On the Field Study of Shark Behavior

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SYNOPSIS The difficulties of observational study of active, wide-ranging sharks in the relatively concealing natural underwater environment are discussed for both baited and non-baited situations. The possible technique of habituating sharks to the diver's presence is considered in view of the logistical and safety problems imposed by the physical limitations of unaided, unprotected human divers. It is concluded that previous shark-observation methods are inadequate, and that supplementary study techniques must be developed and emphasized. These include remote monitoring by ultrasonic telemetry, telemetry-aided direct observation, and the use of miniature submersibles designed specifically for shark observation.

INTRODUCTION

As pointed out by Myrberg (1976) and Gruber and Myrberg (1977), the ethology of sharks remains very incompletely known in comparison to most other groups of large animals, and this stems primarily from the logistical difficulties of (1) keeping these animals in captivity under sufficiently natural conditions, and of (2) adequately observing them in the natural environment. The value of in situ behavioral studies on marine species is now clearly recognized (Herrnkind, 1974), and while the field approach is theoretically very appropriate for shark studies, the realization of its full potential has been blocked by some rather formidable problems. Although during the last decade or two, numerous field studies on large terrestrial species have yielded some nearly complete ethological descriptions, nothing comparable has yet been accomplished for any species of shark.

This is not to say that progress in understanding shark behavior has not occurred. Indeed, since the beginning of the current "emphasis" on shark research stimulated by the formation of the AIBS Shark Research Panel in 1958, much has been learned. For instance, findings on the visual, acoustic, chemical, and electric senses have clearly furthered our understanding of how sharks recognize and locate prey. Studies on both captive individuals and free-ranging "attracted" individuals have established much about how sharks behave in response to certain kinds of stimuli. However, for most species, we know very little about what occurs under completely natural conditions, i.e., the kinds of behaviors of interest to ethologists. We are only now beginning to document the daily routines of activity and movement of sharks in the wild. With few exceptions, we still know almost nothing about social structure, aggression, territoriality, courtship, and mating. Even "normal" (non-opportunistic) patterns of feeding remain quite poorly understood. This lack of species-specific information is probably the reason why the term "unpredictable" has so often been unjustifiably applied to sharks, when there is no good evidence that sharks of a given species behave with any greater variability than individuals of a given species from any other vertebrate group.

Our present meagre knowledge of certain aspects of shark behavior is largely due to the particular difficulties associated with observing these basically shy, wide-ranging animals in an environment as con-
cealing as the ocean. My comments in the remainder of this paper deal with logistical approaches to the in situ study of free-ranging sharks. When I use the term "sharks," I refer mainly to the relatively active carcharhinid types, such as the tropical reef species of the genus *Carcharhinus*.

**DIRECT OBSERVATION BY DIVERS**

Anyone who has attempted close underwater observation of active sharks soon finds that success is greatly dependent upon whether "bait" is used. In general, sharks are seen only infrequently and briefly, if at all, unless attracted in by feeding stimuli such as odors or sounds. In the absence of such "bait," sharks usually avoid divers, especially divers using noisy, open-circuit scuba. If a shark happens to cross paths with a diver, the shark's typical response is to move out of sight of the diver and not return. This situation obviously yields little opportunity for making significant behavioral observations.

There are some exceptions to this generality. For instance there are certain "unbaited" situations where sharks approach divers for apparently investigative reasons. This often happens in pelagic species such as the silky shark, *Carcharhinus falciformis*, and the oceanic whitetip shark, *C. longimanus* (Nelson, 1969). For probably somewhat different reasons, it also frequently happens in the Indo-Pacific gray reef shark, *C. amblyrhynchos*. While significant behavioral observations can be made in such situations, e.g., agonistic display of gray reef sharks towards divers (Johnson and Nelson, 1973), it must be kept in mind that the shark's response is to a somewhat "unnatural" stimulus, the diver himself.

**Baited situations**

It is well known that sharks can be readily attracted into view by certain odors and low-frequency, pulsed sounds (Hobson, 1963; Nelson and Gruber, 1963; Nelson and Johnson, 1972; Myrberg, et al., 1969, 1972). The problem with such baited situations is that what is seen is usually limited to responses appropriate in opportunistic feeding contexts, often further influenced by the obvious presence of the observer. This can create an approach/avoidance situation, with the shark's behavior affected by its tendency to move towards the bait conflicting with its tendency to shy away from the diver.

Certain aspects of behavior can be profitably studied in baited situations, as exemplified by Hobson's (1963) study of feeding patterns in Pacific reef sharks, and this approach is by no means exhausted. When groups of sharks are attracted, the element of competition exists, and this can lead to valuable observations on interactions between individuals, e.g., social facilitation in acoustically attracted sharpnose sharks, *Rhizoprionodon* sp. (Myrberg et al., 1969). However, there are other aspects of behavior which apparently are not readily revealed during feeding situations.

In many animals (e.g., chickens, baboons) experimental presentations of food at one restricted spot can elicit considerable assertions of dominance, threats, and fights, but this effect has thus far not been found with sharks. In Myrberg and Gruber's (1974) colony of captive bonnethead sharks, *Sphyrna tiburo*, the few aggressions that were noted did not occur at the times of food presentation. In the natural environment, similar absences of overt aggressions between competing, feeding sharks were noted by Hobson (1963) and Eibl-Eibesfeldt and Hass (1959). Agonistic display of gray reef sharks towards human divers also occurred less during feeding than during certain non-feeding situations (Johnson, 1977). Thus, to study certain kinds of social interactions, the technique of attracting sharks into view by feeding stimuli may not be the best approach. Other methods should be tried.

**Non-baited situations**

A great deal of natural behavior could be learned if unbaited sharks could be unobtrusively observed in their natural habitat for long periods of time. This is a
standard technique for study of terrestrial species where effective concealment and long viewing distances are possible, or where the subjects have become sufficiently accustomed to the observer to permit his close proximity. For many animals, such observational study has elucidated more or less the entire behavioral repertoire of the species.

For sharks, however, the unobtrusive-observation method has inherent problems of considerable magnitude. In addition to being generally shy of divers, sharks are wide-ranging animals living in a very concealing environment. Specifically, the underwater limit of visibility in even the clearest reef areas (few 10's of meters) is only a small fraction of a shark's typical home-range dimensions (1000's of meters). Therefore, even if diver-avoidance behavior is neglected, the chances of a diver seeing a shark at any one point in its home-range is small; and if one is seen, it is likely to pass out of sight within a few seconds. The diver also lacks sufficient speed to follow a moving shark for very long, especially since the shark will usually accelerate when it senses it is being chased.

A further problem is that many sharks spend much (or most) of their diel cycle at depths too great for scuba observation. In addition, most species are primarily night active, and thus many of their interesting behaviors probably occur under the cover of darkness.

Like other species, sharks do not move randomly about their home ranges, but frequent certain routes or core areas more than others; and such sites, if known, would be the preferred ones for attempted diver observation. But whether use of any such sites would ease the shark-avoid-diver problem is not known. It has not been established whether sharks possess any places of "high priority" where they would remain in spite of the presence of a diver that they would avoid at other places. The question of shark territories (areas defended against intruders) or dominions (areas of elevated dominance) remains open. Nothing of the sort has yet been experimentally established, but some observations suggest their existence, e.g., site-related aggressive behavior (McNair, 1975).

**Habituation to divers**

Some of the above problems are not unique to sharks or even to other large marine species. Many terrestrial animals are also shy of humans, wide ranging, and live in a relatively concealing habitat (e.g., thick jungle), and yet have been successfully studied by observational techniques. A classic example is van Lawick-Goodall's (1968) work with wild chimpanzees in the forests of the Gombe Stream Reserve, Tanzania. When she first attempted observations, she found the chimpanzees both difficult to locate and completely intolerant of her close presence. When she sighted chimps and tried to move closer, they simply disappeared into the forest as she approached. Her eventual success was due to the gradual habituation of these chimps to her presence so they no longer avoided her. This was a very long process, taking months (for significant progress) to years (for complete acceptance) of daily exposure. But it paid off richly, permitting close, detailed behavioral observations that would never have been possible from brief glimpses of the animals at long ranges.

Can a similar habituation to humans be established in free-ranging sharks in the natural environment? The answer appears to be yes—at least for one shallow-water species, the reef white-tip, *Triaenodon obesus*, a group of which was studied at Rangiroa, French Polynesia (Nelson and Johnson, unpublished data). These sharks lost much of their initial shyness towards divers after several months of relatively frequent (often daily) exposure to divers in both baited and unbaited situations. These white-tip sharks, however, were relatively accessible to divers. During daylight hours they were generally found in one particular reef area shallow enough for observation from the surface or by free diving. For more active and deeper species, such as many of the genus *Carcharhinus*, accessibility to the diver for sufficient periods of time will be the major problem in any attempt to establish habituation.
Other impediments to productive observation remain, even if complete habituation has been achieved and the sharks neither avoid nor are attracted to the divers. One problem is to locate the subjects prior to each day’s observation session. Another is to stay with the sharks long enough to take useful quantities of data. Another involves the physical limitations of scuba diving in terms of depth and duration. Underwater observation at night poses another difficulty. A final problem for the unprotected diver is exposure to shark aggression, e.g., agonistic attack by gray reef sharks (Johnson and Nelson, 1973). Thus, at best, the technique of “unaided” direct observation has serious limitations, and there is a real need for the development of additional or supplementary study methods.

REMOTE MONITORING BY TELEMETRY

In view of the difficulties of direct observation, many aspects of shark behavior can best be “observed” remotely from individuals equipped with ultrasonic transmitters. Basic day/night patterns of activity and movement, home ranges, depth and temperature preferences, swimming speeds and directions, etc., can be readily obtained by telemetry—providing the appropriate sensors are included in the transmitter package. The various telemetry systems and techniques, both single-channel and multichannel, that have been used for behavioral studies on sharks are described in detail elsewhere (Ferrel, et al., 1974; Nelson, 1974, 1977).

Signal-detection ranges for ultrasonic transmitters of the types used on sharks are on the order of several km, and therefore approximate the typical home-range dimensions of reef sharks. This means that a shark in an established home range, if left unmonitored for a period of time, can be relatively easily relocated for the next tracking session.

Besides providing data on location, movement, depth, etc., telemetry units can be equipped to detect certain specific behavioral events of the kinds related to feeding or social behaviors (Nelson, 1974, 1977). For instance, “natural” predation by sharks—as opposed to feeding on man-presented bait—is a seldom-observed behavior in need of investigation. Since any feeding activity undoubtedly involves opening and closing of the mouth, one could attach a “jaw-angle” sensor to telemeter the times and places of possible feeding events. Likewise, courtship and mating in active species of sharks is a behavior certainly in need of study. One way to approach this would be to telemeter some specific event believed associated with mating, such as flexing of the claspers, which could be done with an appropriately designed sensor.

TELEMETRY-AIDED DIRECT OBSERVATION

While much valuable data can be obtained remotely by telemetry, or directly by observation of “attracted” individuals, it is evident that neither of these approaches used separately will provide all the behavioral information desired. Probably the maximum potential for ethological study of sharks in the wild lies in the use of a combined telemetry/observation approach.

Although, in the past, ultrasonic transmitters were used primarily to gather and transmit actual data (including locational data), such transmitters can also be used simply to facilitate finding a given individual so that other observations can then be performed. Transmitter-equipped sharks can thus be intercepted by receiver-equipped divers for the purpose of making visual observations, at least brief ones. There is still the problem of withdrawal of unhabituated sharks, but even brief observations can yield some useful data, e.g., group size, structure, microhabitat. More importantly, the repeated encounters possibly by this method will serve to facilitate habituation. Since the shark is ultrasonically “marked,” if it moves out of sight at first contact, it can be easily relocated for additional encounters—subject, of course, to the limitations of the diver’s speed, depth, and endurance. Repeated
contacts of this type are necessary if habituation to the observer's presence is to be accomplished. As with van Lawick-Goodall's (1968) chimpanzees, such habituation seems requisite to really fruitful observation of social behaviors in free-ranging sharks.

In regard to the instrumentation needed, some telemetry systems are better than others for locating subjects underwater. A simple transmitter (pinger) can be located by a diver using a simple directional receiver, but it can be a relatively slow, frustrating process, especially if the target is moving. At close ranges, "loudness" of signal in the receiver headphones is not a very useful way of estimating signal distance, particularly in complex environments where varying degrees of signal blocking and/or multipath reflections occur. Interception of a moving shark is much easier if the telemetry system provides readout of both signal direction and distance—as do the transponding or timefix types (Nelson, 1977). Knowing both direction and distance permits much better planning of the diver's approach/interception/observation strategy, i.e., when to chase, when to hold position, when to seek concealment.

Individual identification

Once a technique is developed which allows adequate durations of observation, the problem of identification of individuals must be solved if the various ethological analysis methods are to be fully applied. It has become common practice in terrestrial (and some aquatic) studies for the observer to learn to distinguish individuals by fine details of external morphology. While such differences are sometimes slight, the observer (using good binoculars) can usually get a relatively clear view even at moderately long distances, and furthermore, often has sufficient time to examine each individual in detail. This procedure is considerably more difficult underwater.

Like other animals, sharks possess individual identifying details in addition to more general characteristics of size and sex. For instance, Myrberg and Gruber (1974) used variations in pigment-spot patterns, scars, and fin tears to identify the 10 bonnethead sharks they studied in a shallow (120-cm depth) semi-natural enclosure. For observations in the natural environment, the problem with using fine morphological details is that they become gradually obscured with increasing through-water distance. While one may be able to detect a shark at the limit of visibility, one needs to be much closer to distinguish any fine details.

Tagging can considerably facilitate underwater identification of sharks. Tags can be applied to either un captured individuals (spear-applied dart tags), or to captured individuals (various tag types). Individuals are identified by the tag's color code and/or its placement site on the shark. While tags are more prominent than most natural markings, they are still not individually readable at distances near the limit of visibility. A further problem with color-coded tags is the gradual obscuring of the code due to accumulation of algae and other fouling growths.

Sharks equipped with standard (long range) telemetry transmitters are normally identified by a combination of transmission frequency and/or pulse rate. However, in addition to the primary usages of telemetry discussed earlier, it may be worth considering a telemetric method for the sole purpose of identifying individuals at very short ranges underwater, i.e., within the limit of visibility. Each shark would carry a small pulse-coded, ultrasonic transmitter in addition to its color-coded, plastic-streamer tag. Transmitters for this purpose would require very little power (relative to long-range units), and could thus be made very small and long-lived. Simple transponders would be best, as having many continuously operating units in close proximity would create a hopeless confusion of signals. The diver-observer would aim the directional interrogate unit at a given shark, fire the interrogate pulse, and receive back the brief coded reply (pulse-position modulated). The identifying code would be automatically displayed in the diver unit.
Human limitations

A final problem remains—that involving the limits of human divers. For extended observation of most of the active, behaviorally interesting species (e.g., gray reef sharks), the ordinary scuba diver lacks sufficient mobility and time-at-depth, and is also not adequately protected against shark attack. A practical method of overcoming these restrictions is needed. As pointed out by Herrnkind (1974), mixed-gas rebreathers eliminate obtrusive bubble exhalation, and provide a partial solution to the time-at-depth problem. But they are costly to purchase and operate, still require decompression after deep dives, and their use at depth entails significant risks—from human error, if not from equipment failure.

The user of any type of scuba, of course, is still exposed to shark aggression, which in view of some recent attacks on divers and small submersibles (Johnson and Nelson, 1973; McNair, 1975), is a hazard that must be taken seriously. This would seem especially true for an observer who repeatedly intrudes into potentially agonistic shark situations. As suggested by McNair, a diver that spends much time in the presence of dangerous sharks should at least carry a proven defensive weapon, e.g., a powerhead.

The Shark-Observation Submersible

The ultimate answer to the in situ observation of sharks, especially dangerous species, may be the small-submersible approach (Nelson, 1974). A properly designed, miniature, one-person, one-atmosphere vehicle would be of great value for intercepting and observing telemetered sharks at depths too great for scuba, and would also provide the desired protection against shark attack. Unfortunately, a vehicle really suited to this purpose is not available. Although many existing dry submersibles have more-than-adequate capabilities for depth, mobility, and life support, these craft are too obtrusive, heavy, and operationally costly to be practical, especially in remote areas. What is needed is a simple, inexpensive, ultra-portable vehicle for short-duration dives to moderate depths. This vehicle should be light enough out of water to be handled by two persons in a small boat.

I suggest that such a Shark-Observation Submersible (SOS) be developed that possesses the pursuit speed, endurance, and unobtrusiveness necessary for repeated contacts with active telemetered sharks at moderate depths,1 hopefully to the extent resulting in shark habituation to the sub. The following characteristics seem appropriate for such a vehicle.

To achieve relatively low drag, and thereby relatively high speed and efficiency, the craft should be torpedo shaped (tapered cylinder), with the operator in the prone position. Both entry and viewing would be through a clear acrylic hemisphere at the forward end. The capsule would be water filled, but kept at surface pressure (1 atm) allowing the use of a simple, silent oxygen rebreather without the need for decompression. Water filling makes additional ballast unnecessary, facilitates emergency escape, and permits the internal use of the underwater telemetry receiver. Speed and operating duration should be flexible, depending on the sizes and numbers of electric thrusters and batteries used. Buoyancy must be adjustable from positive to negative. In the negative condition, with power off, the craft should be able to rest on the bottom in a totally silent, bubble-free condition.

As suggested by R. Johnson, such a vehicle could also be used in an active, experimental role in shark studies, e.g., making aggressive approaches to gray reef sharks to elicit agonistic display and possible attack. Another potential use of the sub would be as a model shark. Various movable “fins” could be added to the vehicle to simulate a shark in specific postural displays.

In conclusion, I believe that a comprehensive field study of shark behavior cannot be adequately accomplished by previous methods such as “bait” attraction

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1 Operating depth should be limited to that permitting safe emergency scuba escape, i.e., about 100 m.
and "unaided" diver observation, and that we must develop new techniques for this purpose. The most promising appear to involve remote study by ultrasonic telemetry, and telemetry-aided diver observation, especially if facilitated by miniature submersibles designed specifically for shark observation.

REFERENCES

Johnson, R. H. and D. R. Nelson. 1973. Agonistic display in the gray reef shark, Carcharhinus mentore-