Vol. 13: 111–116, 2011
doi: 10.3354/esr00332

ENDANGERED SPECIES RESEARCH
Endang Species Res

Published online January 27

NOTE

Range extension of the Endangered great hammerhead shark *Sphyrna mokarran* in the Northwest Atlantic: preliminary data and significance for conservation

Neil Hammerschlag[1,2,3,*], Austin J. Gallagher[2,3], Dominique M. Lazarre[1,3], Curt Slonim[3,4]

[1]Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, Florida 33149, USA

[2]Leonard and Jayne Abess Center for Ecosystem Science and Policy, University of Miami, PO Box 248203, Coral Gables, Florida 33124, USA

[3]RJ Dunlap Marine Conservation Program, University of Miami, 4600 Rickenbacker Causeway, Miami, Florida 33149, USA

[4]Curt-A-Sea Fishing Charters, 117 El Capitan Drive, Islamorada, Florida 33036, USA

ABSTRACT: We provide pilot data from a satellite-tracked great hammerhead shark *Sphyrna mokarran* in the Atlantic, representing the first such data on this species in the literature. The 250 cm shark was tagged off the coast of the middle-Florida Keys (USA) and transmitted for 62 d. During this time it migrated a minimum distance of ~1200 km northeast from the coast of Florida, into pelagic international waters of the Northwest Atlantic. When compared to the primary literature, this migration represented a northeasterly range extension for this species off the continental slope in the Atlantic. The significance of this range extension is discussed in terms of the vulnerability of *S. mokarran* to target and non-target fisheries.

KEY WORDS: Predator · Satellite tag · Argos · Shark · Habitat use · Elasmobranch

INTRODUCTION

The great hammerhead shark *Sphyrna mokarran* is the largest of the hammerhead species (family Sphyrnidae) and is widely distributed in coastal and pelagic tropical waters (Compagno et al. 2005). *S. mokarran* is distinguishable from its smaller congeners by a large sickle-shaped dorsal fin and broad cephalofoil lacking a notch. Clarke et al. (2006) recently demonstrated that the shark fin trade is a major driver of global shark declines. Great hammerheads are highly sought after in the finning industry due to their large fins, and the high fin needle content (cartilaginous fibers) common to all hammerheads (Abercrombie et al. 2005, Chapman et al. 2009). Although not directly targeted in the Northwest Atlantic, *S. mokarran* is taken as bycatch in several fisheries and suffers one of the highest discard mortality rates of any shark species in the Atlantic (National Marine Fisheries Service 2002). In the Northwest Atlantic, *S. mokarran* have been reported to experience greater than 90% at-vessel mortality rates in the US bottom longline fishery (Commercial Shark Fishery Observer Program as reported by Denham et al. 2010). A recent study estimated age and growth of *S. mokarran* based on vertebrae removed from 216 sharks that were retained by research-fishing (Piercy et al. 2010). The study demonstrated that great hammerheads have one of the oldest reported ages (44 yr) for any elasmobranchs (Piercy et. al. 2010). Additionally, *S. mokarran* only reproduces

*Email: nhammerschlag@rsmas.miami.edu

once every 2 yr, making this species vulnerable to rapid over-exploitation and population declines (Stevens & Lyle 1989, Denham et al. 2010).

Recent studies have demonstrated that, globally, populations of great hammerheads have drastically declined (Baum et al. 2003, Shepherd & Myers 2005, Myers et al. 2007, Ferretti et al. 2008). In the Atlantic alone, hammerhead stocks, including *Sphyrna mokarran,* have been estimated to have declined over 89% between 1986 and 2000 (Myers et al. 2007). This loss of apex predatory sharks in the Atlantic has been suggested to induce major cascading ecosystem level effects (e.g. Myers et al. 2007). Accordingly, the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species lists *S. mokarran* as 'Endangered' with population trends decreasing globally (www.iucnredlist.org). In November 2010, the International Commission for the Conservation of Atlantic Tunas (ICCAT) adopted agreements to protect great hammerheads in Atlantic waters (www.iccat.int). In order to implement appropriate conservation management strategies, the ICCAT Standing Committee on Research and Statistics (SCRS) recommended immediate implementation of 'research on hammerhead sharks in the Convention area (Atlantic) […] Based on this research, CPCs [contracting parties and cooperating non-contracting parties, entities or fishing entities] shall consider time and area closures and other measures, as appropriate.' (www.iccat.int/documents/recs/RECS_ADOPTED_2010_ENG.pdf) As such, there is a management and conservation push to identify and characterize areas important to the life history of hammerhead sharks in the Atlantic.

The great hammerhead's geographic range is known to extend throughout coastal warm temperate and tropical waters, occurring within latitudes 40° N to 35° S (Last & Stevens 1994). In the western Atlantic Ocean, they have been positively documented within coastal waters as far south as Uruguay and as far north as North Carolina (Compagno et al. 2005, Denham et al. 2010). While there have been a few individual reports of great hammerheads north of the aforementioned range, these claims are either unsubstantiated or not valid (see 'Discussion' for further details). This paper documents a northeasterly range extension of *Sphyrna mokarran*, off the continental slope in the Northwest Atlantic, and describes the possible significance of these preliminary data for the conservation of this species.

MATERIALS AND METHODS

To provide insights into the spatial habitat use of great hammerheads in the subtropical Atlantic Ocean, we conducted a pilot study off the Florida Keys, USA. A male shark (250 cm total length) was tagged on 20 February 2010, with a near-real time Smart Position and Temperature Transmitting (SPOT5) satellite tag (Fig. 1). The shark was captured in US federal waters off the reef edge in the middle Florida Keys (~24.69° N, 80.85° W; Fig. 2) using baited drumlines as described by Hueter & Tyminski (2007). Drumlines were left to soak for 1 h before being checked for shark presence, to reduce the stress of capture, before applying the satellite tag. To limit bio-fouling of the tag, the transmitter was coated with Propspeed, a non-toxic, non-metallic, anti-fouling agent comprised of several different types of silicone resins that inhibit attachment of marine growth (Hammerschlag et al. 2010). The coated SPOT tag was attached to the first dorsal fin of the shark (following Weng et al. 2005) using titanium bolts, neoprene washers, steel washers, and high carbon steel nuts following Hanson (2001). The attachment metals were selected to ensure that the steel nuts would corrode, resulting not only in tag detachment (Hanson 2001), but also to prevent any metallic corrosion from touching the shark fin (Hammerschlag et al. 2010). SPOT tags contain a saltwater switch, which activates the tag to transmit to an orbiting satellite when above the water surface. Geographic locations of the shark were determined by Doppler-shift calculations made by the Argos Data Collection and Location Service whenever a passing satellite received 2 or

Fig. 1. *Sphyrna mokarran.* Tagged great hammerhead shark swimming off with a SPOT5 satellite tag attached to its large sickle-shaped dorsal fin, which is characteristic of this species. Image courtesy of K. Slonim

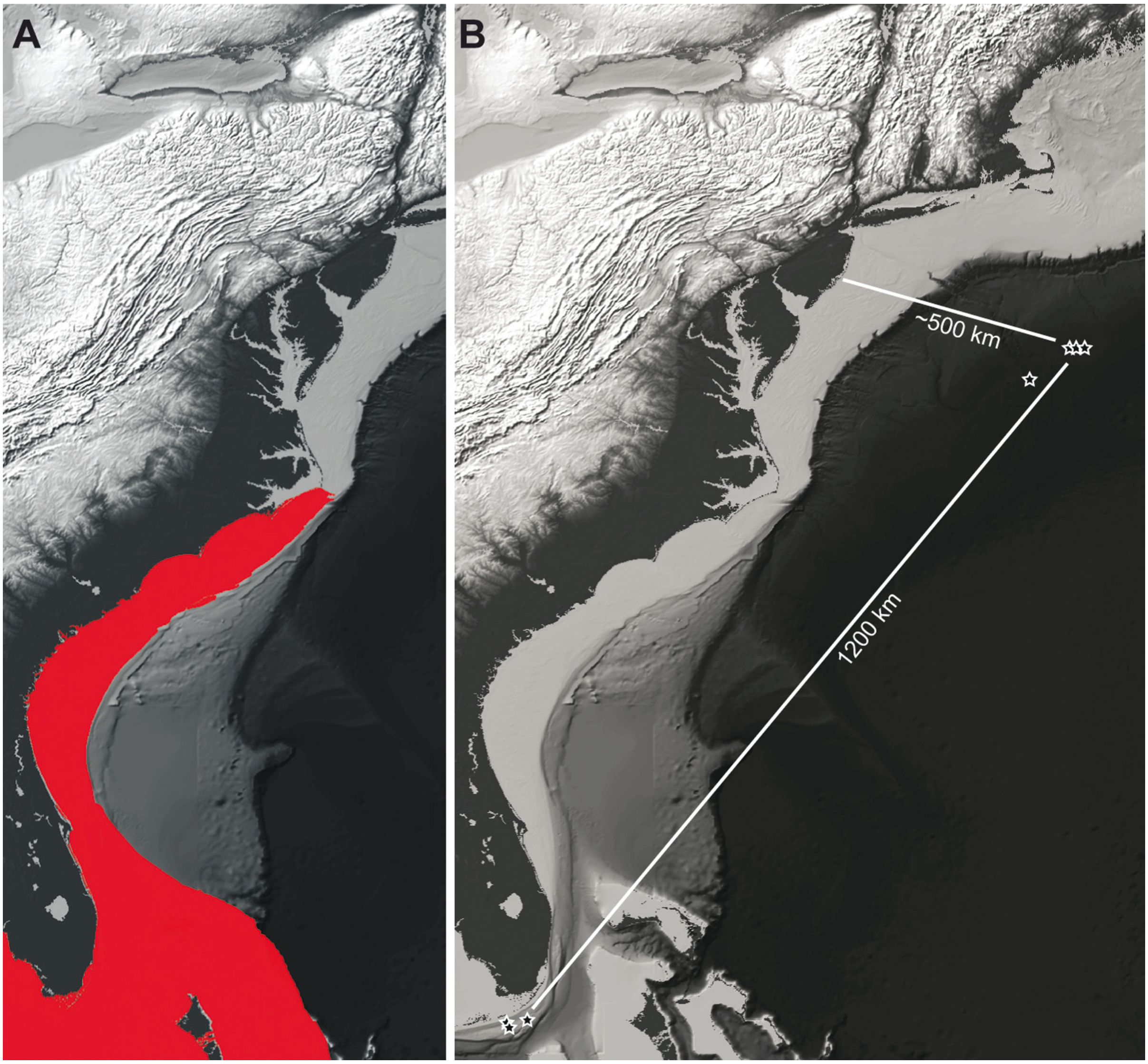

Fig. 2. *Sphyrna mokarran.* (A) Southeastern USA, showing the known distribution of great hammerheads (red) based on Compagno et al. (2005). (B) Locations of a great hammerhead shark tracked with a SPOT5 satellite tag between 20 February and 22 April 2010. Tracks were filtered to provide 7 locations (stars) with accuracies ranging from approximately 500 m to 5 km. Locations in the Atlantic (~500 km west of New Jersey) acquired from 20 to 22 April. Locations acquired in the Florida Keys region between 20 February and 18 March. The straight-line distance from the locations recorded in the middle of the Northwest Atlantic to the initial tagging location in the Keys was ~1200 km. See 'Results and Discussion' for further details

more signals from the tag at the surface. With each position, Argos provides an associated accuracy estimate for the following location classes (LC): LC 3, <250 m; LC 2, <500 m; and LC 1, <1500 m (www.argos-system.org). Argos does not provide estimates for LC 0, A, B, and Z; however, it has been reported in the literature that LC A is accurate to approximately 1 km radius and LC B is accurate to approximately 5 km radius (Tougaard et al. 2008). Class Z indicates that the location process failed and estimates of position are highly inaccurate.

RESULTS AND DISCUSSION

The shark was tracked from 20 February to 22 April 2010, providing data on date and time of surfacing as well as ambient water temperature at transmission. The shark provided 45 total position estimates during this period, but tracks were filtered to remove positions with accuracy estimates below LC B. This provided a data set of 7 spatial locations (Fig. 2) with accuracies ranging from approximately 500 m to 5 km. This error scale, when compared to the scale of shark movement, was sufficient to resolve spatial habitat use in the present study (Bradshaw et al. 2007, Weng et al. 2008). The shark was first tagged 11 km off the coast of Florida, on 20 February. It then appeared to remain within the vicinity of the Florida Keys for about 1 mo, with locations ranging from 44 km offshore in federal waters to just 2 km off the coast in state waters (18 March). With the onset of spring, the shark next surfaced almost 1 mo later (20 April) off the continental slope in the North Atlantic (38.15° N, 69.31° W; Fig. 2). The shark then transmitted 3 consecutive times in the same area over the course of 3 d. These locations were within international waters, approximately 500 km east of New Jersey, well outside the US Exclusive Economic Zone. Location estimates obtained for these positions were relatively accurate, ranging from 1500 to 500 m (LC 1, 2). The tag is negatively buoyant and will sink if not affixed to the animal, so it is impossible that these positions were the result of a detached tag drifting in the Gulf Stream as flotsam. The straight line distance from initial tagging location to the locations recorded in the Northwest Atlantic was ~1200 km. Sea surface temperatures from all tag transmissions ($n = 43$) averaged 21.9 ± 0.4°C (SE; range 17.0–27.9°C), despite near-shore water along the US eastern coast being <18°C during the tracking period (www.noaa.gov). The tag ceased to transmit after 23 April. This is likely the result of either tag detachment or bio-fouling of the tag's saltwater switch.

These results suggest that the tagged hammerhead appeared to follow the northeast pathway of the warm Gulf Stream, a known migratory highway for many large fishes. It is possible that the shark's movements were related to pursuit of prey. For example, dolphin fish *Coryphaena hippurus*, a known prey item of *Sphyrna mokarran* (authors' pers. obs.), are common along the continental shelf from southern Florida to North Carolina (Schuck 1951, Oxenford 1999), but have been found to move north through the Gulf Stream during spring months (Oxenford & Hunte 1986, Farrell 2009) as far north as Nova Scotia, Canada (Vladykov & McKenzie 1935). Similarly, other prey items of *S. mokarran*, such as blue runner *Caranx crysos*, have also been documented to follow a similar seasonal, northern migration via the Gulf Stream (e.g. Rountree 1990). The migratory route and seasonal life history of these potential prey items roughly coincide with the spatial and temporal scale of our tagged shark. Thus, we speculate that the movements observed by our tagged shark may be linked to the seasonal migration of migrating prey fishes; however, this requires further investigation.

We believe our data represent the first concrete scientific evidence for a northeasterly range extension of *Sphyrna mokarran*. This claim is supported by an extensive review of various sources including the primary literature, gray literature, field guides, National Oceanographic and Atmospheric Administration (NOAA) databases, Ocean Biographic Information System (OBIS) databases, Food and Agriculture Organization (FAO) databases, and consultations with shark distribution experts (e.g. L. J. V. Compagno pers. comm.). The OBIS database includes several accounts of possible *S. mokarran* found within the range and even farther north of the animal we tagged. However, our investigation demonstrated that these accounts were either invalid or not reliable. This is typified by an account in the OBIS database of a great hammerhead, captured by the RV 'Alfred Needler' 300 miles (~500 km) north of our satellite-tracked shark; the specimen is now housed in the Atlantic Reference Center museum. Upon further investigation, this account proved to be a database error. The RV 'Alfred Needler' is a plankton-sampling vessel, and the catalogued specimen associated with this catalog number is a planktonic larva. This was confirmed by the museum curator (L. Van Guelpen pers. comm.). Moreover, the OBIS lead data manager confirmed this database error; further, she could not find any valid records in the entire OBIS database which would suggest that our data do not represent a range extension for this species (B. Herlach pers. comm.). Similarly, the North Atlantic Right Whale Consortium, which has been recording shark species encountered throughout their aerial and boat surveys of right whales *Eubalaena glacialis* in the North Atlantic and Bay of Fundy for over 40 yr, has no record of a single great hammerhead species in their database which would invalidate our claim (R. Kenney pers. comm.). Finally, L. J. V. Compagno (pers. comm.), who compiled the revised FAO shark catalog (2010), confirmed that there are no verified records of *S. mokarran* off the continental shelf and north of North Carolina.

Problems with hammerhead species identification as well as with obtaining accurately recorded fisheries data make it difficult to assess the status of *Sphyrna mokarran* (Ferretti et al. 2008). High mortality rates when captured makes the great hammerhead highly vulnerable to any fishing pressure, whether targeted or as bycatch (Denham et al. 2010). This problem is illustrated in a report by Cortés & Neer (2005), in which they provided updated data on commercial and recreational landings of Atlantic sharks. They documented that in 2003, the US Atlantic commercial shark fishery landed 150 368 lbs (~68 206 kg) of unidentified hammerhead sharks, while no *S. mokarran* were reportedly caught. Similarly, in 2002, the US recreational fishery reported landing 5293 unidentified hammerhead sharks, of which only 4 were reportedly great hammerheads.

A recent study using genetic and molecular tools to trace the geographic origins of shark fins found that over 21% of scalloped hammerhead shark (the morphologically similar congener *Sphyrna lewini*) fins originated from the western Atlantic (Chapman et al. 2009). Moreover, the majority of Atlantic shark landings are made in international waters by non-US vessels (Crowder & Myers 2001, Mandelman et al. 2008). When considering recent population declines of *S. mokarran* and their vulnerability to fishing, our preliminary findings are especially troubling for great hammerheads swimming throughout international waters of the North Atlantic, a region where there are compounding pressures from both target and incidental fisheries.

This preliminary work demonstrates that the movements and habitat use of great hammerheads still remain inadequately documented, despite their continued declines. To our knowledge, this pilot study is the first published report of a satellite-tagged great hammerhead in the Atlantic Ocean (Hammerschlag et al. 2010). Further satellite tagging studies are warranted, as they may continue to reveal interesting biogeographical information of this species. The great hammerhead is listed in Annex I, Highly Migratory Species, of the UN Convention on the Law of the Sea, which requests countries to collaborate over the management of *Sphyrna mokarran*. Our preliminary results provide support for the recommendations made by Denham et al. (2010) that 'precautionary adaptive collaborative management of target and bycatch fisheries is urgently needed for this unproductive shark [*S. mokarran*]. It is also essential to improve data collection and develop stock assessments for this species.' (Denham et al. 2010, www.iucnredlist.org). As such, effective conservation management of this species will require a comprehensive understanding of *S. mokarran* life-history patterns, physiological and behavioral responses to anthropogenic stressors (e.g. angling), habitat use and vulnerability to fishing capture.

Acknowledgements. Funding for this pilot work was provided by the Batchelor Foundation, Herbert W. Hoover Foundation, NOAA LMRCSC, Save The Blue, the Richard and Marian Dunlap Permanent Fund at the St. Paul Foundation, and the RJ Dunlap Marine Conservation Program (RJD) at the University of Miami. For field support, we thank all RJD interns. For assistance with supplying distribution data and verifying records of *Sphyrna mokarran*, we thank L. J. V. Compagno of the Shark Research Institute, B. Herlach of OBIS, B. Kenney and K. Mahoney of the North Atlantic Right Whale Consortium, and L. Van Guelpen of the Atlantic Reference Center Museum. Special thanks to M. Dunlap, D. Die, K. Slonim, C. Wongen, D. Stakem, H. Baer, K. Mansfield, M. Billingsley, J. Greene, Wildlife Computers, Propspeed USA, YSI Inc., Robin Materials, and Argos CLS for ongoing support. This work was conducted under permits from the National Marine Fisheries Service Highly Migratory Species Division (SHK-EFP-10-01), Florida Keys National Marine Sanctuary (FKNMS-2010-006), Florida Fish and Wildlife (SAL-957), and the University of Miami Institutional Animal Care and Use Committee (IACUC) Protocol no. 09-187. We also thank S. Cooke and the anonymous reviewers whose comments helped strengthen our paper.

LITERATURE CITED

Abercrombie DL, Clarke SC, Shivji MS (2005) Global-scale genetic identification of hammerhead sharks: application to assessment of the international fin trade and law enforcement. Conserv Genet 6:775–788

Baum JK, Myers RA, Kehler DG, Worm B, Harley SJ, Doherty PA (2003) Collapse and conservation of shark populations in the Northwest Atlantic. Science 299:389–392

Bradshaw CJA, Sims DW, Hays GC (2007) Measurement error causes scale-dependent threshold erosion of biological signals in animal movement data. Ecol Appl 17: 628–638

Chapman DD, Pinhal D, Shivji MS (2009) Tracking the fin trade: genetic stock identification in western Atlantic scalloped hammerhead sharks *Sphyrna lewini*. Endang Species Res 9:221–228

Clarke SC, McAllister MK, Milner-Gulland EJ, Kirkwood GP and others (2006) Global estimates of shark catches using trade records from commercial markets. Ecol Lett 9: 1115–1126

Compagno LJV, Dando M, Fowler S (2005) Sharks of the world. Collins field guide. Harper Collins Publishers, London

Cortés E, Neer J (2005) Updated catches of Atlantic sharks. NOAA Fisheries LCS05/06-DW-16, Panama City, FL

Crowder LB, Myers RA (2001) 2001 first annual report to The Pew Charitable Trusts: a comprehensive study of the ecological impacts of the worldwide pelagic longline industry. Available at http://moray.ml.duke.edu/faculty/crowder/research/crowder_and_myers_Mar_2002.pdf

Denham J, Stevens J, Simpfendorfer CA, Heupel MR and others (2010) *Sphyrna mokarran*. IUCN Red List. Available at www.iucnredlist.org

Farrell ER (2009) The habitat, movement, and management of dolphin, *Coryphaena hippurus*, in the western North Atlantic, Caribbean, and Gulf of Mexico. MS thesis, Duke University, Durham, NC

Ferretti F, Myers RA, Serena F, Lotze HK (2008) Loss of large predatory sharks from the Mediterranean Sea. Conserv Biol 22:952–964

Hammerschlag N, Gallagher AJ, Lazarre DM (2010) A review of shark satellite tagging studies. J Exp Mar Biol Ecol 386: 125–132

Hanson MB (2001) An evaluation of the relationship between small cetacean tag design and attachment duration: a bioengineering approach. PhD dissertation, University of Washington, Seattle, WA

Hueter RE, Tyminski JP (2007) Species-specific distribution and habitat characteristics of shark nurseries in Gulf of Mexico waters off peninsular Florida and Texas. Am Fish Soc Symp 50:193–223

Last PR, Stevens JD (1994) Sharks and rays of Australia. CSIRO, Melbourne.

Mandelman JW, Cooper PW, Werner TB, Lagueux KM (2008) Shark bycatch and depredation in the U.S. Atlantic pelagic longline fishery. Rev Fish Biol Fish 18:427–442

Myers RA, Baum JK, Shepherd TD, Powers SP, Peterson CH (2007) Cascading effects of the loss of apex predatory sharks from a coastal ocean. Science 315: 1846–1850

National Marine Fisheries Service (2002) The directed shark gillnet fishery: right whale season 2002. In: Carlson J, Baremore I (eds) SFD Contribution PCB-02/13. Southeast Fisheries Science Center, Panama City, FL

Oxenford HA (1999) Biology of the dolphinfish (*Coryphaena hippurus*) in the western central Atlantic: a review. Sci Mar 63:277–301

Oxenford HA, Hunte W (1986) A preliminary investigation of the stock structure of the dolphin, *Coryphaena hippurus*, in the western central Atlantic. Fish Bull 84:451–460

Piercy AN, Carlson JK, Passerotti MS (2010) Age and growth of the great hammerhead shark, *Sphyrna mokarran*, in the north-western Atlantic Ocean and Gulf of Mexico. Mar Freshw Res 61:992–998

Rountree RA (1990) Community structure of fishes attracted to shallow water fish aggregation devices off South Carolina, U.S.A. Environ Biol Fish 29:241–262

Schuck HA (1951) Notes on the dolphin (*Coryphaena hippurus*) in North Carolina waters. Copeia 1951:35–39

Shepherd TD, Myers RA (2005) Direct and indirect fishery effects on small coastal elasmobranchs in the northern Gulf of Mexico. Ecol Lett 8:1095–1104

Stevens JD, Lyle JM (1989) Biology of three hammerhead sharks (*Eusphyra blochii, Sphyrna mokarran*, and *S. lewini*) from northern Australia. Aust J Mar Freshw Res 40:129–146

Tougaard J, Teilmann J, Tougaard S (2008) Harbour seal spatial distribution estimated from Argos satellite telemetry: overcoming positioning errors. Endang Species Res 4: 113–122

Vladykov VD, McKenzie RA (1935) The marine fishes of Nova Scotia. Proc N S Inst Sci 19:17–113

Weng KC, Castilho PC, Morrissette JM, Landeira-Fernandez AM and others (2005) Satellite tagging and cardiac physiology reveal niche expansion in salmon sharks. Science 310:104–106

Weng KC, Foley DG, Ganong JE, Perle C, Shillinger GL, Block BA (2008) Migration of an upper trophic level predator, the salmon shark *Lamna ditropis*, between distant ecoregions. Mar Ecol Prog Ser 372:253–264

Editorial responsibility: Steven Cooke, Ottawa, Ontario, Canada

Submitted: September 7, 2010; Accepted: November 18, 2010
Proofs received from author(s): January 20, 2011