BRIEF COMMUNICATION

Effects of capture and transmitter attachments on the swimming speed of large juvenile lemon sharks in the wild

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The swimming speed of seven large juvenile lemon sharks *Negaprion brevirostris* following attachment of an external speed-sensing ultrasonic transmitter was significantly higher during the first 18 h after release compared to the average swimming speed obtained >48 h after release. The external speed-sensing transmitter can be used to monitor the voluntary swimming speed of large fishes in the field, but data during the first 24 h period should be excluded from analysis of natural speeds, at least from species similar in behaviour to *N. brevirostris*.

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The study of sharks and other large fishes in their natural environment is complicated because of their size, behaviour and the fact that they live in a relatively inaccessible and concealing medium. Thus, direct observation is ordinarily not possible when conducting long-term field studies on sharks. Instead, ultrasonic transmitters have been employed in a number of field studies on elasmobranch behaviour (Sundström *et al.*, 2001) and physiology (Lowe & Goldman, 2001). Unfortunately, except when a transmitter can be fed to the fish, capture is often required for transmitter attachment although an exception is described by Klimley & Nelson, (1984). With more sensors and advanced functions, transmitters have become larger and the potential negative effects have increased, for example through increased drag or conspicuousness. Therefore caution must be taken when interpreting data obtained from telemetry, including the recently employed Crittercam (a video camera unit integrated with a computer and sensors, Heithaus *et al.*, 2001, 2002). In this study, the effects of capture and transmitter attachment on large juvenile lemon sharks *Negaprion brevirostris* (Poey) were evaluated by measuring changes in swimming speed directly after release.

Seven *N. brevirostris* were captured between March 1996 and August 1997 on long fishing-lines east of the shallow, subtropical lagoon at Bimini Islands (25°41′ N; 79°18′ W), Bahamas, *c.* 100 km east of Miami. Lines were set after dusk, checked every 4 h and removed just after dawn. Lemon sharks captured were immediately tied alongside a skiff and turned over, which caused them to enter tonic immobility, and thus no sedatives were required during transmitter attachment. The lemon sharks ranged in size from 1·54–1·83 m (total length, L_T, snout to tip of tail) and were equipped with two ultrasonic transmitters (Table I). The first, a cylindrical speed-sensing transmitter was of the paddle-wheel type with magnets attached to the blades (33 × 201 mm, output frequency of 69 kHz and life span of *c.* 21 days). A reed switch sensor inside the

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834

TABLE I. Data on seven large juvenile *Negaprion brevirostris* captured east of Bimini Islands, Bahamas and fitted with speed-sensing transmitters of the paddle wheel type darted to the back just below the first dorsal fin. F, female; M, male

Shark number	1	2	3	4	5	6	7
Transmitter attachment date	30 Mar 1996	15 Mar 1996	27 Jun 1997	8 Jul 1997	23 Jul 1997	5 Aug 1997	21 Aug 1997
Sex	F	F	F	F	F	M	M
L_T (m)	1·54	1·70	1·64	1·60	1·74	1·80	1·83
Release time (h)	0030	0430	0030	2330	0400	2315	2300
Total tracking time (h)	58	78	78	46	77	83	49
Track interval (h)	10–33	15–36	2–30	46	34–43	5–57	2–24
Span of tracking (days)	6	9	8	3	4	6	5
Reference speed ± s.d. (m s^{-1})[1]	0·54 ± 0·13	0·57 ± 0·14	0·64 ± 0·12	—	0·52 ± 0·08	0·57 ± 0·10	0·59 ± 0·07

[1]Calculated from measurements taken >48 h after release.

transmitter detected the magnetic field, created by a passing magnet, which was electronically converted into an acoustic signal. The transmitter was attached to a rectangular PVC plate and then secured below the shark's first dorsal fin using three to four steel darts and monofilament lines. A pulse-interval coded ultrasonic transmitter (pinger; 12×100 mm, output frequency of 76 kHz, and a life span of at least 18 months), used for identification of the shark, was tied to the speed-sensing transmitter with monofilament line. This allowed recovery of the expensive speed transmitter, which would fall off within a few weeks due to corrosion of the steel darts. Immediately after release lemon sharks were tracked from a skiff using a hydrophone connected to an ultrasonic receiver. The number of ultrasonic impulses from the previously calibrated speed-sensing transmitter was recorded for 1 min every 5 min and later converted to average swimming speed using the calibration curve. Detectable speeds, based on design limits and calibration, were 0.36–4.2 m s^{-1} with a sensitivity of ± 0.015 m s^{-1}, which varied slightly between speed-sensing transmitters. Details on capture, attachment, elemetry specifications and tracking procedure are provided by Sundström & Gruber (1998) and Sundström et al. (2001).

For each shark, swimming speed measurements were grouped into eight 6 h periods directly after release and one period for all measurements obtained more than 48 h after release. During the latter period (reference period) swimming speed was assumed not to be affected by capture and the speed during this period was taken as a measure of the natural swimming speed of the sharks (reference speed). Next, the average swimming speed was calculated for each period resulting in nine values for each shark (except for shark 4 for which no data were obtained >48 h after release). Thereafter, average speeds during each 6 h period were compared with the reference speed using ANOVA and two-sided Dunnett post hoc t-test.

The seven N. brevirostris were intermittently tracked for a total of 469 h ranging over 3–9 days (Table I). No speed measurements during the first 24 h after release were below that detectable by the transmitter while 3.4% were below the detectable speed during 24–48 h after release. During the reference period, 7.9% of all measurements were below the speed detectable by the transmitter.

Preliminary GIS-analysis revealed no differences in spatial behaviour during the first 24 h after release compared with later periods. Neither were there any significant correlations between L_T and swimming speed during any period. Swimming speeds clearly decreased during the first hours after release (Fig. 1). Average speeds during the first 6 h period varied between 0.72–1.06 m s^{-1} for the seven sharks while the average reference speed varied between 0.54–0.62 m s^{-1}. Compared with the average reference speed (0.57 m s^{-1}) for all sharks, post-release speeds were significantly higher during the first 18 h (ANOVA: $F_{8, 41} = 12.0$, $P < 0.001$; Fig. 1). An ' unaffected ' speed appears to be reached after c. 24 h and clearly within 42 h.

The elevated speed following release is probably caused by stress rather than fatigue since the latter would have been expected to cause a lower swimming speed immediately after release compared to later. Detailed reports on effects of capture and transmitter attachment in sharks are rare. Lowe et al. (1998) monitored swimming speed with a tailbeat transmitter on a 0.63 m scalloped hammerhead shark Sphyrna lewini (Griffith & Smith) that settled into regular swimming patterns within 3–4 h after attachment. Holland et al. (1993) regarded both increased and decreased swimming speeds as a sign of post-release trauma in other juveniles of the same species. Some grey reef sharks Carcharhinus amblyrhynchos (Bleeker) departed rapidly from the tagging area after attachment of transmitters using dorsal-fin mount (similar to this study), body-cavity insertion and ingestion (McKibben & Nelson, 1986). The dorsal-fin mount method caused the greatest influence on behaviour and the transmitter itself caused continual irritation. The ingestion method had the least negative impact, however, as grey reef sharks regurgitated the transmitter within days. Morrissey & Gruber (1993) reported that 17 juvenile N. brevirostris recaptured 8–1055 days after having the transmitter intraperitoneally inserted had normal colour and muscle tone and appeared healthy. This suggests that the most effective method is to place the transmitter in the shark's body cavity. Unfortunately, the fish still has to be captured and the surgical operation may
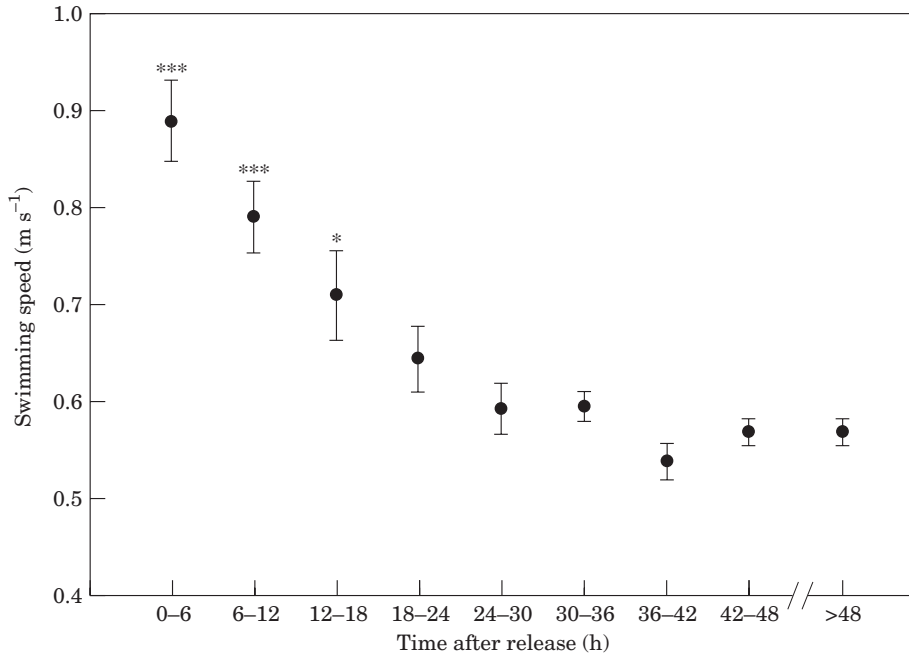
FIG. 1. Mean ($\pm$ s.e.) swimming speed of seven large juvenile *Negaprion brevirostris* directly following release after being captured on long fishing lines and fitted with speed-sensing transmitters. Significant differences (*$P<0.05$, ***$P<0.001$) between the speed during a time period and the reference speed (>48; ANOVA with Dunnett two-sided *t*-test with the reference speed as control) are indicated.

cause an initial trauma and increase the risk of bacterial infection (Grimes *et al.*, 1985). Furthermore, body cavity insertion will complicate the monitoring of parameters such as swimming speed that require external sensors.

Heithaus *et al.* (2001) attached a large Crittercam to the dorsal fin of >3 m tiger sharks *Galeocerdo cuvier* (Péron & Lesueur), but found no significant difference in swimming speed compared to tiger sharks with acoustic transmitters only. The Crittercam also allowed them to determine that five tiger sharks fed within 30 to 70 min after release. Blaylock (1990) found that for cownose rays *Rhinoptera bonasus* (Mitchill) the transmitter had no significant effect on swimming speed as long as the transmitter-to-ray mass ratio was <0.03. The transmitter package in this study was <1% of the body mass of any of the fish suggesting that the transmitter mass should not affect swimming speed.

The reference speed obtained in this study corresponds well with previous studies on *N. brevirostris* swimming speed. Laboratory studies on the swimming speed of juvenile *N. brevirostris* have shown mean speeds of *c.* 0·3 m s^{-1} (Bushnell *et al.*, 1989; Scharold & Gruber, 1991), or <0·2 m s^{-1} (Nixon & Gruber, 1988; Cortés & Gruber, 1994). Speeds from larger specimens (1·8 and 2·1 m, 0·74 and 0·69 m s^{-1} respectively) in the field are higher (Gruber *et al.*, 1988), and 1·06 m s^{-1} was reported for a big shark (>2·0 m) swimming in a large pool (Webb & Keyes, 1982). Translated into body lengths per second (L_{B}s^{-1}) all these speeds ranged from 0·2–0·5 L_{B}s^{-1}, which encompasses the speeds found in the present study.

The capture and transmitter attachment caused an initial period of elevated activity in *N. brevirostris*. Data from such a period should therefore be removed when analysing results on voluntary swimming speed in this species and perhaps for other sharks exhibiting similar habits. For a few weeks, the use of an external speed-sensing transmitter may be feasible, however, its use over longer periods cannot be recommended as it will incur drag that may eventually reduce growth of the tagged fish (Manire &

Gruber, 1991). Thus, an external speed-sensing transmitter can be used to reliably determine the voluntary swimming speed of medium-size and large active sharks in the field over an intermediate timescale.

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