MAKO SHARK EXPERIMENT ON 'WIECZNO', MARCH 1978

Report to NMFS

by

Francis G. Carey and Leslie Middleton
Woods Hole Oceanographic Institution
Woods Hole, MA

and

Charles Stillwell, Wes Pratt, Nancy Kohler, Cheryl Cavin
National Marine Fisheries Service
Northeast Fisheries Center
Narragansett Laboratory
Narragansett, RI

Laboratory Reference No. 78-27
National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole, MA 02543
1 May 1978
MAKO SHARK EXPERIMENT ON 'WIECZNO', MARCH 1978

Report to NMFS

Francis G. Carey and Leslie Middleton
Woods Hole Oceanographic Institution
Woods Hole, MA

&

Charles Stillwell, Wes Pratt, Nancy Kohler, Cheryl Cavin
National Marine Fisheries Service
Northeast Fisheries Center
Narragansett, RI

BACKGROUND

Mako, *Isurus oxyrinchus*, porbeagle, *Lamna nassus* (and probably the white shark, *Carcharodon carcharias*) have warm bodies. As is the case with other warm fish, these lamnid sharks conserve their metabolic heat by a system of counter current heat exchangers in their circulatory systems. The viscera, as well as the muscle, are warm. The visceral heat exchanger described by Burne (1923) is located in the hepatic sinuses and consists of an arterial tree which divides and redivides into fine arteries which fill the lumen of the sinus with an arterial sponge (Figure 1). Venous blood from the liver trickles over this sponge in a counter-current fashion to the arterial flow and heat is transferred from the venous to the arterial blood.

A large venous channel passes through the center of this arterial mass. When this channel is open, venous blood flows through it and not over the arteries. A well-developed sphincter in this channel allows it to be shut off. Clearly, the circulation is arranged so that venous blood can flow through the heat exchanger or be shunted around it. When venous blood flows over the finely divided arteries, metabolic heat passes from the venous to the arterial blood and back into the viscera, causing the temperature to rise. When the shunt is open, the warm venous blood by-passes the heat exchanger, heat is lost and the temperature of the viscera should decrease. Almost certainly this heat exchanger and shunt provide a mechanism for controlling visceral temperature.

This heat exchanger and shunt in the Lamnid sharks is the only situation in any of the warm fishes where we have found an anatomical basis for temperature control. Thus it is an ideal situation for a physiological experiment. We have tried three times in the past to get evidence for temperature control in the stomachs of mako sharks. The experiments involve hauling a shark aboard, placing an acoustic telemetry transmitter in its stomach, then releasing the fish and following it. We hoped to observe temperature variations in the stomach which could be interpreted as resulting from the proposed control system, but in the past the experiments have been inconclusive.
Figure 1. Corrosion preparation of the visceral retia from a mako shark. The arteries were filled with latex and the tissue dissolved away leaving a cast of the arterial lumen. The large vessels are branches of the pericardial artery which invade the hepatic sinus, branch repeatedly, and fill it with a sponge of fine arteries. The structure is viewed here from the anterior end. It is paired with a large venous channel (not shown) between the retia.
Last summer working with bluefin tuna, we noticed that the presence of food in the stomach caused a marked rise in temperature. It seemed likely that we might find a similar phenomena in the mako and we planned an experiment in which we would place food in the stomach of the shark along with the transmitter.

THE EXPERIMENT

On 27 March of this year we had an opportunity to do this experiment and see if the stomach of the shark warmed during digestion. A large (perhaps 160-180 kg) female mako was taken on longline in 30 fathoms of water southeast of Cape Canaveral (29°7'N, 80°4'W). The shark seemed to be in lively condition. A noose of 2 cm diameter soft braided nylon rope was taped to a hoop, maneuvered over the tail, and the shark quickly hoisted aboard and set on deck. Being lifted by the tail is supposedly harmful to sharks, but it allowed us to bring the animal aboard quickly and easily without apparent damage. We immediately placed a hose in its mouth and irrigated the gills with a large flow of water at low pressure. The eyes were covered and the shark lay quiet during the approximately five minutes that we worked on her. A low of water over the gills prevents the fish from thrashing about in respiratory distress and (in turn) quickly restores a steady heartbeat after the bradycardia which results from being in air. A temperature transmitter was clipped to the end of a 1-meter rod and pushed deep into the stomach. This was followed by five 400g mackerel which were pushed in on top of it. A second temperature transmitter was attached near the dorsal fin with a small harpoon dart. This transmitter would broadcast water temperature. The shark was hoisted over the side and swam from sight with a few powerful strokes. We felt that it was in good condition.

To follow the shark, we used hydrophones mounted on a V-fin depressor and towed over the side at a depth of about 20 meters. There were four hydrophones on the ventral side of the V fin arranged in a square. They had broad directivity patterns facing horizontally outward. By switching between them we could determine the direction that the strongest signal was coming from and the bearing to the target. It was a cumbersome system, but practical considerations such as lack of permission to weld the required structures on the Wieczno, having only one day in port to mount the gear, and the large rise and fall of the bow when pitching, which is normal for a vessel this length, prevented us from using the much more accurate bow mounted hydrophone which we normally would have employed.

The stomach temperature transmitter operated at 40 KHz and the water temperature transmitter at 33 KHz. The signals from each were readily separated in two receivers. The temperature information was coded as a variable pulse rate. We set up our receivers on the bridge of the Wieczno and kept a plot of the temperatures as they came in (Figure 2). We timed the pulses with a stopwatch and converted pulse rate to temperature using a calibration factor. We kept watch in pairs, one keeping the vessel near the fish and the other counting pulses. We all became skilled at taking the data which is of excellent quality, and I am very pleased with everyone's performance.

XBT's were dropped every two hours by Polish scientists, Jozef Wysocki and Antoni Kurowicki who maintained the XBT watch. This information was used to construct a chart of isotherm depth and on this, in turn, the water temperature at the shark was plotted, thus determining how deep it was (Figure 3). A Loran
Figure 2. Temperature plotted from midnight to midnight. Upper smooth line, stomach temperature. Lower varying line, water temperature.
Figure 3.

Depth for Mako #4 as obtained by plotting water temperature at the fish on a chart of isotherms constructed from XBT drops. Horizontal axis is time plotted for the 32 hour span from 1600 to midnight of the following day. The overlap achieved by plotting time in this fashion aids in visualizing common features in the daily activity pattern. Sunrise and sunset are indicated by vertical bars drawn through all four panels. Isotherms are drawn at 2°C intervals.
Figure 3
MAKO #4

27-28 March

28-29 March

29-30 March

30-31 March

DEPTH, meters
position for the ship was taken every hour and plotted on the chart (Figure 4). We thus had continuous real-time plots of position, depth and temperatures which added greatly to the interest of the experiment and allowed us to manage it in an intelligent fashion.

We followed the fish for 105 hours over a total distance of about 280 km. After release the shark moved into deeper water. It was carried north by the Gulf Stream, but was actively swimming to the east. During the second day it had crossed the Stream, coming out of it at about the latitude of Daytona Beach, and continued swimming east in the waters north of the Bahamas. The transmitters weakened during the fourth day and we lost the shark the following night. It had gone as far east as 29°N, 78°W, then turned and was moving southwest, reversing its course. Our last contact was at 28°40'N, 78°15'W. After losing the shark we made a long-line set in the area, but did not catch her again. There would have been considerable interest in seeing how far those mackerel had been digested.

The shark's stomach temperature remained relatively constant at 24 to 27°C during the experiment. There was no sign of the warming during digestion which we have found in bluefin tuna and which we hoped to see here after placing five mackerel in her stomach. Possibly the effect we hoped for would require a larger meal, for sharks of this size can ingest large amounts of food.

The small changes in stomach temperature which we observed seemed to follow the trend in water temperature variation with a lag of perhaps four hours (Figure 2). The stomach temperature was usually 5 to 7°C warmer than the water. This is a similar temperature differential to that observed in mako #3, Figure 5. At the beginning of the experiment, stomach temperature and water temperature were the same, a result comparable to that in earlier experiments with mako #1 and #2. This small differential at the beginning of the experiment may have resulted from the stomach cooling due to the stress of being caught on long-line gear. On the other hand, it is interesting to note that this small temperature differential is not due to the stomach being unusually cool, but to the water being warmer than it ever was to be again during the time we were with the fish. Perhaps this situation, with the stomach staying constant or warming slightly, while the water temperature decreased, is the evidence for temperature control that we are looking for. We would prefer it in more dramatic form, however, and will have to think this over for a while.

The external transmitter which broadcast water temperature gave us an interesting record (Figures 2 and 3). We were able to convert water temperature at the shark to depth by comparison with the isotherm depth plot made from XBT drops (Figure 3). This showed that the mako was seldom above 100 meters. It came to the surface for a few minutes on two occasions. Much of the time it swam at a depth greater than 300 meters. It exceeded 400 meters 10 times and made two dives which took it to 480 meters. Before this experiment we had considered the mako to be a surface dweller and was quite surprised to find it going to these depths. Wes Pratt pointed out that the mako has a large eye, the big black pupil of which adds to its distinctive appearance. The large eye is probably associated with a need to see in dim light and perhaps with the habit of swimming deep.
Figure 4. Course followed by Mako # 4. The shark traveled about 180 miles (280 km) in 105 hours. Tics at one hour intervals. Open circles (0), sunrise. Closed circles (●), sunset. Bottom contours in fathoms.
Solid line features were discerned on 3,5,6 Apr.
NOAA-5 infrared VHR SAT imagery; SST data to MAR 5APR.

Date 05 APR 1978
Figure 5

Temperature, °C

Mako 3 17April '71
In the region where the experiment was done there was not a great range of water temperatures to test the mako's willingness to change water temperature. The coldest water it entered was 13°C, and that only briefly on the first day. It generally swam in a 5°C wide band of isotherms between 17°C and 21°C. It made many rapid excursions up and down within this range, but generally avoided the 100-meter thick mixed layer of 22 to 24°C surface water. The rapid movements up and down make it seem unlikely that water temperature was a limiting factor in the shark's activities.

This mako did not show the clear day-night vertical movement pattern which we have come to expect for swordfish. There is a variable pattern of movement, however, which seems to include the following features: early in the day, between midnight and dawn, the shark held a relatively constant depth along the 20°C isotherm. At first light, about one hour before dawn, it would dive and be below 400 meters by sunrise. A variation on this was 29 March when the dawn was overcast and rainy. The morning dive was almost an hour later than on clear mornings. This is probably an indication that the descent is triggered by a light level, and was postponed by the overcast.

The shark did not remain long below 100 meters, but returned to mid-depths to spend the daylight hours moving up and down in large excursions between the 18 and 20°C isotherms, each excursion taking about an hour or two. After sunset the depth became somewhat more constant near the 20°C isotherm with some excursions to greater depths. Thus there is a general pattern of swimming deep during the day and shallow at night, but not the clear pattern we have seen in swordfish. There is large variation in depth and much motion up and down. This may be an appropriate hunting scheme for a top predator seeking out other large animals. We hope to have the opportunity to repeat these observations.

We are most grateful for the fine cooperation and good fellowship given us by Captain Bogdanovich and the crew of the Wieczno and would be pleased to have an opportunity to make future cruises with them.