California Fish and Wildlife 106(2):186-190; 2020

First record of pughead deformity in the threatened Clear Lake Hitch

JESSICA KATHAN,* MATTHEW YOUNG, AND FEDERICK FEYRER

U.S. Geological Survey, California Water Science Center, 6000 J Street, Placer Hall Sacramento, CA 95819-6129, USA

**Corresponding Author: jkathan@usgs.gov*

Key Words: Clear Lake, Clear Lake Hitch, osteological deformity

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Clear Lake Hitch, a potamodromous minnow endemic to Clear Lake, CA, USA and its tributary creeks, is listed as threatened under the California Endangered Species Act (CESA), and is currently under petition for listing under the federal ESA (CBD 2012). We have encountered two Clear Lake hitch with pugheadedness, a cranial deformity. Based on literature review, we believe pugheadedness has not previously been documented in Clear Lake Hitch or any other fish species within Clear Lake or its watershed, though interviews with researchers and anglers would be helpful in solidifying this claim. Within California, the deformity has been documented in the closely related California Roach (Leidy 1985), as well as in Rainbow Trout (Croker 1931), and Brown Rockfish (Adams and Ryan 1982).

Pugheadedness is a skeletal deformity resulting in a characteristically steep forehead, bulging eyeballs, and a reduced upper maxillary. In severe cases, the mouth may be unable to close (Schmitt and Orth 2015). Skeletal abnormalities are exceedingly rare among wild fish, usually under 1% of the total population in undisturbed ecosystems (Dahlberg 1970, Berra and Au 1981). Surveying fish for deformities in an undisturbed freshwater creek, Berra and Au (1981) collected 2771 Bluntnose minnows (*Pimephales notatus*), of which 18 were pugheaded (0.65%). Dahlberg (1970) reported incidences of .05% and .25% for two estuarine species in the Chesapeake Bay. Among heavily disturbed environments, the rate of pugheadedness may be greater; in a heavily polluted stretch of the Rhine river, 2.6% of bream (*Abramis brama*) encountered were pugheaded (Sloof 1982).

The maxillary and cranial deformities characteristic of pugheadedness present early in development, and many individuals with the condition likely die as embryos (Morgan et al. 1981). Individuals that survive to adulthood may have reduced foraging efficiency (Schmitt and Orth 2015) or inefficient respiration due to impaired buccal pumping (Lijalad and Powell 2009).

Over three summers of an ongoing study of the habitat and status of Clear Lake Hitch (*Lavinia exilicauda chi*; Feyrer et al. 2019), we have encountered two pugheaded Clear Lake Hitch. The first was captured 27 June 2017 in a gill net set at 0749 hours in the Upper Arm of Clear Lake, CA (39.035, -122.905). It measured 257 mm standard length and weighed

185 grams (Figure 1). The second individual was captured 25 June 2019 in a gill net set at 1510 hours, also in the Upper Arm of Clear Lake, CA (39.029, -122.097). It measured 236 mm and weighed 235 grams (Figure 2). The upper maxilla of both individuals was severely reduced, giving the appearance of a protruding lower jaw and rendering the mouth unable to close. Both individuals displayed several visible tears on the caudal and anal fins, possibly caused from entanglement in the gill net, but displayed no other obvious deformities or external parasites.

The individual captured in 2017 appeared emaciated and was substantially lower in weight than expected based on a length-weight relationship generated from 643 Clear Lake Hitch observed during our study (Figure 3). The individual captured in 2019 appeared relatively normal in weight (Figure 3; Data are available from Steinke et al. (2018); https://doi.

Figure 1. Pugheaded Clear Lake Hitch collected in 2017, length 257 mm, weight 185 g.

Figure 2. Above, non-deformed Clear Lake Hitch, length 240 mm, weight 290 g. Below, pugheaded Clear Lake Hitch collected in 2019, length 236 g, weight 235 mm.

org/10.5066/P9A03OI6). This could be due to a variation in the etiology of pugheadedness, or differing levels of respiration or foraging impairment.

While causes of pugheadedness are not fully understood, most evidence points to epigenetic causes triggered by environmental factors (Schmitt and Orth 2015). However, no direct evidence links our observation of the pugheaded individual to any environmental condition. However, many factors linked to morphological deformity are present in Clear Lake, including pollution, periodic low concentrations of dissolved oxygen, and high temperatures (CBD 2012; Feyrer et al. 2019). Pollution, specifically heavy metal contaminants such as mercury and selenium, has been implicated in the development of skeletal deformities (Bengtsson et al. 1985; Lemly 1992). The operation of the Sulphur Bank Mercury Mine, now a U.S. Environmental Protection Agency Superfund site, has subjected Clear Lake to severe mercury contamination. Since the mine's closure in 1957, erosion of tailing piles and leaching from drainage pits have continued to add mercury to the system (Rueda et al. 2008). Gassel et al. (2005) found a methylmercury concentration of 0.16 ppm in Clear Lake Hitch tissue, the lowest concentration of any Clear Lake species sampled. Before the species was listed, the EPA suggested children and women of childbearing age limit their consumption of Clear Lake Hitch, to one serving a week (Gassel et al. 2005). All fish in the lake are subject to similar recommendations.

Clear Lake is also contaminated with numerous pesticides, both those applied directly to the lake to control aquatic weeds, and those used in the surrounding vineyards and orchards which contaminate runoff that drains into the watershed. Copper, organophosphates, and organochlorine are among the most commonly used agricultural pesticides in Lake County (CBD 2012); all of these are documented teratogens at acute doses (Eisler 1997; Sabra and Mehana 2015).

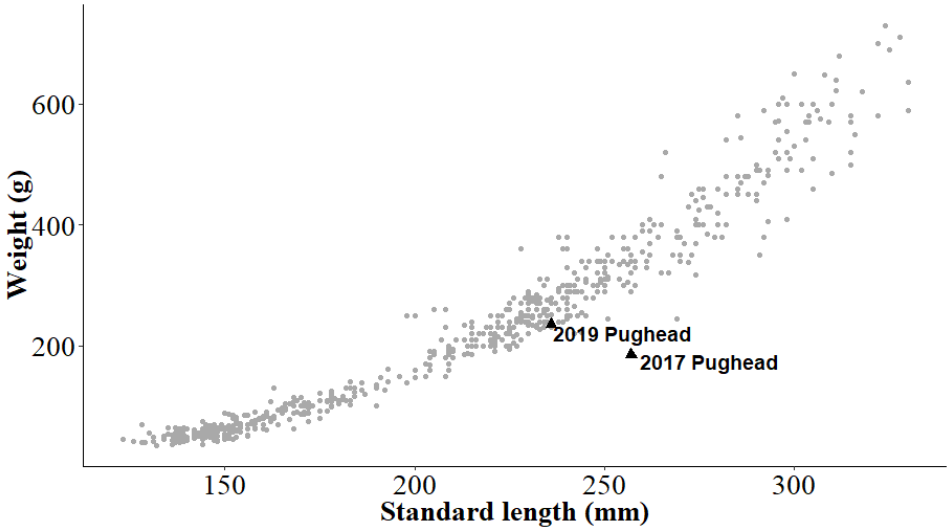

Figure 3. Length-weight relationship of Clear Lake Hitch collected from Clear Lake from 2017 to 2019 showing that the pugheaded individual encountered in 2017 was substantially lighter in weight than expected. Data are available from Steinke et al. (2018).

Highly eutrophic, Clear Lake is prone to noxious algal blooms and outbreaks of hypoxia that sometimes cause fish kills (Goldman and Wetzel 1964; Richerson et al. 1994). Water quality monitoring concurrent with fish sampling efforts (Feyrer et al. 2019; Steinke et al. 2019) found a hypoxic "dead zone" similar to those found in the Gulf of Mexico and the Chesapeake Bay, covering a large area of the lake bottom. Low dissolved oxygen has been linked to bodily anomalies (Berra and Au 1981; Slooff 1982), and Schmitt and Orth (2015) suggested that repeated encounters of pugheaded Blue Catfish in the Chesapeake Bay may be linked to hypoxia caused by eutrophication. Shallow water and hot summers also lead to elevated water temperatures in Clear Lake. In aquaculture operations, high temperatures have been linked to larval pugheadedness (Morgan et al. 1981).

Over three years and 644 Clear Lake Hitch observed, only two pugheaded specimens were encountered, an incidence of 0.31%. Comparing this rate to those in other populations is difficult due to differing sample sizes, methods, and species. However, our observed rate is lower than both the incidences reported by Sloof (1982), and Berra and Au (1981), but higher than those reported by Dahlberg (1970). Our observed incidence may be indicative of the overall rate of pugheadedness within the population, but higher effort and a larger sample size is needed to confirm this. Additionally, many deformed larvae have low survivability (Koo and Johnson 1970), and the rate of pugheadedness in early life stages may exceed our observed incidence among adults. If larval pugheadedness is high, larval mortality may be negatively impacting Clear Lake Hitch reproductive success and recruitment. In addition to the known threats Clear Lake Hitch face from habitat loss, poor water quality, and introduced predators (CBD 2012), teratogeny may be an additional factor impacting the species. Additional investigation is needed to determine the extent of pugheadedness within the population. Future research, including tissue and otolith analyses of pugheaded individuals, may yield more evidence towards a potential cause.

Author Contributions

Conceived and designed the study: FF, MY
Collected the data: FF, MY, JK
Performed the analysis of the data: MY, JK
Authored the manuscript: JK
Provided critical revision of the manuscript: MY, FF

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Submitted 14 August 2019
Accepted 20 October 2019
Associate editor was F. La Luz