

TRACKING THE LEATHERBACK SEA TURTLE

**ST. CROIX, U.S. VIRGIN ISLANDS
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**Scott A. Eckert, Ph.D.
Hubbs Sea World Research Institute
1700 South Shores Road
San Diego, California
92109**

Background: The leatherback sea turtle (*Dermochelys coriacea*), the largest and most pelagic of the sea turtles, is morphologically and physiologically distinct from other sea turtle species. Leatherbacks dive deeper, and venture into colder waters than do any other reptile. Adult females nesting on St. Croix, U.S. Virgin Islands average 155 cm in shell length and weigh as much as 500 kg. The turtles are entirely skin encased and lack the more familiar bony shell of most turtles. Their body form is exceptionally streamlined to ease long-distance swimming.

Leatherbacks are reported from all major oceans, ranging from the southern coast of Chile to the Arctic Circle, and claim the most extensive distribution of any reptile. Evidence from tag returns and strandings suggest that adults engage in routine migrations between boreal, temperate and tropical waters to optimize both foraging and nesting opportunities. The longest known migration for any reptile was that of an adult female leatherback, which traveled at least 5900 km to Ghana, West Africa, after nesting in Suriname in 1970 (Pritchard 1973).

Leatherbacks are known to feed on pelagic jellyfish in temperate and boreal latitudes. Foraging has been observed at the surface and has been hypothesized to occur at great depth as well. This pelagic water column foraging behavior is probably unique among sea turtles, for all other sea turtle species are primarily benthic foragers as adults (Eckert et al. 1989).

The most important nesting habitat for the Endangered leatherback sea turtle (*Dermochelys coriacea*) in the northern Caribbean, is Sandy Point, St. Croix, (U.S. Virgin Islands). Sandy Point supports 30 to 60 leatherbacks annually and produces up to 18,000 hatchlings each year. Due to the importance of this nesting beach, Sandy Point was designated Critical Habitat by the Fish and Wildlife Service in 1980, and in 1984 became the first National Wildlife Refuge established specifically for sea turtles. Since 1982, continuous protection of the nesting colony has been maintained by the Virgin Islands Division of Fish and Wildlife with support from Earthwatch volunteers and Hubbs-Sea World Research Institute (since 1991). The killing of adult turtles and the taking of eggs has been eliminated at this site. Furthermore, due to an egg relocation scheme, annual hatchling production has increased over 100% from pre-project levels. A local

education campaign has stimulated tremendous interest in preserving sea turtles. Survival for this nesting colony is far from assured however, because current measures only protect the turtles when they are on the nesting beach.

Because each female leatherback likely remains in the vicinity of the nesting beach for about 4 months and lay up to 11 clutches of eggs they are vulnerable to being killed by fishing boats operating in the area. Of particular concern is the increasing use of long-line fisheries in the Caribbean Sea. In an article in the Marine Turtle Newsletter (1991), W. Tobias reported a leatherback foul-hooked by a (fishing) long-line off the south shore of St. Croix and four others hooked in the British Virgin Islands, just to the east of St. Croix. Tobias reported that the intensity of long-line fishing around St. Croix is increasing rapidly and that the 19 long-line vessels operating from St. Croix (in 1988) set about 400,000 hooks annually. Leatherbacks are extremely prone to foul hooking or entanglement in long-lines. Because this fishery often attaches chemical lightsticks (which can mimic bioluminescence of jellyfish) above each hook as fish attractors, leatherbacks may be enticed to approach the monofilament fishing lines. While a Sandy Point leatherback has yet to be reported caught (most fishing boats rarely land a foul hooked leatherback to read its tag - most are just cut away still carrying the hook and line), the killing of even one nesting female will represent a significant portion of the nesting population. Each female can produce up to 800 hatchlings per nesting season. Research into the aquatic behavior and movement of these nesting females is necessary to understand the potential interaction between these turtles and the longline fishing fleet.

Studies on the offshore behavior of the nesting females began in 1983 when we deployed Time-Depth-Recorders on 2 turtles. These instruments were capable of continuously recording dive depth, duration, surface duration and diving profile during the internesting interval. This study of dive behavior was continued through 1984 with the monitoring of 5 more turtles. Results of these studies have been published elsewhere (Eckert et al. 1986, 1989). The behavioral patterns documented by these studies was remarkable. Leatherbacks rarely appear to stop or rest during the 10 day internesting interval. Diving is continuous with the turtles averaging between 6.9-14.5 minutes per dive, and 35 - 122 meters in depth. Maximum dive depths were truly extraordinary, with the turtles

diving beyond 500 meters and in a few cases beyond 1000 meters. Nocturnal dives were more frequent and shorter than day dives which led us to conclude that the turtles were feeding at night on vertically migrating prey. The lack of body weight changes during the course of the season corroborated this conclusion.

With this project we proposed to determine the movement patterns of the Sandy Point turtles during the internesting interval. It is important to understand whether the turtles are residing near areas of intense fishing effort if we are to predict adverse interactions, and propose concrete mitigation actions. We are confident that we understand the dive behavior, but have not attempted to identify where the turtles were during this time. Thus, this project proposed to radio-track the female leatherbacks during their internesting intervals. The methods are similar to a project we carried in the South China Sea near the Terengganu (Rantau Abang) leatherback nesting beach for the government of Malaysia (Chan et al. 1989). In that case our results led to the establishment of a Marine Reserve to protect the female leatherbacks and has been extremely successful.

Another part of this study monitored on swim speeds of the leatherback. We were interested in utilizing this information to help us clarify some features we noted in earlier studies of diving. Specifically, we wondered if the long surface periods at midday represent surface resting - with the turtles remaining motionless, or whether the turtles continue to swim while at the surface. Further, we desired to understand something of the energetics involved in the turtles dive behavior, thus we intended to measure heart rates simultaneously with the diving behavior and swim velocities. Finally we planned to use the velocity recorders to measure total distance travelled and thus better understand migratory capabilities of this species.

Methods:

A selection of nesting female leatherbacks were equipped with VHF transmitters with a reception range of 45 km and life expectancy of 30 days. Each transmitter equipped turtle was located daily by triangulation from a mobile shore based reception system, comprised of Telonics TR-4 receivers and 5 element

YAGI antennae. A Trimble Global Position System receiver was utilized to determine the receiver location on shore and a compass mounted to the antennae mast was used to determine bearing of the turtle from the reception point. Bearings were plotted on a standard navigational chart to determine location. Since error in determining the bearing can vary between operators, and this project utilized a number of volunteer operators, two methods were used to quantify that error. A sample of the volunteers were tested to determine their accuracy against a known radio location and during daily tracking sessions checks were made by the senior investigator (whose error margin was previously established) of the bearings as they were collected. Finally the various locations were edited by the senior investigator and obviously erroneous data was discarded (e.g. the bearing indicated that the turtles was in the center of the island). To further limit error we often used geographic features such as the central mountain ridge of the island to isolate signal reception. With transmitters as powerful the ones used in this study a close transmitter could often compromise the directionality of the signal and appear to be located at four equal points around the compass - in such cases geographic features of the island were used to screen various directions to deduce which of the bearings was the correct one.

Some turtles were also equipped with Time-Depth-Recorders (TDR), and Velocity Recorders (VR) to monitor swim speed and dive depths. The TDR's (Wildlife Computer Mk3) are microprocessor controlled and are capable of sampling depth and duration at programmable intervals. Each recorder contains 128 k of memory and programs supplied by the manufacturer allow the determination of dive depth, dive duration, surface duration, ascent rate, descent rate and bottom time. Each cylindrical recorder measures 15 cm x 2.5 cm and weigh 100 g and are accurate to 2 m. The Velocity Recorders are custom made instruments which electronically count revolutions of a small nylon turbine and integrate those counts over time to determine speed and distance travelled. Each VR measures 8 cm x 5 cm x 2 cm and weigh 60 g. The velocity recorders are accurate to .01 meters per second and can be set to integrate data over 4 or 8 second intervals. Laboratory tank tests indicate that the recorders are relatively insensitive to the angle of approach, and thus remain accurate for a wide range of mounting profiles. Each velocity recorder was individually calibrated before use in the laboratory.

around to the north side, where it remained until returning to Sandy Point to nest. Our field notes indicate that the radio signals from the 9th and the 11th were very weak, and were made from an elevated (250 m) tracking station. Thus, we suspect that the turtle had moved to the north beyond reception range - which was like in excess of 65 km from this elevated receiving location. This would explain why we received no radio signals until the 17th when the turtle came back into range

AAG 958 (Fig 2): This turtle was extremely mobile during its internesting interval. For the first three days after nesting, it was detected generally south of Sandy Point, but by May 23 it had moved around the island to the north side. By May 24, the turtle had moved to the east side of the island and was detected just north of the Lang Banks, a reef area to the east of St. Croix. By May 25 the turtle was back off the Northwest corner of St. Croix. On May 26 the turtle was detected just southwest of Sandy Point, but by the next day the turtle had moved back to the northeast of St. Croix. On May 28 the turtle was detected at 0600 h to the southwest of Sandy Point and by 1600 h the turtle had moved back off the northeast, close to its location on the 27th. Interestingly, there was an unidentified and unsuccessful nesting attempt on the west side of Sandy Point that night, which might be attributed to AAG 958. No locations were obtained again for this turtle until it nested on 5/30 at 01:51 h.

AAG 928 (Fig. 3): AAG 928 was incredibly mobile, moving around the entire circumference of the island during its internesting interval. Bearings for the turtle were recorded for 6 of the 8 days of the internesting interval with good triangular locations established on 5 days. Most of the locations were relatively close to the island. After nesting the turtle moved off the south coast then around the west side and (presumably) down the north side to a location NE of Buck Island. It then appeared to proceed back down the south side of the island to nest on again on May 15.

AAR 950 (Fig 4): Turtle AAR 950 was first detected two days after nesting on May 20, 11 km south of St. Croix. The turtle appears to have proceeded around the west end of the island to the northwest corner where it remained for at least 3 days (May 22-24). It was next detected on May 27, northeast of Buck Island

about 10 km from shore. By May 28, the turtle had moved back to the west end of St. Croix where it remained for two days. The turtle renested on May 29th at 2220 h about 3 km east of the Sandy Point nesting area.

AAR 863 (Fig 5): Locations were recorded for 5 of the 9 interesting days for this turtle, with 4 of the 5 noted as exact locations. On May 10, three separate locations were detected for this turtle over the span of a few hours. The post-nesting movement was to the north side of the island immediately after nesting where it remained until the day prior to nesting. On that day the turtle was detected 10 km off the south shore. On the day of renesting the turtle had moved directly south of Sandy Point.

AAG 439 (Fig 6): The turtle was not detected for two days after nesting and was finally located May 9, about 10 km off the north side of St. Croix. It remained in the same general vicinity for 5 days moving to within 2 km of shore and then was detected in the channel between Buck island and St. Croix. The next day the turtle had moved NNE of Buck Island and was located approximately 19 km from St. Croix. On May 19, at 1500 h the turtle was detected about 6 km off the north side of St. Croix, and moving west. At 23:21 h AAG 439 had moved around the west side of the island and by 0440 h had landed at Sandy Point to nest. Radio signals were received from this turtle on 8 of the 13 days of its interesting interval.

AAG 405 (Fig. 7): The turtle remained off the southwest tip of St. Croix for its entire interesting interval, making it almost impossible to set up the radio receiver in a manner that would allow good triangular bearings. Three good triangular fixes were obtained. On May 8 we were able to obtain a good triangulation by using a boat to approach the turtle and establish one leg of the bearing, the turtle was 1 km south of Sandy Point. On May 10 the turtle was detected about 30 km south of Sandy Point. On May 12, the turtles was detected 13 km west-southwest of Sandy Point. For the other days of the interesting interval the turtle was within radio range (within 45 km) but only the general direction of the turtle could be established (shaded area of the map)

Velocity Records:

Seven velocity recorders were deployed, however one became sand-fouled upon leaving the beach, so six records were obtained. Swim velocities were very constant for each turtle with modal swim speeds ranging from .54 m/s to .83 m/s (Fig 9). There was virtually no time in the records where turtles were not moving (Fig 9) figure of swim speeds - use dots instead of lines). Total distance (including vertical distance) travelled for each turtle ranged from 278.2 km to 673.9 km (Table 2) over the interesting interval.

Time Depth Records:

Two of the turtles were equipped with TDR's. TDR data is summarized in Table (3) and Figure (10). Overall, the dive patterns were similar to those observed in our earlier studies. Turtles dove directly to depth and returned directly to the surface with only limited excursions during the dive (Fig 11). There were significant statistical differences in dive behavior between the turtles for all but the bottom time (time spent at maximum depth) (Mann-Whitney U-Test: $p < .05$). Diel differences were also significantly different as has been reported by us in previous studies. Day dives were deeper, longer, with longer surface and bottom durations and faster ascent and descent rates than those at night.

Heart Rate:

While deployment of this instrument was successful - we have not been able to obtain any usable data from the recorder to date. The existing record appears to be corrupted or the electric signal too weak to decipher with our current equipment. We are exploring alternative techniques to obtain a clean data record. Because of technical challenges associated with proper placement of the heart rate electrodes only one deployment was attempted.

Discussion:

Movement patterns of the turtles during their interesting intervals were much more extensive than had been anticipated with the turtles moving all around St. Croix. Tracking, therefore proved to be quite challenging. Turtles were located exactly (within the inherent accuracy of the tracking system) 42.3% of the interesting days and to general area for another 24.4 % of the interval (total = 66.7%). 68.7 % of the days (during which exact locations could be established)

found the turtles outside of the 5.6 km (= 3 nautical mile) state waters and thus within Federal jurisdiction. Current Virgin Islands regulations prohibit longline fishing within 5.6 km of St. Croix (Toby Tobias, pers. comm.). Any regulations to control potential fisheries impacts will by necessity need to be Federal regulations rather than Territorial Law. There was no particular area where the turtles would "congregate", however there was a distinct predisposition to spend time on the north side of the island.

Swim speed recorders confirmed that the turtles moved continuously travelling at relatively slow but constant speeds. Each turtle showed a distinctive speed preference and all turtles preferred speeds between .5 and 1 meter per second (Fig 9). There did not seem to be any size influence on swim speed choice with the largest turtle preferring to swim at speeds almost identical to the smallest turtle. Also it should be noted that AAG 958 and AAG 928 were missing approximately 1/2 of their right front flippers yet their modal and maximum speeds were indistinguishable from those of the other turtles. Reports of swim speeds by other authors (determined by following in boats) are similar to those we measured directly: .52 m/s - 2.6 m/s (Duron 1978); 1.0 - 1.5 m/s (approximated) (Brongersma, 1972); .86 m/s (avg.), 1.38 m/s (maximum) (Standora et al. 1984); 15.7 m/s (this value is highly suspect and was not actually measured by the author) (Spoczynska, 1970).

Combining swim speed and dive profiles for turtles carrying both a TDR and Velocity recorders answered our question about turtles resting at the surface. In most cases, turtles at or near the surface continued to move forward (Fig 11). Turtles that were transitting to another location tended to have less diving with longer periods of high speed swimming e.g. May 13 for turtle AAG 439 (Figs. 6 & 11), when the turtle moved from the north shore of the island to the northeast corner of the island. Also, turtles tended to have their most rapid speeds at the beginning and the end of dives (Fig 12). One possible explanation for this latter observation is that the turtles are stroking hard on the descent to overcome buoyancy and on the return are taking advantage of lung re-expansion and the return of positive buoyancy to get back to the surface.

Total distance travelled by the turtles was between 278 and 674 km for the interesting interval. Average distance travelled per 24 h ranged from 40.5 km to

60.4 km. While this includes vertical distance travelled, it does give a sense of the capabilities of the leatherback.

Given the average distance travelled per 24 hours it is interesting to examine what this might mean for leatherback migrations. If we assume for the sake of calculation that the turtles did little or no diving and travelled in a relatively straight line, how long might it take to travel from temperate feeding areas to tropical nesting grounds? The pelagic nature of this species means that the turtles probably do not make point to point migrations, but rather move from the nesting beaches to foraging regions. However, for the sake of this exercise we can use some areas where non-breeding leatherbacks are known to inhabit, and calculate how long it would take a turtle to get to that area from the nesting beaches. Such regions include the Northwest Atlantic Ocean (Lazell 1980), the Northwest Pacific Ocean (north of Hawaii at about 45 degrees north latitude) (Wetherall et al. 1994) and the coast of Chile (Frazier 1990). The nesting areas that could conceivably be linked to these foraging areas are the nesting colonies along the Pacific coast of Mexico; Costa Rica and Malaysia, and the Atlantic nesting colonies at St. Croix and French Guiana. Table 4 lists the approximate distance between these points and the time it would take (in days) for the turtles to make such a migration.

The migration times listed in table 4 are undoubtedly faster than leatherbacks typically travel because they don't allow for diving, and assume straight line migrations. However, they are surprisingly close to some known migration times such as that of a leatherback female that washed up dead in Atlantic City, New Jersey after nesting on St. Croix (Boulon et al., 1988). The turtle swam a minimum of 3112 km in 85 days, an average of 36.6 km per day. Despite this overly simplistic calculation, what becomes apparant is that it takes these turtles a long time to move between foraging and nesting grounds. A leatherback leaving the large nesting colony in French Guiana could take between 2 and 3 months to reach the North Atlantic feeding grounds and another 2-3 months to return. A six month migration cycle and a 6 month nesting season, leaves little or no time for foraging. Thus, it is problematic for the turtle to build up enough resources for reproduction and growth in one year. This may explain at least in part why leatherbacks have a modal remigration rate of 2 years.

Conclusions:

During the interesting interval leatherback sea turtles rarely cease swimming, at modal speed ranging from .5 and 1 m/s. The majority of the interesting interval is spent more than 5.6 km from the island, typically to the North side of St. Croix. Finally, the turtles do not remain in any one location, but prefer to move around the perimeter of the island with each individual demonstrating its own preference. Some questions that remain to be answered are whether the individual turtles continue the same movement patterns between every nesting and are there seasonal or environmental influences on that movement?

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Table 1-4 Captions:

Table 1: Up to seven leatherback females were equipped with instrumentation to monitor movement patterns, swim speed and dive profiles. Table describes size, date of deployment and recovery and the type of instruments carried by each turtle.

Table 2: Modal and maximum swim speed and total internesting interval distance travelled as well as average daily distance for six female leatherback sea turtles around St. Croix in the U.S. Virgin Islands.

Table 3: Summary descriptive statistics on dive behavior of two female leatherback sea turtles during one internesting interval around St. Croix in the U.S. Virgin Islands. Dive depths are in meters, durations are in minutes and rates are in meters per second.

Table 4: Predicted number of days it would take for a leatherback female to migrate from the listed nesting colonies to the listed foraging grounds. Values are based on the average distance travelled per day by a female leatherback moving around St. Croix.

TABLE 1

TURTLE	LENGTH*	WIDTH	DEPLOYMENT	RECOVERY	INSTRUMENTS**
AAG 923	145.3	100.6	05/06	05/19	V,T
AAG 958	149.0	109.3	05/17	05/29	V,T
AAG 928	151.4	115.8	05/06	05/15	V,T
AAR 950	151.7	104.8	05/18	05/29	V,T
AAR 863	159.9	116.3	05/07	05/15	V,T,D
AAG 439	165.6	116.9	05/04	05/13	V,T,D
AAG 405	169.0	122.5	05/04	05/13	V,T

* cm , over-the-curve ** V = Velocity Recorder; T = VHF Transmitter; D = Time-Depth-R

TABLE 2

TURTLE	SWIM SPEED (m/s):		DISTANCE TRAVELLED (km):	
	MODE	MAXIMUM	TOTAL	AVG. / DAY
AAG 958	0.67	2.1	661.4	60.4
AAG 928	0.59	2.6	423.0	47.0
AAR 950	0.70	2.0	488.3	53.7
AAR 863	0.54	1.9	412.0	45.6
AAG 439	0.83	2.6	673.9	57.8
AAG 405	0.57	2.8	278.2	40.5
AVERAGE	0.65			51.8

TABLE 3

	DIVE DEPTH	DIVE DURATION	SURFACE TIME	BOTTOM TIME	DESCENT RATE	ASCENT RATE
AAR 863						
MEAN	93.0	10.3	3.4	2.6	.54	.42
STD	72.8	6.8	7.9	1.9	1.4	.58
MAX	490*	23.3	166.6	8.7	24.8	9.4
n	971	971	971	971	971	966
AAG 439						
MEAN	64.2	10.3	8.9	3.2	.28	.30
STD	57.1	7.2	19.4	2.6	.11	.14
MAX	480*	29.3	294.0	11.7	1.2	1.0
n	971	971	971	971	971	971

* Maximum capacity of TDR, dive depth was likely deeper.

TABLE 4		FORAGING AREA		
NESTING	COLONY	NW ATLANTIC	NW PACIFIC	CHILE
	FRENCH GUIANA	83.4	----	----
	ST. CROIX	51.2	----	----
	MALAYSIA	----	196.8	----
	COSTA RICA	----	161.0	95.4
	PACIFIC MEXICO	----	119.3	127.1

Figure 1-12 Captions:

Figure 1: Distribution of triangulated locations established during the tracking of seven leatherback females during one internesting interval. Most locations represent a single day for each turtle.

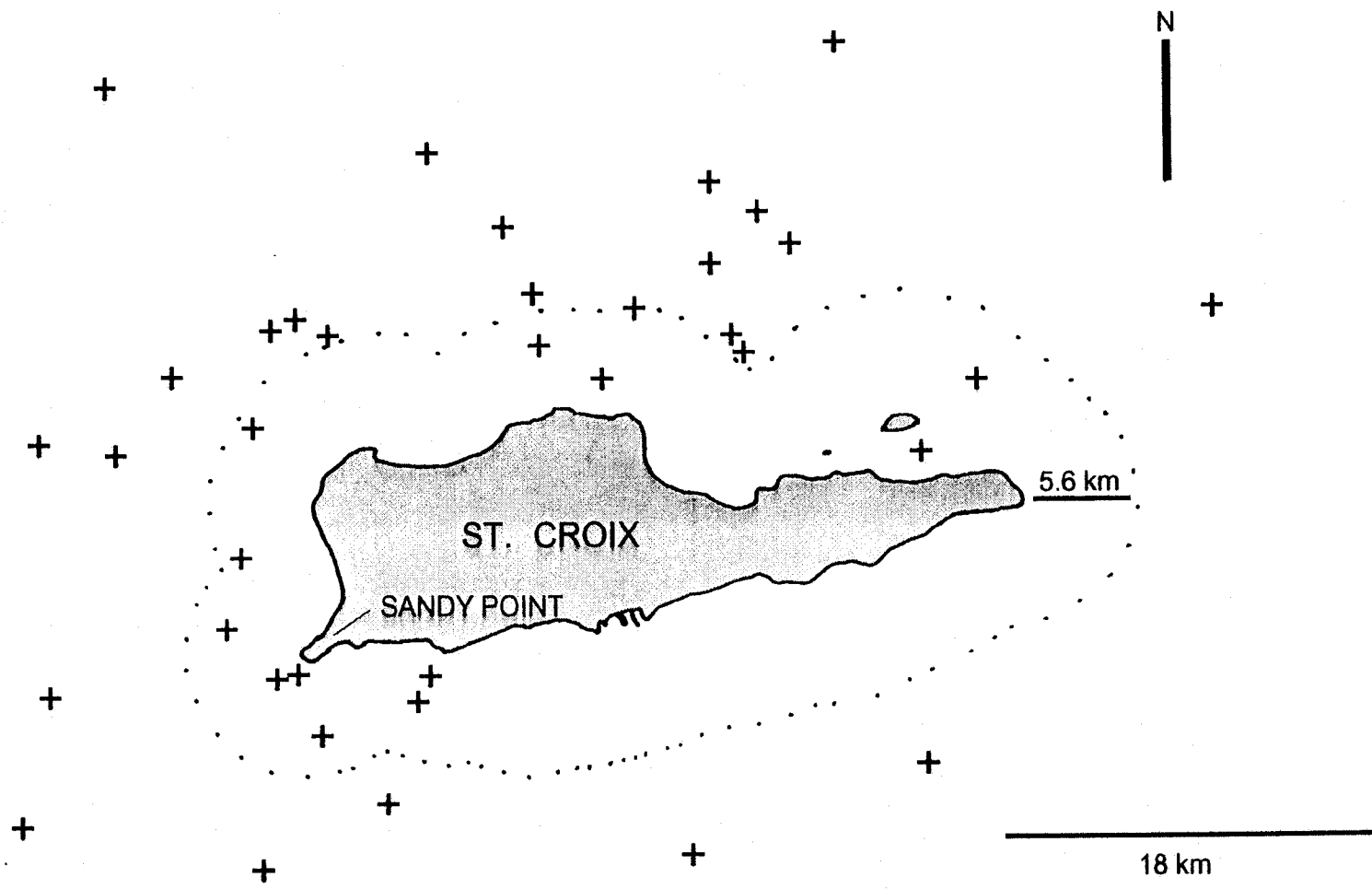
Figure 2 - 8: Movement patterns of 7 leatherback females (one figure for each turtle) during a single internesting interval around St. Croix, U.S. Virgin Islands. The arrows and lines represent hypothetical movements primarily used to connect radio fixed locations in consecutive order. + marks represent triangulated fixes and shaded area represent general locations based on one or more radio bearings that did not intersect. Dotted lines denote movements connecting non consecutive days.

Figure 9: Distribution of velocity records (based on either a 4 or 8 second sampling rate of the velocity recorders) for 6 leatherback sea turtles gathered during one internesting interval at St. Croix.

Figure 10: Frequency distributions of dive parameters for 2 leatherback turtles during a single internesting interval at St. Croix.

Figure 11: Example of one twenty-four hour section of the dive and swim speed record for leatherback turtle AAG 439 at St. Croix, U.S. Virgin Islands.

Figure 12: Example of one 6 hour section of the dive and swim speed record for leatherback turtle AAG 439 at St. Croix, USVI to illustrate a regular pattern of increased swim speeds at the beginning and end of dives.

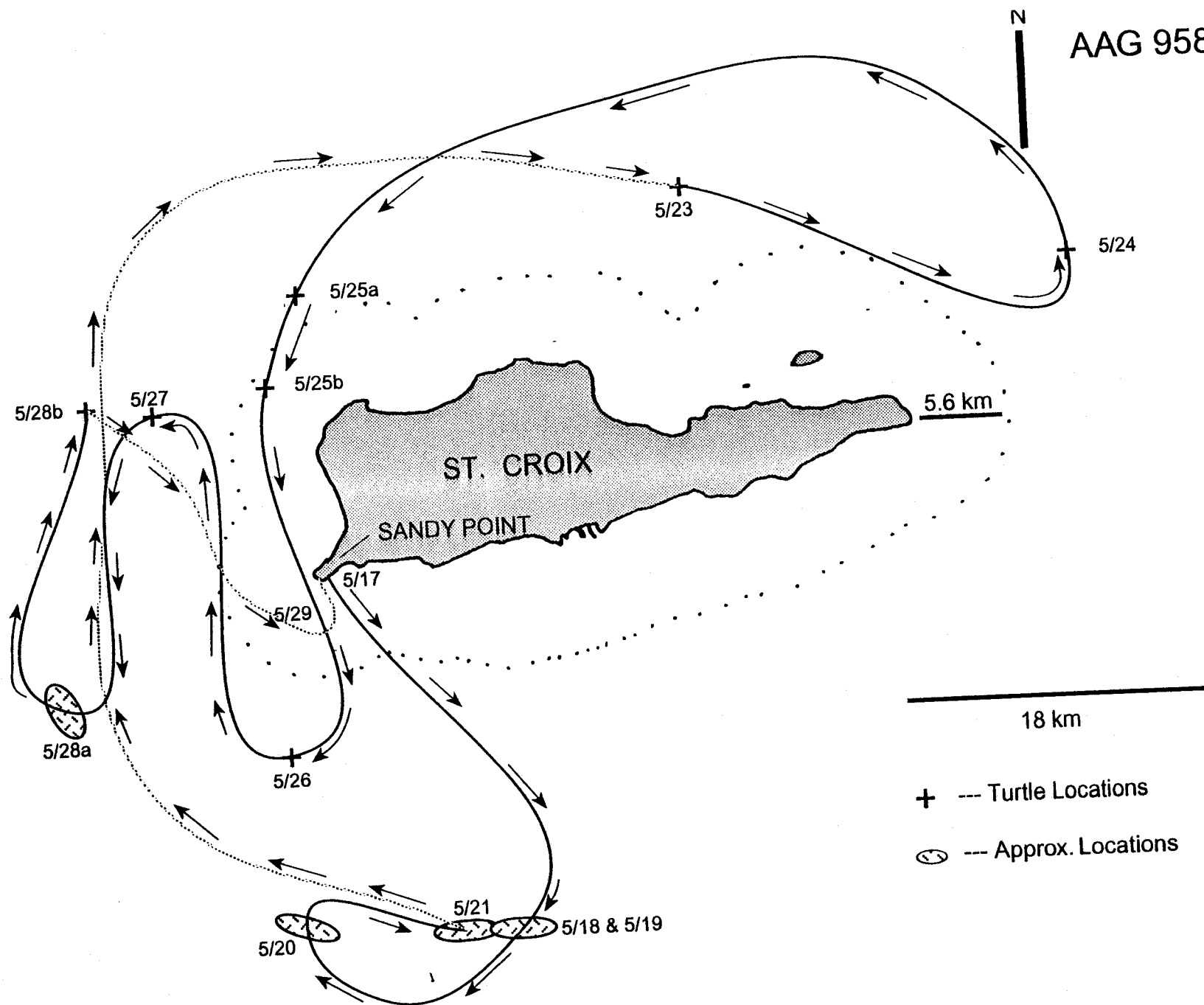


+ --- Turtle Locations

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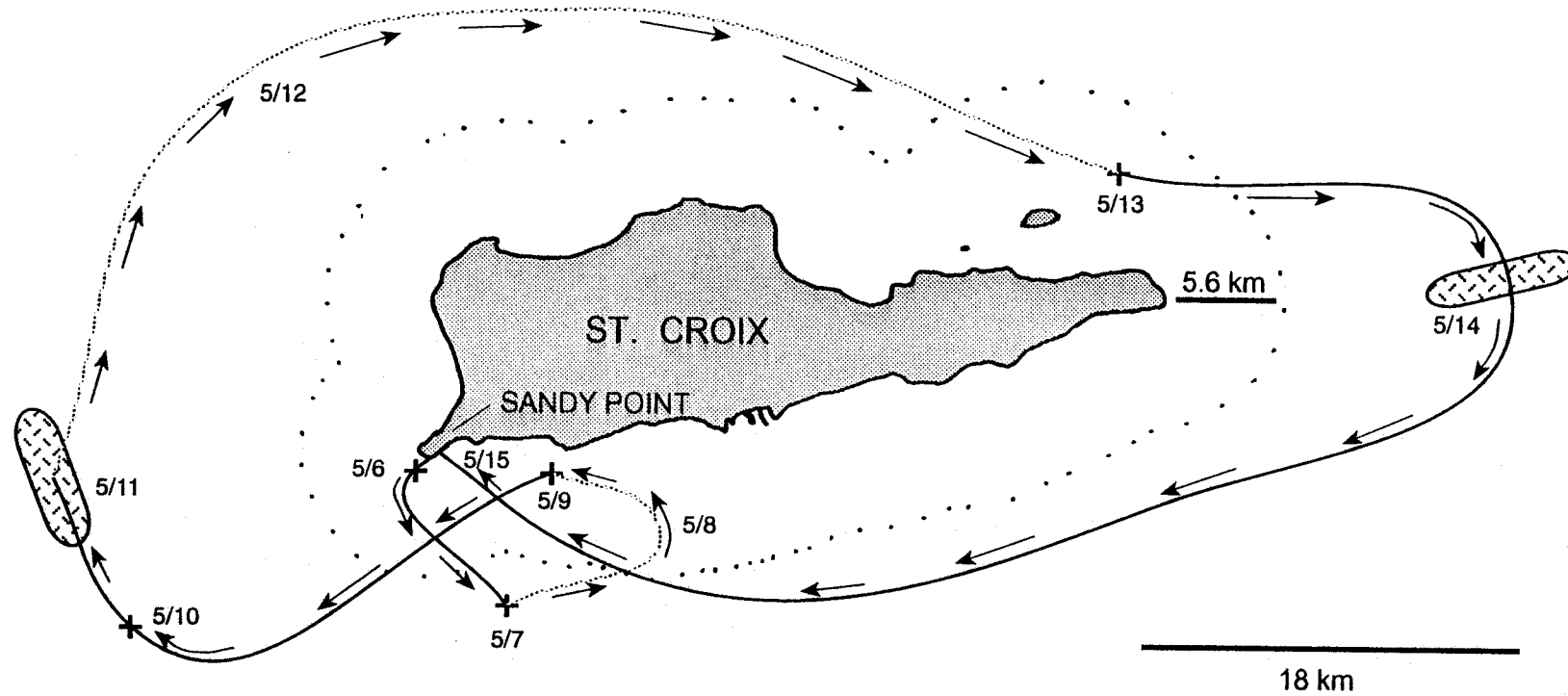


AAG 958





AAG 928

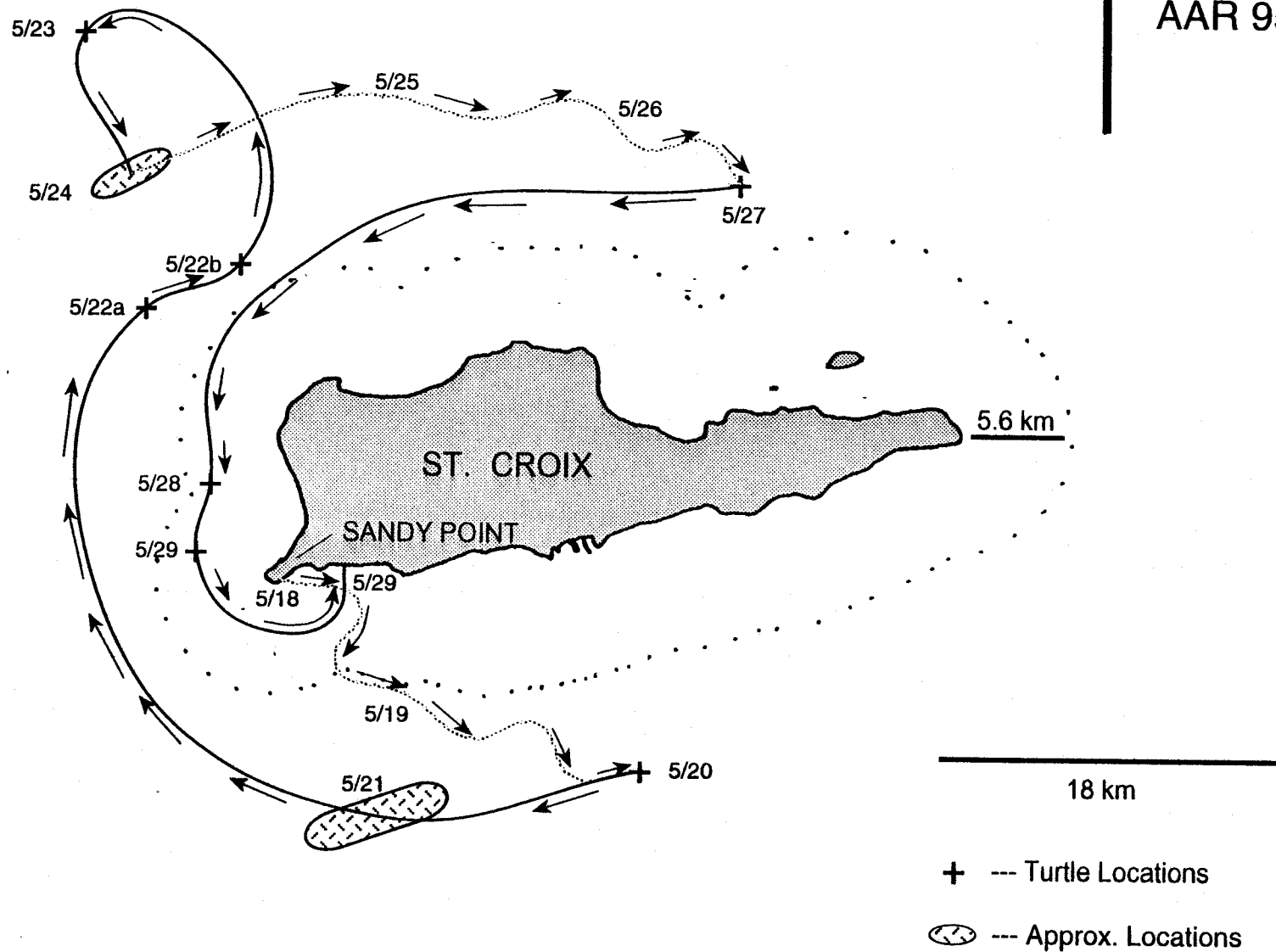


+ --- Turtle Locations

--- Approx. Locations

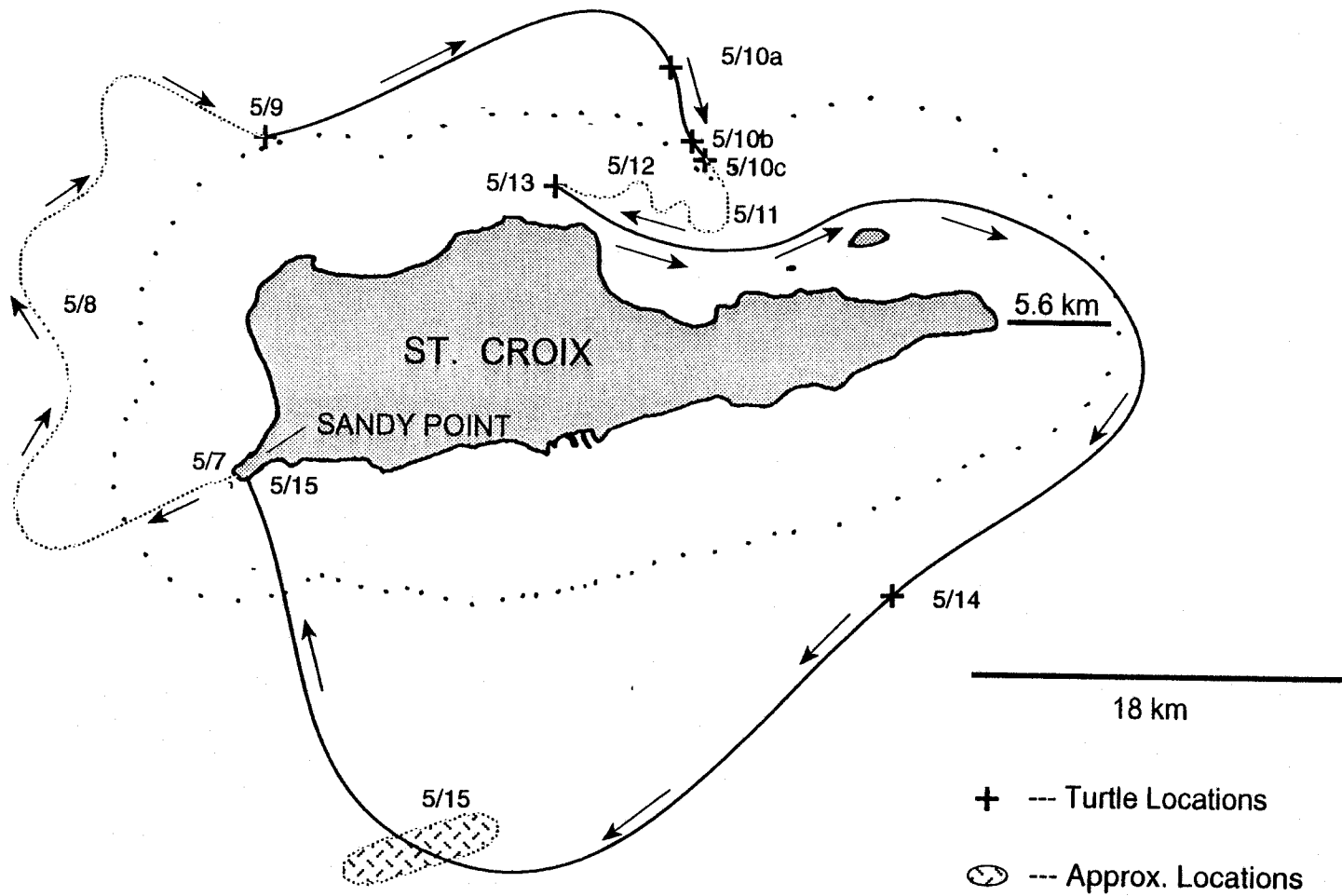
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AAR 950



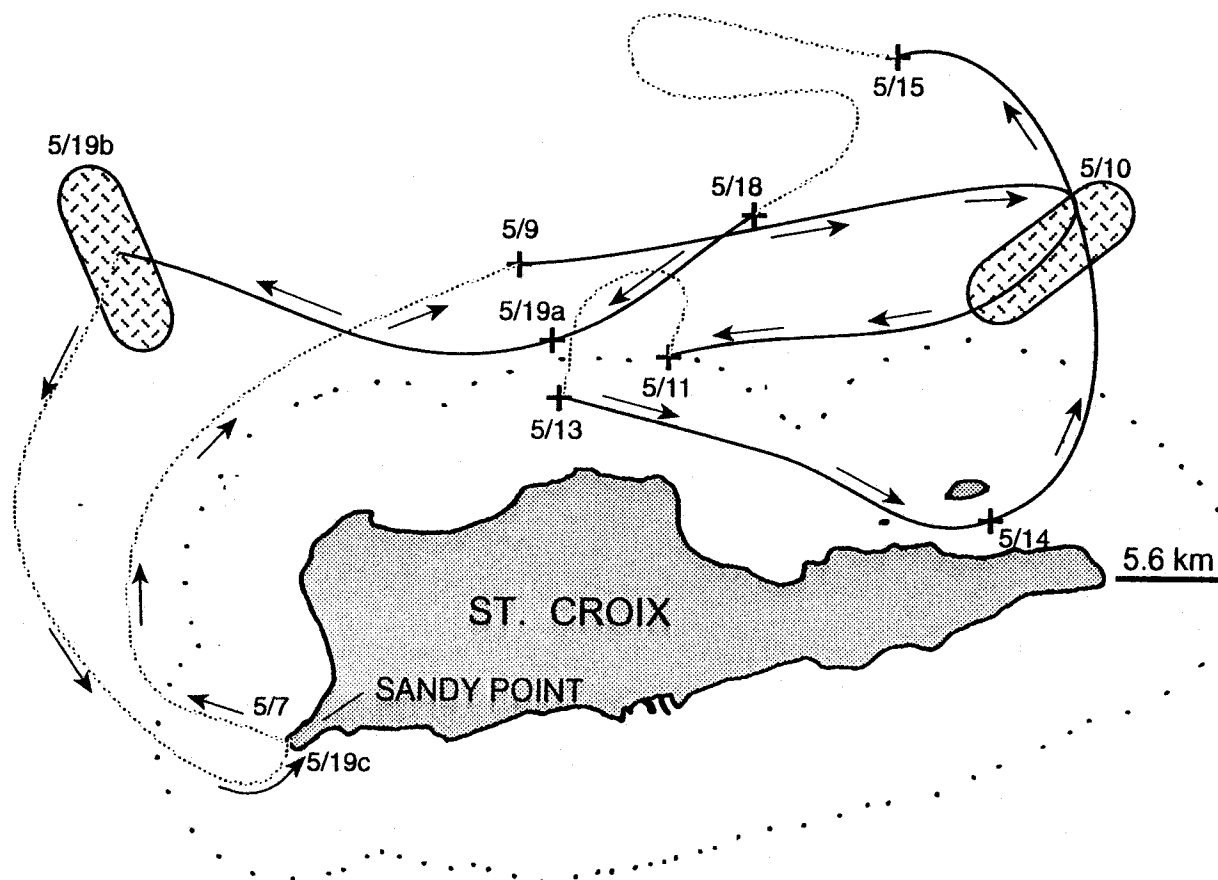
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AAR 863



N

AAG 439

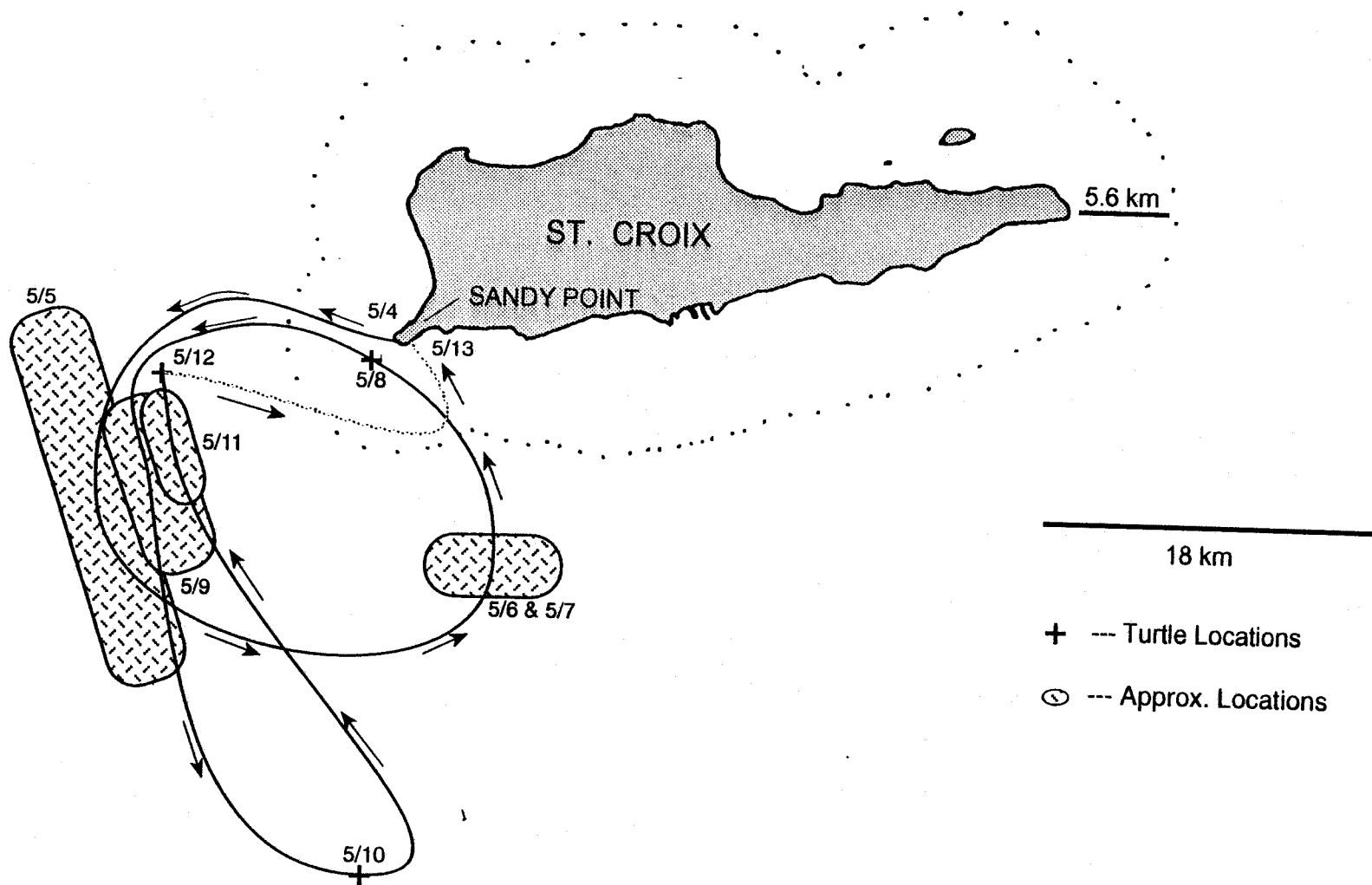


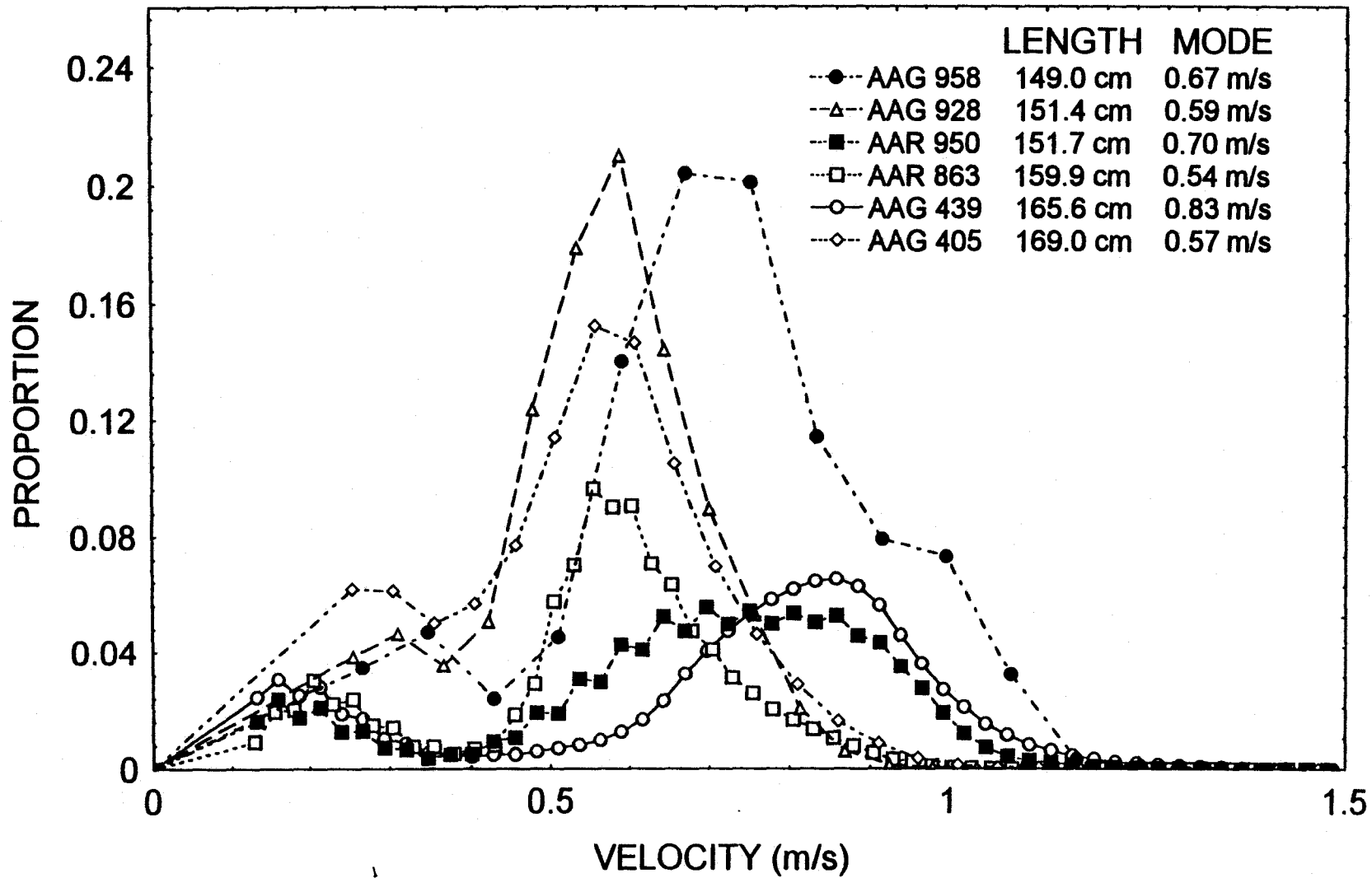
5.6 km

18 km

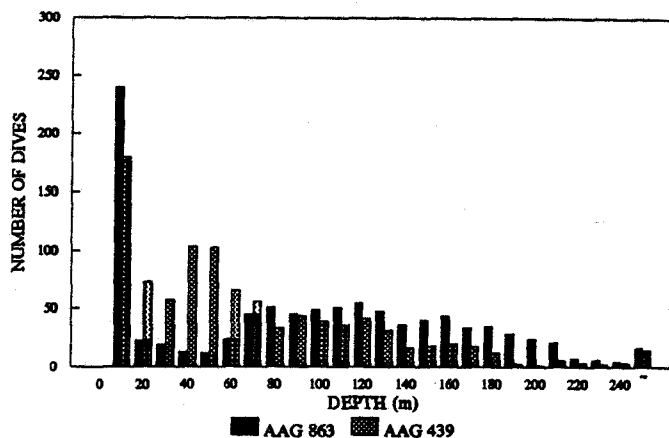
+ --- Turtle Locations

--- Approx. Locations

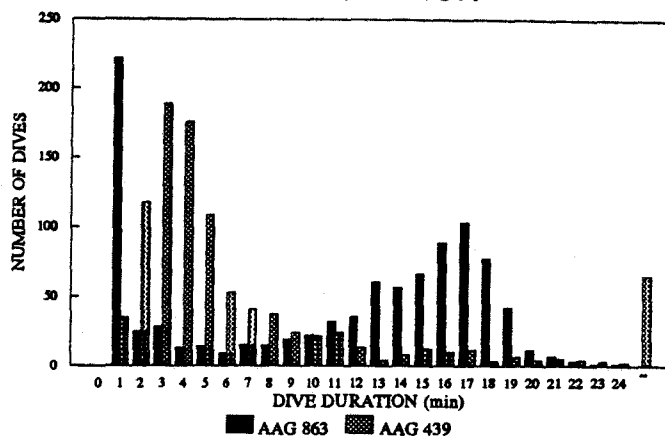




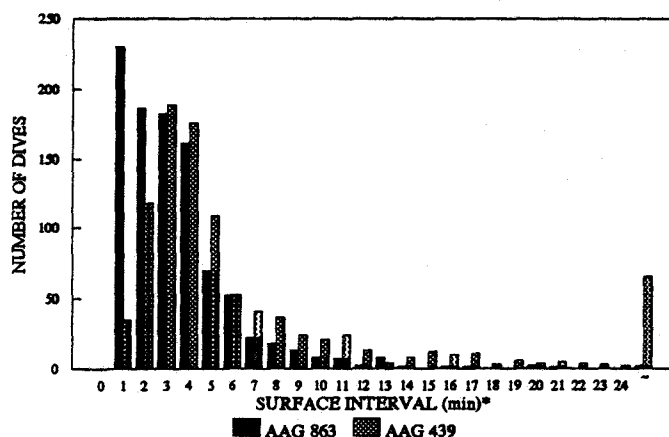
DIVE DEPTH



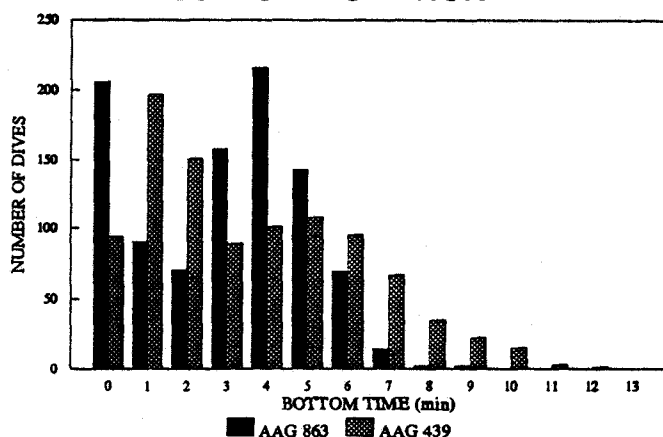
DIVE DURATION



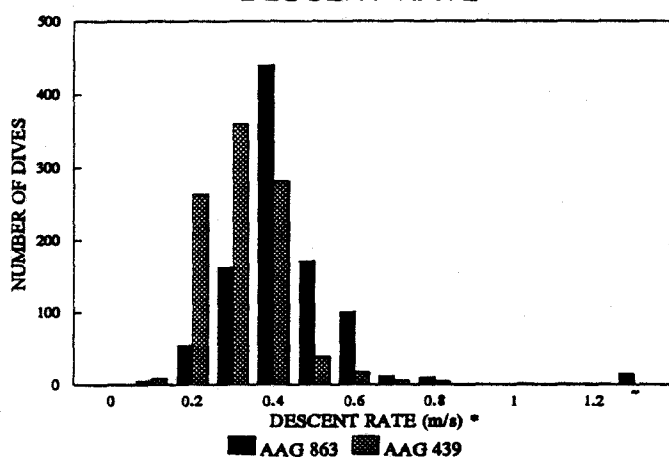
SURFACE INTERVAL



BOTTOM DURATION

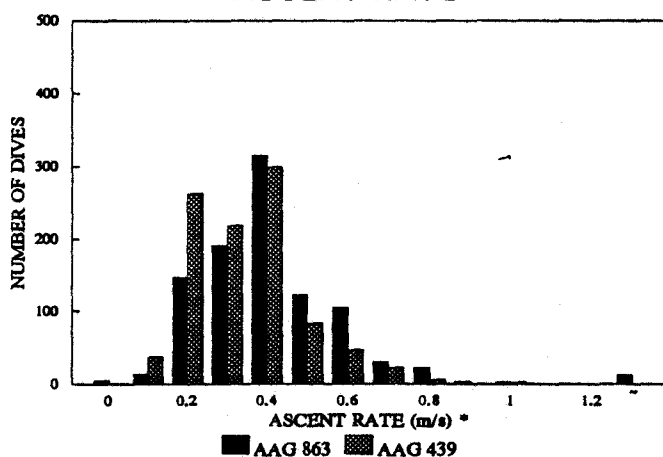


DESCENT RATE



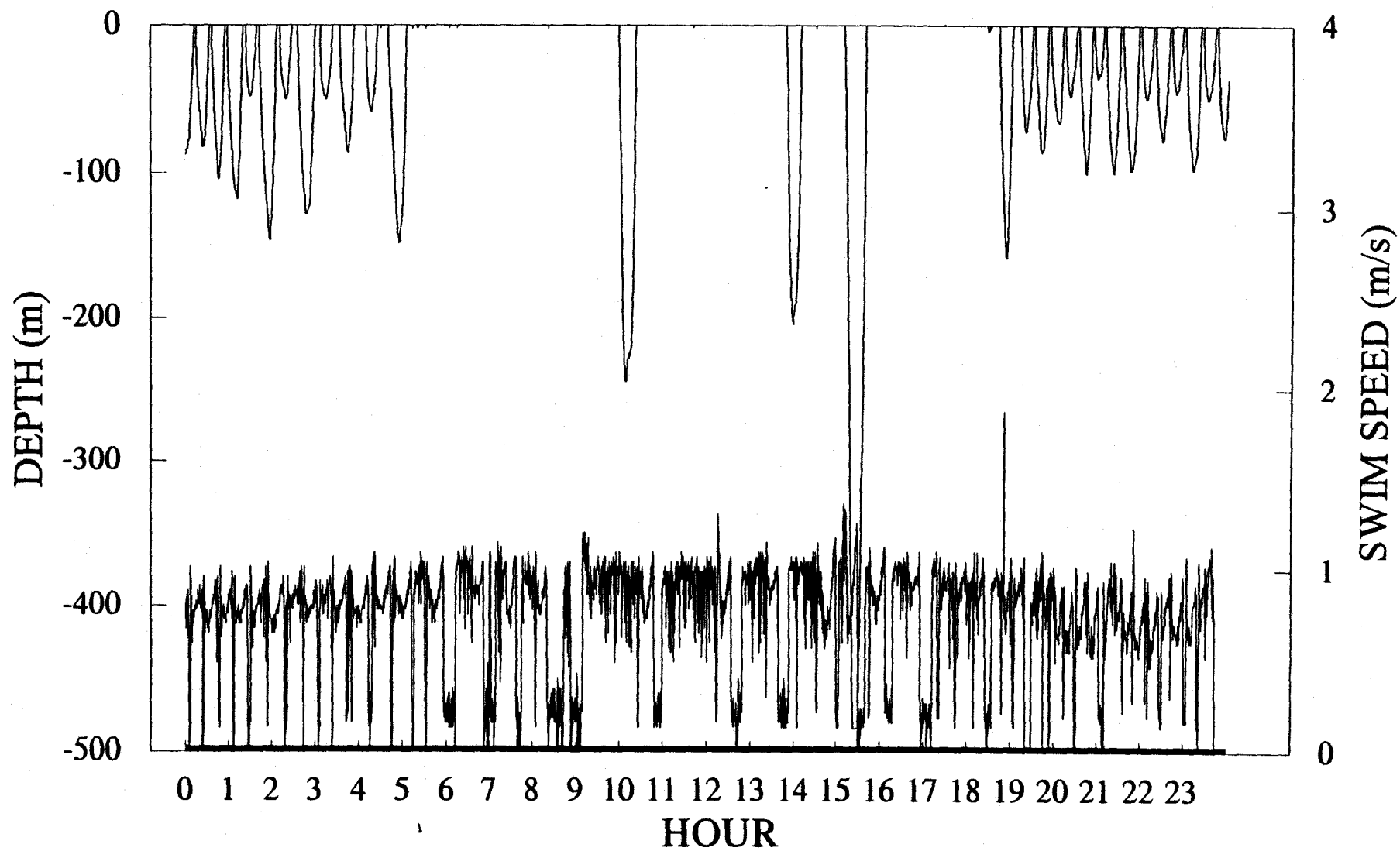
* Calculated on average per dive

ASCENT RATE



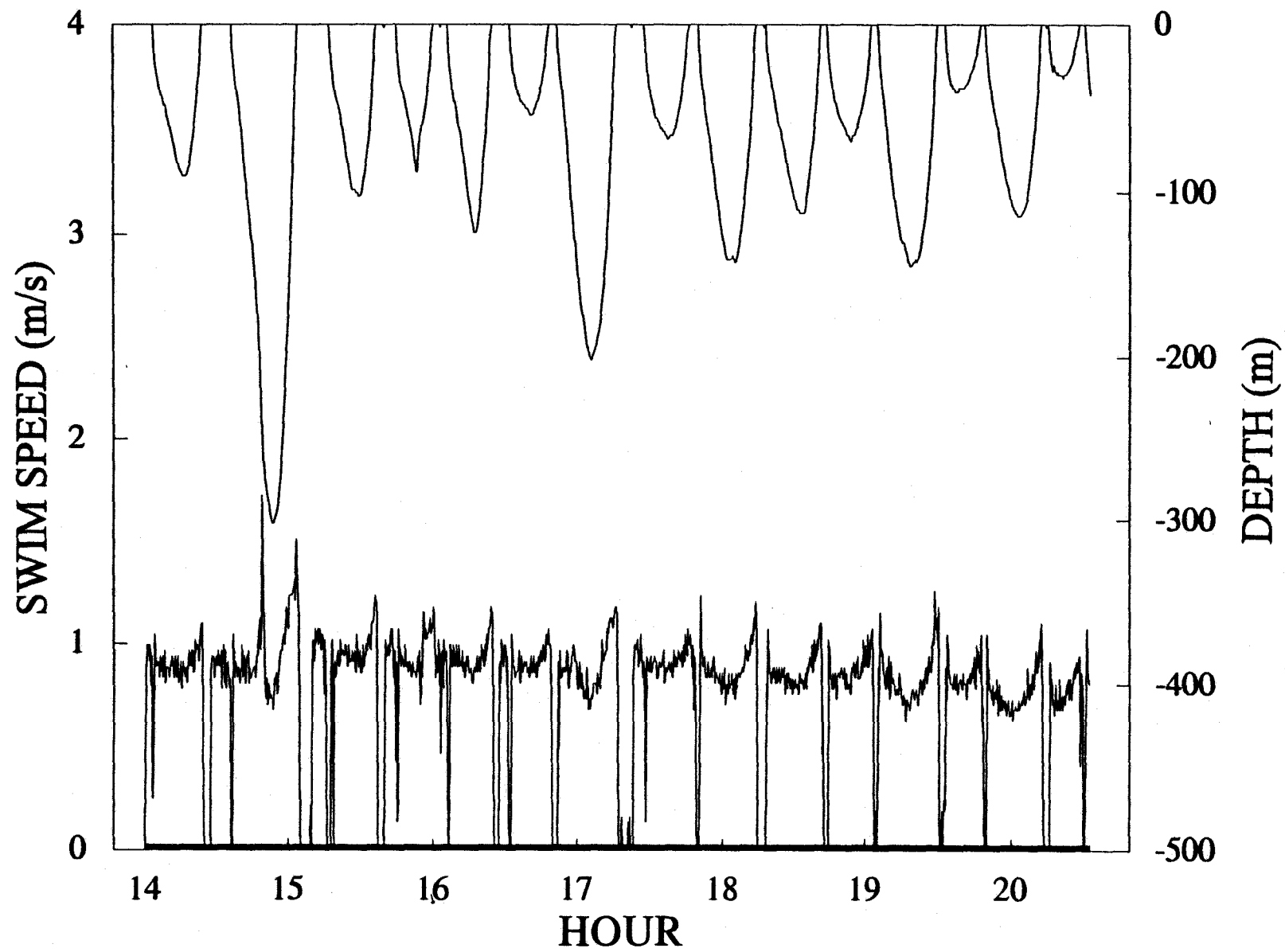
* Calculated on average per dive

AAG 439
TDR 103, VM 0



MAY 13, 1993

AAG439



MAY 7, 1993