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Discovery of the *Apristurus* "*brunneus* Group" of Catsharks (Carcharhiniformes: Scyliorhinidae) in Hawaiian Waters with Comments on Catshark Ecology in the Hawaiian Archipelago[1]

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The Pacific Ocean consists of some 30,000 seamounts, islands, and atolls that can serve as either stepping stones for dispersal or "oases" for biodiversity (Smith & Jordan, 1988; Crow *et al*., 1996; Kvile *et al*., 2014). Those that comprise the Hawaiian Archipelago are located in the central North Pacific Ocean and extend 3,450 km. They are considered to be the most isolated marine habitats in the world (Carlquist, 1980; Clague & Dalrymple, 1989). This isolation is believed to reduce species dispersal rates. However, accurately determining these rates is complicated even for shallow species (Hilario *et al*., 2015), and extremely difficult for deep-sea species. This is especially true for animals that do not occur in high densities and which have been very difficult to collect, such as engybenthic sharks.

Within this group, the genus *Apristurus* catsharks (family Scyliorhinidae) are believed to be restricted to continental shelves with only a few exceptions (Springer, 1982). These sharks are thought of as sluggish swimmers, and presumably the abyssal plains serve as natural barriers to range expansion (Nakaya & Shirai, 1992). The genus *Apristurus* has 38 described species (Nakaya, pers. comm., 2016) and has been captured in deep-water on continental slopes, trenches, and submarine ridges at depths of 400 – 2,000 m in all oceans except polar seas (Nakaya & Kawauchi, 2013). However, the general lack of sampling in deeper water throughout the Hawaiian Archipelago (Gilbert & Cramer, 1897; Gilbert, 1905; Clark, 1972, Struhsaker, 1973; Humphreys *et al*., 1984; Borets, 1986; Chave & Jones, 1991) as well as throughout the central Pacific is undoubtedly the reason why so few *Apristurus* specimens exist.

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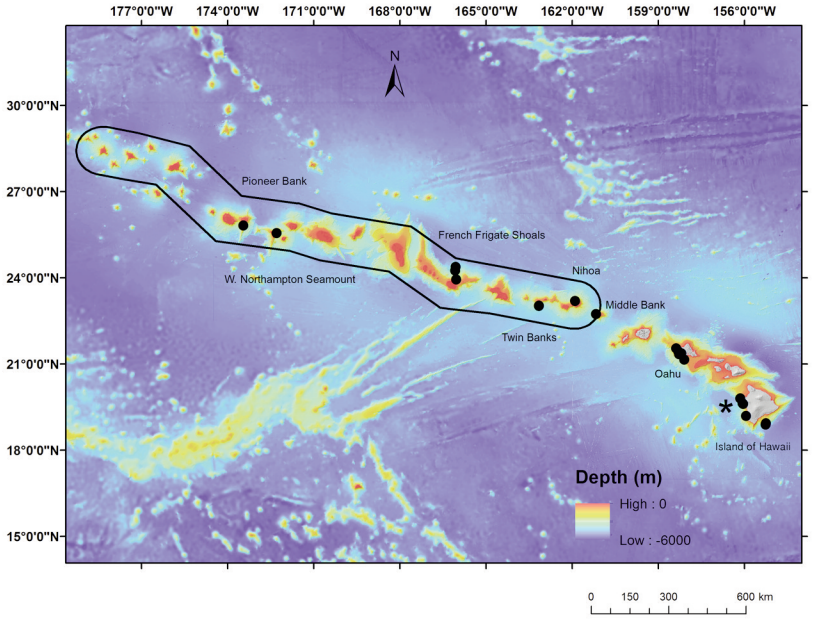

Figure 1. Map of locations where catsharks have been observed or captured throughout the Hawaiian Archipelago. Filled circles are HURL *in situ* submersible observations and star location of the NELHA pumping station. The curved circular line represents the pre-September 2016 boundary of the Papāhanaumokuākea Marine National Monument.

Apristurus catsharks are divided into three main groups; 1) the "longicephalus group" with *Apristurus longicephalus* and *A. herklotsi* that have a long snout; 2) the "*brunneus* group" with a longer upper labial furrow, discontinuous supraorbital sensory canal and 13–22 valvular intestine turns; and 3) the "*spongiceps* group" with upper labial furrows subequal or shorter than lower labial furrows, continuous supraorbital sensory canal and 7–12 valvular intestine turns (Nakaya & Sato, 1999). These groupings provide natural subdivisions within the *Apristurus* that can help in specimen placement (Nakaya & Sato, 1999).

Only one specimen of *Apristurus* has previously been collected in Hawai'i. Identified as *Apristurus spongiceps* (Gilbert, 1905), it had upper labial furrows that were shorter than the lower ones and continuous supraorbital sensory canals (Springer, 1979; Nakaya & Sato, 1999). This specimen was captured 5 Aug 1902 via black beam trawl at a depth of 572–1593 m off the island of Nihoa, Northwestern Hawaiian Islands (NWHI) (Gilbert, 1905; Nakaya & Sato, 1999; Mundy, 2005; USNM 51590). The 514 mm TL female (Gilbert, 1905; Nakaya & Sato, 1999) had two eggs *in utero* with a non-tendril case length of 52 mm and 23 mm width (Springer, 1979; photos see Crow & Crites, 2002). One additional specimen of this species was collected from the Banda Sea off southern Sulawesi. It was a male,105 mm TL, captured on mud bottom at 1,158 m (Weber, 1913; Compagno, 1984). The only other catshark recorded in the vicinity of the Hawaiian Archipelago was

Figure 2. Hawai‘i NELHA catshark specimen (BPBM 40879) immature male 174 mm TL. Courtesy of J.E. Randall.

Figure 3. Lateral view of Hawai‘i catshark (BPBM 40879). Courtesy of Doug Perrine.

Figure 4. Ventral view of Hawai‘i catshark (BPBM 40879). Courtesy of Doug Perrine.

a specimen of A*pristurus fedorovi* collected from the Emperor Seamount chain (38°46’ N, 171°11’E) (Dolganov, 1985; Nakaya & Shirai, 1992). The Emperor Seamounts are the northern part of what is considered to be the Hawaiian-Emperor seamount chain and continue northward from the Hawaiian Archipelago for an additional 2,300 km (Clague & Dalrymple, 1989; Mundy, 2005). Both *A. spongiceps* and *A. fedorovi* belong to the “*spongiceps* group” (Nakaya & Sato, 1999).

The Hawaiian Archipelago has been explored by the Hawai‘i Undersea Research Laboratory (HURL) at the University of Hawai‘i. This laboratory began submersible operations in 1986 to a maximum depth of 366 m using its *Makali‘i* submersible. In 1996, HURL acquired its first 2,000 m *Pisces* submersible and since then, HURL submersible dives have led to the collection and video documentation of numerous new species to science and new species records for the central Pacific (Chave & Mundy, 1994; Chave & Malahoff, 1998). The greater depth capability of the *Pisces* resulted in 41 observations of catsharks in the Hawaiian Archipelago from 17 September 1996 to 15 September 2011 (HURL Dive Operation log records). Of these, 21 separate day submersible *in situ* observations were used to map catshark location and depth records (Fig 1). From these observations, it is clear that *Apristurus* catsharks are widely distributed throughout the Hawaiian Archipelago in areas ranging from the new underwater volcano Lo‘ihi east of the island of Hawai‘i, all the way up to Pioneer Banks in the NWHI. These observations were all made along slopes or on seamounts and banks at depths between 842 and 1,479 m.

In Hawai‘i, water temperature varies from 23 to 28 °C at the surface and drops abruptly to 9 to 12 °C at the thermocline—roughly 100 to 300 m below the surface (Chiswell e*t al*., 1990). Oxygen concentrations in Hawaiian waters are typically 4.8 mg/L at 300 m depth, declining to 0.64 mg/L at 600 m (Chiswell *et al*., 1990; Chave & Mundy, 1994). The water temperature and oxygen concentrations associated with the catshark observations from submersible dives between 500–800 m were 3.5 to 5.3 °C and 1.4 to 2.4 mg/L, respectively. In Japan, catsharks identified as *Apristurus platyrhynchus* were captured in water temperatures of 4.5 to 8.0 °C and oxygen levels of 1.8 to 2.5 mg/L (Kobayashi, 1986). The presence of a faunal break—observed in Hawai‘i at a depth range of 500 to 1,000 m—corresponds to the oxygen minimum zone (OMZ) (Yeh & Drazen, 2009). The OMZ has relatively stable conditions of continuously low oxygen levels and low temperatures at intermediate ocean depths of (400 to 1,000 m) over vast areas of the ocean (Childress & Seibel, 1998). The depths that the catsharks occupy in Hawai‘i correspond to the depths where the oxygen levels are the lowest. Similar to crustaceans, cephalopods and bony fishes (Childress & Seibel, 1998) that live in the OMZ, catsharks appear to have adapted to the OMZ by developing the ability to regulate their oxygen consumption rate in this reduced oxygen environment.

An unusual collecting opportunity presented itself when a shark was captured at the Natural Energy Laboratory of Hawai‘i Authority (NELHA), at Keahole Point on the Island of Hawai‘i. This facility has several seawater suction pipelines that provide water to onsite research facilities, and these pipelines occasionally entrap specimens that can be captured near the onshore pumping station. The deepest of these pipelines extends 3,124 m from the shoreline to a depth of 915 m with an intake 6.1 m off the bottom. It also has a 1.4 m diameter pipe with a pumping capacity of 1.8 m^3/sec flow. On 30 August 2007 this pipeline captured a 174 mm TL male catshark that was clearly not *Apristurus spongiceps* or from the “*spongiceps* group”. The specimen was photographed and maintained in a cold water aquarium for two days before being frozen and shipped to Bernice P. Bishop Museum (BPBM), preserved in 10% formalin and transferred to alcohol for curation.

Apristurus sp. “brunneus group”

Material examined. **Island of Hawai‘i**, Keahole Point, NELHA deep water pumping station, Jan War collector: BPBM 40879; male 174 mm TL (1 spm) with healed umbilical scar, (Figs. 2 - 4).

Diagnosis: General identification: The "brunneus group" identification for this specimen was based on a combination of the following: 1) longer upper labial furrows (7.1 mm; 4.1 % of TL) than lower labial furrow (4.4 mm; 2.5% of TL); and 2) discontinuous type of supraorbital sensory canal.

In the genus *Apristurus,* species identification has proven challenging due to the soft body form that is easily deformed and shrivels in preservative, making accurate measurements difficult (Nakaya *et al*., 2008). Ontogenetic changes in proportional measurements can also impact positive species identification (Nakaya *et al*., 2008). As a result of the juvenile nature of this specimen and formalin preservation, a positive species identification was not possible. However based on this specimen diagnosis, the Hawai'i catshark belongs to the "*brunneus* group". Two of the three groups of catsharks—the "*spongiceps* and *brunneus* groups"—are now documented in Hawai'i.

Ecological Comments: The location of capture for the catshark at NELHA had the following water parameter means and (ranges) for salinity 34.48 (33.85–34.77) ppt, temperature 5.4 (4.6–6.5) °C, pH 7.61 (7.44–8.26), alkalinity 2.37 (1.79–2.72) mEq/L, total suspended solids 0.86 (0.19–4.31 mg/L and dissolved oxygen 1.77 (1.28–3.86) mg/L (nelha.hawaii.gov/wp-content uploads/2014/01/appendix c_ pipeline_2015.pdf) (11 Aug 2005 to 3 Jun 2015, NELHA records for 1.4 m diameter, deep water pipeline last accessed 30 May 2016).

The depth of capture, water temperature and dissolved oxygen concentration from NELHA matches the HURL submersible observations that catsharks in Hawai'i are present in the OMZ.

Conclusions

Catsharks of the genus *Apristurus* are more common and widespread in the Hawaiian Archipelago than previously thought. Two groups of Apristurus catsharks are now recognized in Hawai'i, "spongiceps" and "brunneus". These sharks reside in the OMZ at submersible observed depths of 842 to 1,479 m. In recent decades the OMZ has increased worldwide in size both vertically and horizontally, has experienced a reduction of oxygen concentration and was estimated to have expanded by 4.5 million km^2 (Sramma *et al*., 2010). This expansion will have profound impacts on species habitat utilization and may alter biodiversity. This paper represents only the second report of catsharks in the Hawaiian Islands since the first capture in 1902. The deep-sea benthic habitat surrounding the Hawaiian Islands undoubtedly has a higher biodiversity than is currently reported and is in need of more detailed scientific investigation before manganese mining and other harvesting permanently alters this environment.

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