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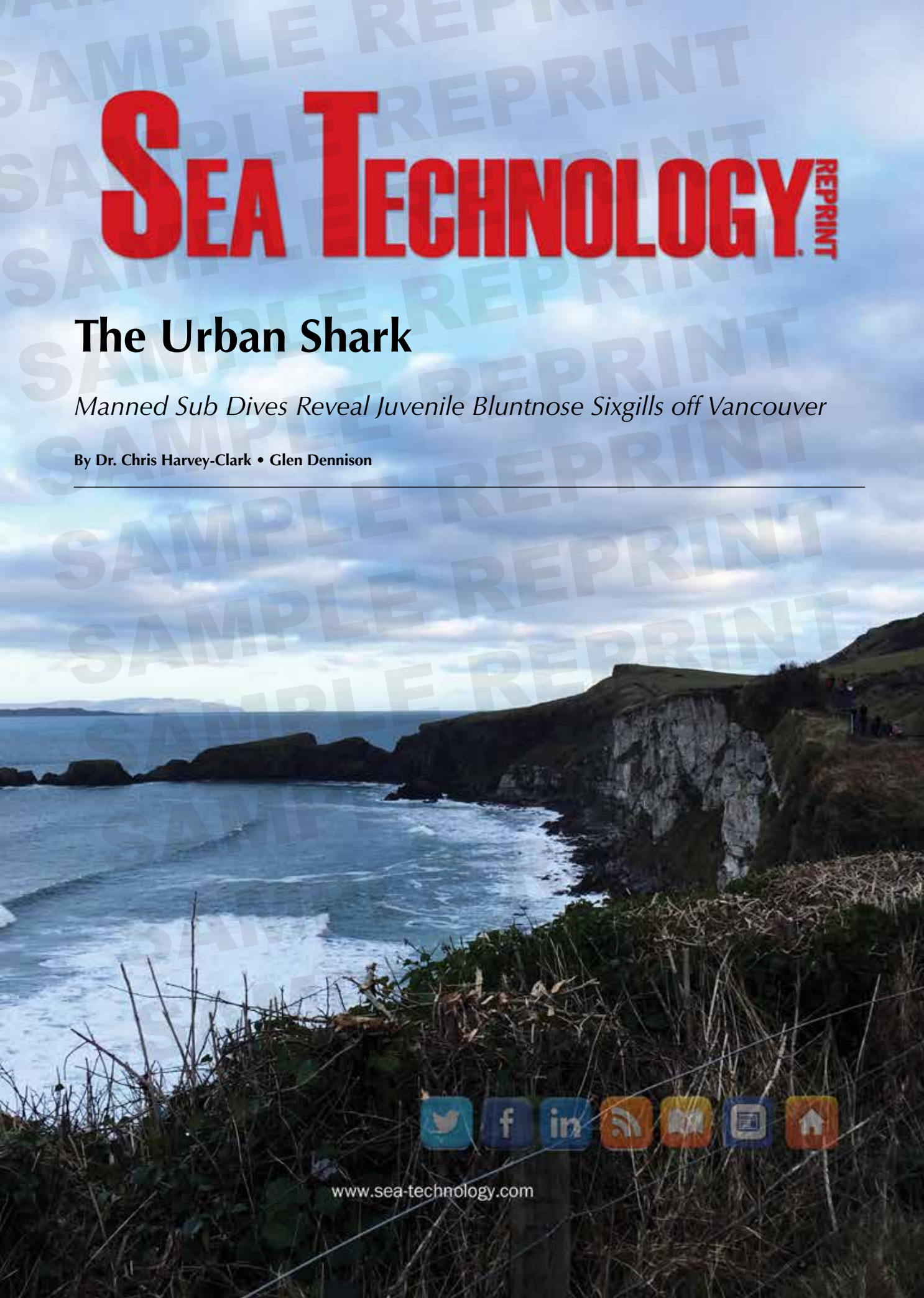

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A Canadian-made prototype manned submersible, deployed from the waterfront of Vancouver, British Columbia, Canada, was instrumental in the discovery of the presence of juvenile sixgill sharks, *Hexanchus griseus*, in 100-m depths. The relative ease of finding juveniles of this "urban shark" species close to the city of Vancouver in depths deeper than divers can penetrate or fishermen regularly fish reflects the presence in nearshore habitat for a species that is well known south of the U.S.-Canada border in the large marine catchment area of the Salish Sea.

Background

The bluntnose sixgill shark is a large-bodied carnivorous shark typically found in deepwater (to 2,000-plus m) throughout the oceans and in certain shallow waters. It has been rarely observed from deep-sea research submersibles. Sixgills have a wide dietary range, from marine mammals to teleost fish and benthic invertebrates, and are one of the largest species of carnivorous sharks, with total lengths (tl) approaching 5 m. Females mature at 4.2 m and males at 3.0 m. Although worldwide in distribution, there are no validated aging studies of this species, which is thought to be slow growing and long lived. The sixgill is considered data deficient and a species of special concern by the Committee on the Status of Endangered Wildlife and Canada's Species at Risk Act.

Species vulnerability is a reasonable consideration due to large physical size prior to maturity and presumed longevity. Globally, only one inshore nursery area has been identified for this species: Puget Sound, Washington, known for concentrations of sixgill juveniles. Acoustic telemetry and tagging studies documented numerous sharks in the 2-m-tl range in Elliot Bay and Admiralty Inlet in the waters around Seattle. In the early 1990s, a directed fishery for sixgill sharks in British Columbia coincided with subsequent decrease in diver observations of this species at locations known previously for their presence.

Publications characterizing recent presence or abundance of juvenile sixgill sharks in the waters of British Columbia are scarce. One study reveals a 90 percent decrease in shark observations at a site at Hornby Island over a five-year period. In 2017, eight juvenile sixgill sharks were tagged, five male and three female, in the Strait of Georgia at depths between 156 and 280 m; these juveniles were documented spending 94 percent of total time at depths in excess of 100 m. This agreed with findings in 2009 in Puget Sound, where tagged juvenile sharks spent the majority of their time below 100-m depths.

Rare reports of this species in British Columbia exist in gray literature from scuba diver observations published in sport-diving magazines. These observations at Whytecliffe Park, West Vancouver, and around Vancouver Island at Tahsis, Hornby Island and Barkley Sound have been primarily of larger semi-mature and mature animals (tl 3.0 to 4.5 m). Observations of larger animals on a regular basis at many locations effectively ended by 2005.

The objective of our study was to determine the feasibility of using a three-man research submersible in conjunction with attractants at a location close to urban Vancouver as a census method for sixgill sharks that extends the search range for uncommon taxa beyond the depths normally encountered by divers and fishers. We predicted that with relatively low survey effort, by sampling beyond the range of sport divers/fishers, the presence or absence of sharks could be ascertained.

Methods

On September 5 and 7, 2017, submersible survey dives to 97.6 and 107.9 m were conducted off West Vancouver at lat. 49.357510, long. 123.292900, approximately 1 km from shore. These dives were conducted using a newly designed and constructed submersible, the Aquatica Stingray 500 three-man, 1-atm research submersible (aquaticasubmarines.com). The submersible is a Canadian-built, 152-m-depth-rated system with extended bottom-time capabilities, equipped with 4-by-

(Top) The prototype Stingray 500 three-man submersible being deployed by crane at the marina launch site close to the dive site. (Bottom) A juvenile male sixgill shark estimated at 2.0 m tl, adjacent to ballast chamber of Aquatica manned submersible (diameter of chamber 60 cm for scale). Sharks were highly attracted to metal and electrical elements of the submersible.

4,000-lumen LED floodlights facing forward and computer-based current/tide/depth/altitude measurement instrumentation. The submersible carries two observers and one pilot within a 1.52-m-diameter, clear-acrylic dome that provides unrestricted 270° forward/up/down field of view.

An olfactory attractant on a deepwater mooring attached to a surface float was deployed on September 3, 2017 at the dive location. The attractant consisted of mashed frozen bigeye tuna (*Thunnus obesus*) blood, flesh and viscera held in three plastic 20-liter buckets perforated with multiple 1-cm holes, together with several whole commercial tilapia (*Oreochmis nilotica*). The attractant was suspended 3 m from the bottom and allowed to disperse via currents estimated at 2 to 3 km/hr. The submersible was maintained on the bottom, stationary at the location of the attractant with LED floodlights providing illumination because this depth is aphotic. Horizontal visibility was limited from 2 to 4 m due to seasonal plankton abundance. Presence of marine taxa was recorded using a handheld camcorder (Sony AX100); image review and extraction for publication was accomplished using Final Cut Pro X editing software.

Results

Bottom times on station were 3 and 8 hr., respectively; the latter being a longevity record for this submersible, with a total submerged time approaching 12 hr. Bottom topography was flat, sloping to deepwater with a fine mud substrate at the survey location. Bottom seawater temperature range was 9.7 to 10° C, and tidal currents ranged from 0 to 3 km/hr. during the observation period at the study site.

On September 5, 10 dogfish sharks (*Squalus acanthias/suckleyi*) were sighted, as well as four Quillback rockfish (*Sebastes maliger*) and numerous planktonic species, including nereid worms and squid. However, no sixgill sharks were sighted.

On September 7, more than 20 dogfish sharks were observed foraging in the mud adjacent to the submersible for scraps of attractant. Several spotted ratfish (*Hydrolagus collei*) remained close to the submersible, and one Quillback rockfish took up residence behind the pilot station of the submersible for the entire duration of the dive and only left the submersible when it ascended to within 30 m of the surface. Numerous small (1-cm-diameter) unidentified planktonic octopods attached to the dome of the submersible, as well as several small (6 cm tl) flatfish (unknown species). Three juvenile sixgill sharks (tl estimated at 2.0, 1.2, 2.0 m, respectively), including one animal with visible claspers (male, 2.0 m tl), were observed over the 8-hr. station period. The first sighting was of a larger animal (2 m tl), which rapidly passed the submersible on the port side in limited visibility and could not be sexed. The second, smaller (1.2 m tl) animal was observed foraging for scraps of attractant on the bottom mud in front of the submersible and could not be sexed. The third (2.0 m tl) male animal spent a prolonged period (3 hr.) intermittently near the submersible and appeared to be attracted by the electrical elements of the submersible (batteries, lights) and the acrylic passenger compartment, repeatedly approaching and bumping these items with the rostrum. All animals approached the submersible initially from down-current locations, indicating the olfactory attractant played a role in enticing the animals to within 2 m of the large, brightly lit craft. There were no visible skin or oral/dental lesions or fishing gear noted on the sharks.

Analysis

Using the Stingray submersible with attractant proved

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to be a highly effective strategy in pursuing an elusive subject. The low amount of effort per observation indicates that sixgill juveniles were relatively abundant in the deeper waters close to Vancouver at the time of observation. Catch per unit effort (CPUE) measurements are commonly used by biologists and managers to indicate the presence and abundance of commercial fish and are generally expressed as number or mass of a species caught per thousand hooks per unit time. In this instance, it is difficult to convert short duration observational data (11 hr. observation, three sharks seen, 3-m visibility) into a meaningful CPUE equivalent for sixgill sharks. If the attractant under 3-m visibility is counted as one hook over 11 hr. of observation, that means a rate of 272 sharks/1,000 hooks or 0.272 sharks per hook per hour. Using 20-hook-long lines in nearby Puget Sound, a study in 2010 established a mean CPUE of 0.13 sharks caught per hour for this species, with a maximum level of 1.3 sharks per hour. In terms of CPUE at 0.27, the impression in this study was that juvenile sixgill sharks were relatively locally abundant.

With a birth tl of 68 cm and a growth rate estimated at 12 cm per year, these observations dovetail with previous telemetry evidence for migration of juvenile sixgill sharks into and possibly transiting the deeper waters off the littoral of Vancouver en route to Howe Sound. Whether this is a seasonal or year-round presence remains a subject for future study. Sport scuba divers have rarely reported larger specimens (2 to 3 m tl) of this species seasonally in late summer from locations in West Vancouver such as Whytecliffe Park, where thousands of divers per year consistently visit the location daily down to the 35-m limits of sport diving. A low rate of observation for this species within sport diving limits belies the fact that other studies indicate the juvenile sharks spend the majority of their time below diving limits and, therefore, sixgill sharks may be far more abundant than previously appreciated below these depth limits. The population size for sexually mature sixgills in the Salish Sea was estimated at approximately 7,900 using genetic techniques in 2005. While the abundance of juveniles is unknown, they are less frequently sighted than adults by divers, perhaps reflecting the bathymetric segregation of juveniles in a species known for cannibalism.

Previous telemetry studies have tracked juvenile sixgill sharks leaving Puget Sound, Washington, traversing the Strait of Georgia and Juan De Fuca, and passing the Vancouver waterfront. In one case, a shark made a circuit of Howe Sound for two consecutive years, each year returning to Elliot Bay, Seattle. The Vancouver/Howe Sound region has been historically overfished for more than 100 years, resulting in the local extirpation of taxa, including certain rockfish (*Sebastes* sp.), which form part of the prey base for sixgill sharks. The manned submarine dives have demonstrated the deepwater presence of these and other important sixgill prey species such as ratfish and dogfish contiguous with shark observations. Some of these sixgill prey species have been rarely observed locally within sport-diving depth limits around Vancouver in the past 30 years.

The presence of juvenile sixgill sharks reveals that while present in the Vancouver region, they are mostly found beyond the range of divers and fishermen, and this agrees with predictions by other studies based on depth distribution for juveniles of this species. That the juvenile sixgill sharks observed were free of lesions and fishing gear would indicate they are recruiting from areas of relatively low fishing effort in a region with high fishing pressure from both sport and commercial fishing.

Acknowledgments

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References

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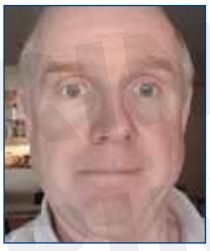
Dr. Chris Harvey-Clark, Dalhousie University, is a marine biologist and veterinarian specializing in the health of aquatic species. He is the author of more than 60 papers, books and chapters on coldwater species and veterinary aspects of marine life. He is also a professional underwater cameraman with more than 100 nature-TV and film broadcast credits, most recently "Sharkwater II: Extinction." He conducts research on northern elasmobranchs, notably the Greenland and sixgill shark, and the Atlantic torpedo ray.



Glen Dennison is a citizen scientist and marine life activist with a special interest in technology and electrical engineering. He helped forge a campaign to preserve and study nine glass sponge reefs in Howe Sound and the Georgia Strait. Dennison is involved with the Marine Life Sanctuaries Society and the Underwater Council of British Columbia. In 2017, he was honored by the Coastal Ocean Awards for his study of Howe Sound's glass sponge reefs and has been honored for his inventive design and application of technologies to examine these prehistoric sponges.