spotted at a distance in the field (Figure 5). This use of the camera continued to be investigated by Mote Marine Lab for a few weeks after the 1999 capture on two radio-tagged bottlenose dolphins. Although some thermal image processing was possible, the fixed 50 mm focal length of the DTIS 500 camera limits its usefulness in gathering high precision temperature data at significant distances in the field.

Our quantitative analysis of thermal images from the Sarasota 1999 captures exposed a limitation of the soft- and hardware systems in the original camera. The camera we brought to the field was designed for clinical evaluations of thermal profiles. Thus, the camera's output was filtered to exaggerate high-slope thermal boundaries and minimize signal where temperature changes were more gradual. This filtering system rendered extremely precise thermal image profiles of temperature differences, but limited uniform quantitative evaluations of those profiles. Despite these limitations, the images illuminated a number of key features of the thermal profiles of dolphin dorsal fins: (1) the areas of highest temperature tended to be along superficial vessels and near the distal tip, (2) the hottest areas of the fin could change over time – that is, the thermal profile is dynamic, and (3) lesions on the fin were easily detected.

We were able to use the results from our first field season to work with Emerge Interactive to improve both the soft- and hardware systems for the DTIS 500. This work resulted in a completely rebuilt camera and new software system. The new DTIS 500 outputs a uniformly filtered digital image that permits quantitative assessment of thermal differences across an entire frame. The camera's fixed level means that this unit functions as close to a true radiometric camera as is possible without significant environmental conditioning of the infrared sensor. We were able to carry out preliminary lab-testing of the new DTIS 500 before taking it out to the field for the June 200 captures, and were encouraged by the accuracy of both the temperature and temperature differential outputs from the camera under controlled conditions.

In June 2000, we undertook a set of experiments aimed at getting a suite of thermal data from at least one dolphin per set, as soon as possible after the capture event. These experiments required a re-organization of the normal capture routine, which was graciously undertaken by the Dolphin Biology Research Institute. Our research team was on a boat that was closely present during encirclement and capture of the dolphin(s). Immediately upon restraint, dolphin thermal images and deep core temperatures were taken. To field-test the accuracy of the thermal camera, we placed a known-temperature object in each image frame. After a 10-minute imaging session, we carried out a second thermal experiment. We placed a harness on the dorsal fin that held three heat-flux discs and three thermocouples in place upon the skin surface. Two heat-flux discs were placed near the center of the fin - one directly over and one off a superficial vein - and one at the distal tip. Continuous records of these thermal sensors, along with heart rate and respiration rate, were recorded for 10-15 minute sessions. Our goal was to determine the relationship between respiration rate (a behavior that can be easily and non-invasively measured in the field) and heat-flux rate across the dorsal fin. These experiments, which supplement the thermal dorsal fin tag experiments, are aimed at better understanding whether other non-invasively measured, physiological parameters can be used to assess the thermal status of ETP dolphins.

Summary of Products:

(1) Thermal trac-pac that measures heat-flux and temperature at the dorsal fin of free-swimming dolphins.

(2) Field-testing and re-design of quantitative infrared imaging camera and first quantitative data set of thermal images of wild dolphins.

(3) First simultaneous recordings of multiple heat-flux and temperature records, respiration rate and heart rate for a wild cetacean.

Presentations:

Westgate, A. J., Pabst, D. A., McLellan, W. A., Williams, T. M., Wells, R., and Scott, M. 1999. An instrument to record heat-flux and surface temperature from free-swimming dolphins. The 13th Biennial Conference on the Biology of Marine Mammals. Nov.28-Dec. 3, 1999. Maui, Hawaii.

Pabst, D. A. 1999. Opening Plenary Address: Locomotor functions of dolphin blubber. The 13th Biennial Conference on the Biology of Marine Mammals. Nov.28-Dec. 3, 1999. Maui, Hawaii.

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We wish to express our thanks to the NMFS for funding this work. Dr. Michael Scott contributed in significant and critical ways to the development of the thermal trac-pac. We also thank the Dolphin Biology Research Institute and all their volunteers, and Mr. Billy Hurley and the Marine Mammal Staff at Long Marine Lab.

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Rommel, S.A., Pabst, D.A., McLellan, W.A., Mead, J.G. and Potter, C.W. 1992. Anatomical evidence for a countercurrent heat exchanger associated with dolphin testes. *Anatomical Record.* 232(1):150-156.

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Appendix

Presentations at international meetings that included results from this project.

Westgate, A. J., Pabst, D. A., McLellan, W. A., Williams, T. M., Wells, R., and Scott, M. 1999. An instrument to record heat-flux and surface temperature from free-swimming dolphins. The 13th Biennial Conference on the Biology of Marine Mammals. Nov.28-Dec. 3, 1999. Maui, Hawaii.

Dolphins are chased and captured in the tuna-purse seine fishery in the Eastern Tropical Pacific. This study is part of a series to test whether thermal stress resulting from prolonged chases is detrimental to dolphin populations. To assess the thermal status of wild dolphins we developed an instrument to measure heat-flux and temperature at the dorsal fin. The instrument was attached to the dorsal fin using a plastic saddle that was held in place using small suction cups. The recording device consisted of a 2.5 x 2.5 cm heat-flux disk that was connected to an amplification circuit. The amplified signals were recorded to a data logger. Temperature was also recorded using a thermistor. The electronics were potted in epoxy and fitted into lateral pockets into the sides of the saddle. The instrument had a mass of 460 g and covered approximately one third of the dorsal fin's surface. The logger was deployed on a bottlenose dolphin (*Tursiops truncatus*) at Long Marine lab in May, 1999. The water temperature during these deployments ranged between 15 and 19.8°C. Dynamic heat-flux data were obtained from the dorsal fin during five deployments that lasted up to 19 minutes. These deployments represent the first time that dynamic heat-flux has been recorded *in situ* from a free-swimming dolphin. A maximum reading of 481.5 W/m2 was recorded underwater during heavy exercise. Resting heat-flux values ranged from 209-261 W/m2. Readings taken when the dorsal fin was at the surface were very unstable due likely to evaporative effects on the heat-flux disk. Temperature data obtained during these deployments were less reliable owing to problems associated with the thermistor. These temperature problems have been addressed and deployments on wild bottlenose dolphins are currently being conducted in Sarasota, FL.

Pabst, D. A. 1999. Opening Plenary Address: Locomotor functions of dolphin blubber. The 13th Biennial Conference on the Biology of Marine Mammals. Nov.28-Dec. 3, 1999. Maui, Hawaii.

The blubber of marine mammals has historically been characterized simply as fat. Many of blubber's functions, such as its role as a metabolic energy depot, dynamic thermal barrier, and buoyancy regulator, rely upon its lipid content. In cetaceans, though, blubber also functions as a dynamic locomotor organ. Cetacean blubber is formed by a highly ordered, three-dimensional weave of collagen and elastin fibers surrounding fat cells - thus, it can be characterized as a structural biocomposite, rather than simply as fat. Additionally, blubber possesses mechanical attributes very different from those of fat. In bottlenose dolphins (*Tursiops truncatus*) for example, blubber behaves like a resilient spring with a dynamic stiffness similar to that of high-quality, synthetic rubbers. Thus, blubber is capable of temporarily storing and releasing nearly all of the energy required to deform it. This observation leads to the hypothesis that blubber could decrease the metabolic costs of swimming, by decreasing the inertial work required of muscles to decelerate and accelerate the tail during a locomotor cycle. Kinematic analyses of exercising bottlenose dolphins, coupled with mechanical tests of caudal keel blubber, support this hypothesis. Although similar studies are difficult to carry out on large cetaceans, scaling models permit us to investigate the role of their blubber. Modeling cetaceans as springs, oscillating at their optimal frequency, accurately predicts observed tailbeat frequencies for twelve species of large cetaceans, suggesting that blubber plays a similar role in these animals. Thus, there exists growing evidence that blubber contributes to the energetic efficiency of cetaceans by decreasing their metabolic costs of locomotion. This function adds to our understanding of blubber's varied contributions to the energetics of marine mammals.

Table 1. Bottlenose dolphins (*Tursiops truncatus*) fitted with thermal trac-pacs in Sarasota, FL in June 1999.

Animal ID	Date	Sex	Mass (kg)	Deployment Duration
FB 157	10 June	Female	189.8	30 minutes
FB 117	10 June	Female	140.8	4 hours 9 minutes
FB 33	11 June	Female	176.6	37 minutes
FB 192	14 June	Male	232.8	7 hours 25 minutes
FB 194	15 June	Male	238.4	1 hour 20 minutes

Table 2. Bottlenose dolphins (*Tursiops truncatus*) whose core temperatures and thermal images were taken in Sarasota, FL in June 1999. Core temperature reported here is taken at thermocouple 2 as soon after capture as possible. Thermal image # is the number of in-focus, close-up images collected. We also measured heat-flux across the dorsal fin, flukes and caudal peduncles of selected animals.

Animal ID	Date	Sex	Mass (Kg)	Core (C°)	Thermal Image #	Heat flux?
FB 117	10 June	Female	140.8	37.7	30	No
FB 118	10 June	Male	144.6	37.3	14	No
FB 157	10 June	Female	189.8	36.1	18	No
FB 186	10 June	Male	105.6	37.5	4	No
FB 33	11 June	Female	176.6	36.7	21	Yes
FB 188	11 June	Male	90.2	37.2	26	Yes
FB 190	12 June	Male	108.6	36.8	40	Yes
FB 192	14 June	Male	232.8	36.7	30	Yes
FB 192	15 June	Male	NE	36.6	6	Yes
FB 109	15 June	Female	125.8	37.3	32	Yes
FB 194	15 June	Male	238.4	36.9	28	Yes

Table 3. Changes in colonic temperatures as a function of time after capture for bottlenose dolphins (*Tursiops truncatus*) in Sarasota, FL in June 1999. Delta temp represents the difference between the mean of 5-7 temperatures at Time 1 minus their mean at Time 2 (*i.e.* "+": mean temperature was warmer, closer to the time of capture; "-": mean temperature was cooler closer to the time of capture).

Animal ID	Date	Sex	Time Net Out	Time Restraint	Time 1st temps	Time 2nd temps	Delta Temp (°C)
FB 117	10-Jun	F	11:42	11:59	12:48	15:36	+ 0.9
FB 118	10-Jun	M	11:42	11:59	12:58	16:36	+ 0.3
FB 157	10-Jun	F	11:42	11:59	12:16	14:04	- 0.8
FB 33	11-Jun	F	12:23	12:34	13:09	14:14	+ 0.3
FB 192	14-Jun	M	14:43	14:46	15:46	16:06	+ 1.0
FB 109	15-Jun	F	10:02	10:24	10:32	11:32	- 0.1
FB 194	16-Jun	M	14:40	14:53	15:05	approx. 16:00	- 0.2

Figure 1. Heat flux record, collected with the thermal trac-pac, for FB 117, a female bottlenose dolphin from Sarasota, FL on 10 June 1999.

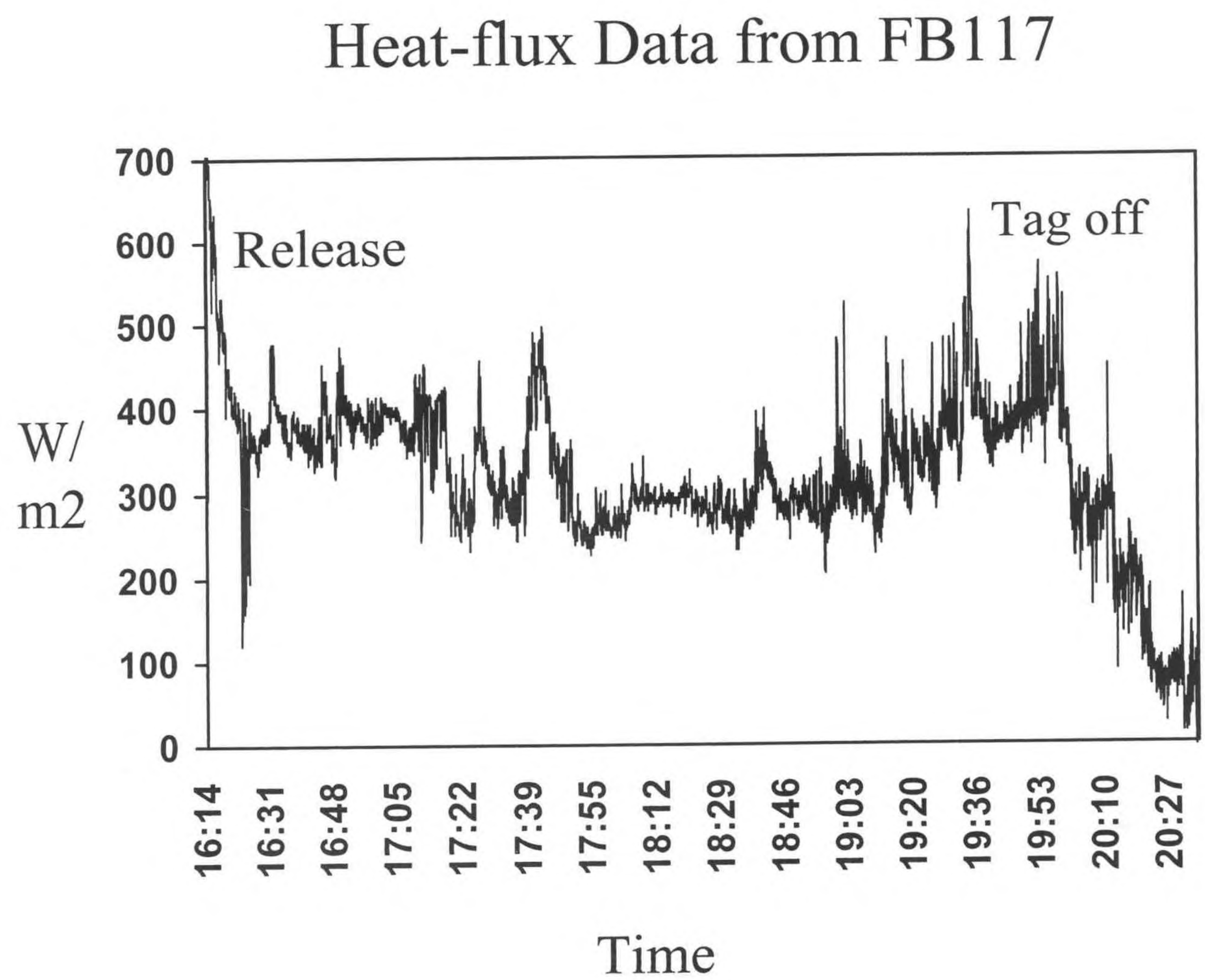
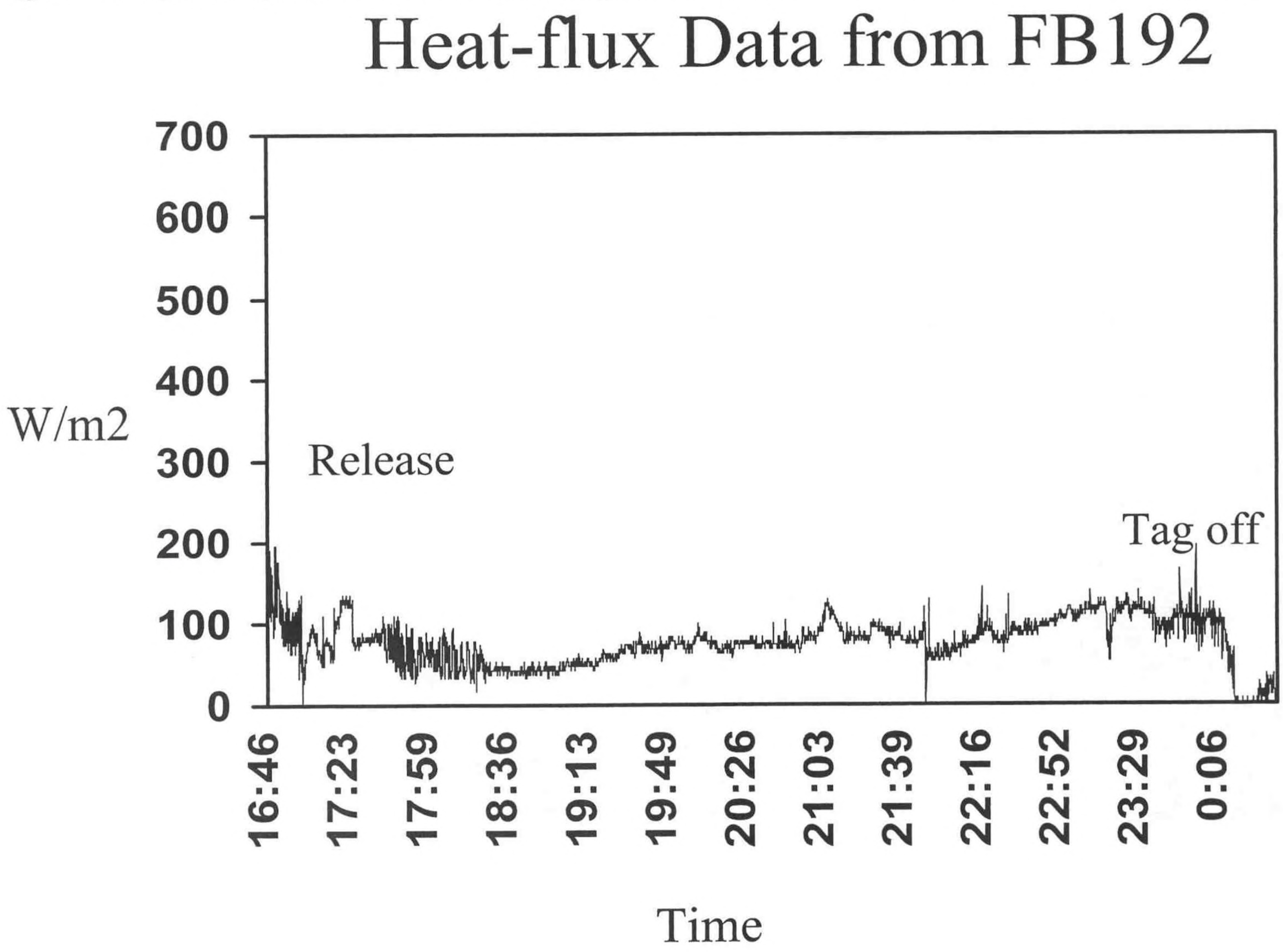


Figure 2. Heat flux record, collected with the thermal trac-pac, for FB 192, a male bottlenose dolphin from Sarasota, FL on 14 June 1999.



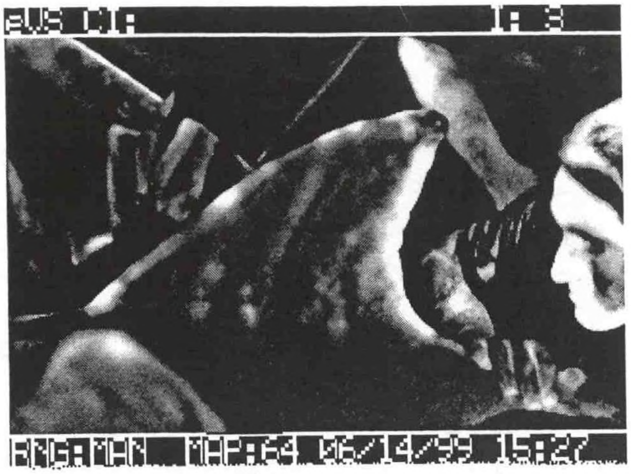


Figure 3. Infrared thermal image of dorsal fin of bottlenose dolphin, FB 192, on the processing boat, in Sarasota, FL, June 1999. Notice the dark vertical scar along the center of the fin, a feature that has been identifiable on this individual for many years.

Figure 4. Infrared thermal image of dorsal fin of bottlenose dolphin, FB 194, on the processing boat, in Sarasota, FL, June 1999. Notice the curving light gray lines on the fin that represent the tracks of superficial veins.

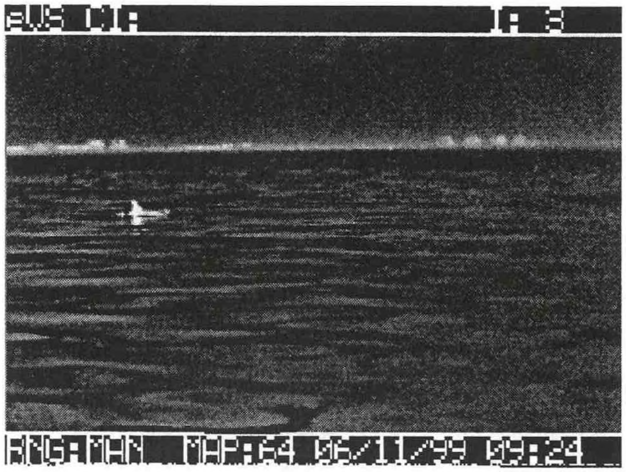


Figure 5. Infrared thermal image of a wild bottlenose dolphin in Sarasota, FL, June 1999. Notice that the warm dorsal fin is very easily detected under calm weather conditions.