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Mussels of the Upper Klamath River, Oregon and California

Earl Byron* And Jeff Tupen

CH2M, 2485 Natomas Park Drive, Ste. 600, Sacramento, CA 95834 (EB-retired, JT)

**Correspondent: earlbyron4@gmail.com*

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The purpose of this study was to provide baseline information that may assist in the development of protection, mitigation, and enhancement measures for freshwater mussels in the Klamath River in Oregon and California. The river is of concern for water quality and fisheries issues as well as the possibility of future dam modifications or removal (PacifiCorp 2003). In addition, this study generally updates the baseline characterization of the larger bivalve species (mussels) of the upper Klamath River by adding a number of upstream locations that corroborate and extend the extensive statewide surveys of Howard (2010; 2015). Prior surveys of California and Klamath River locations for bivalves did not include most of these Klamath River locations upstream of the Shasta River confluence (Ingram 1948; Bonnot 1951; Taylor 1981; Williams et al. 1993; Frest and Johannes 1998; Nedeau et al. 2009). In addition, our records of Klamath River mussels provide further data on the abundance and diversity of these species over time.

Our study, which was completed from 2-6 September 2003, focused on large (generally, five to ten centimeters) bivalve species of the order Unionoida, which in California includes the genera Anodonta (floaters), Gonidea (ridgemussel), and Margaritifera (pearlmussel). Anodonta and Gonidea are classified within the family Unionidae, while Margaritifera is classified within the family Margaritiferidae (note: in this paper, we collectively refer to mussels of the order Unionoida as "unionid mussels", which is not technically correct).

Sampling locations are quantified as river kilometers (RK) measured upstream from the mouth of the Klamath River at the Pacific Ocean. For purposes of this freshwater bivalve study, the study area is defined as that portion of the Klamath River mainstem from immediately downstream of the Keno Dam (RK 409), which impounds Upper Klamath Lake, and the Shasta River confluence (RK 284), a distance of 125 km.

The study area may be further partitioned into five distinct reaches of the Klamath River and one of Fall Creek, with reach breaks generally occurring between reservoirs and defining the intervening riverine habitats. Fall Creek may be considered comparable habitat but outside the influence of the mainstem Klamath reservoirs. These reaches and individual sampling locations are shown in Figure 1. All sites were lotic, beginning immediately downstream of Keno Dam, and included locations upstream and downstream of each of the 3 reservoirs within the study boundaries (J. C. Boyle, Copco, and Irongate; Figure 1).

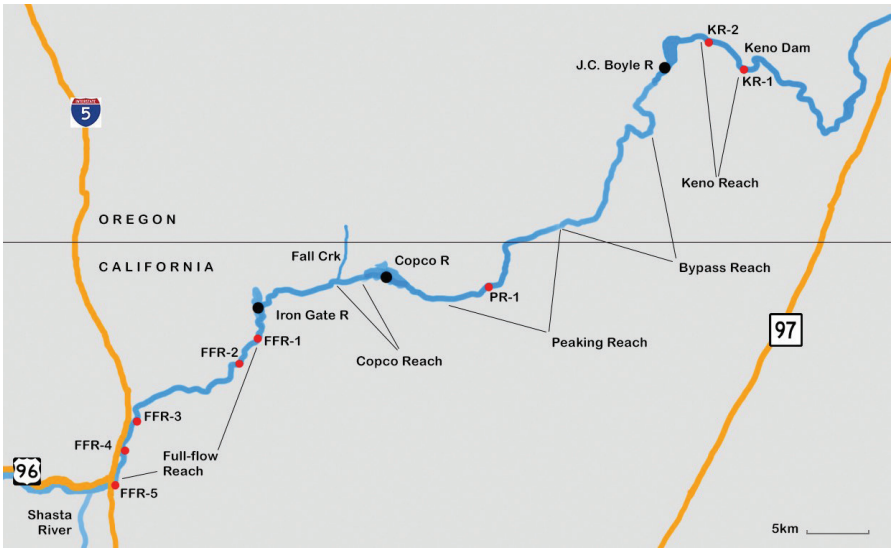

FIGURE 1.— Map of the Northern California/Southern Oregon study section of the Klamath River from Keno Dam to the Shasta River showing the separate study reaches, reservoirs (R), and individually numbered sampling sites for mussels (e.g., FFR-4)

Suitable habitat for large bivalve sampling was determined by a review of available literature (i.e., Frest and Johannes 2000) and professional judgment of the biologists conducting this study. In general, suitable habitat included those areas with benthic substrates finer than gravels (i.e., coarse sands to silts). Exceptionally swift and deep water areas were not sampled due to safety concerns, and sampling was therefore restricted to low- to moderate-velocity locations of approximately 0.6 m/s or less.

Accessible areas of suitable habitat were first inspected for the presence of empty shells (valves) on the riverbank, or in the nearshore water. Empty shells are commonly indicative of small mammal (e.g., muskrat, river otter) predation (Convey et al. 1989) and the likely presence of nearby bivalve beds. Where empty shells were observed, biologists used buckets with clear Plexiglas bottom panels to view the nearshore sediments in wadeable depths of 0.5 to 1 m, depending on water visibility. Deeper habitats (1 to 2 m) in areas of low to moderate flows were examined using snorkeling gear.

If large bivalves were found using either method, the "bed" was characterized in terms of its size and species composition referencing the methods of Duncan (2008) and Strayer and Smith (2003). Several methods were used to characterize located mussel beds. For large, dense beds, composition and abundance was determined by observations within randomly located 0.25-m quadrats. For smaller and/or less-dense beds, bed margins were located and all bivalves located within the bed were identified and enumerated through intensive searches. Substrate composition was noted for each collection location and characterized as fines, gravel, cobble, boulder, or bedrock.

Results of bivalve abundance, diversity, and site characteristics within the study area by specific sampling location are shown in Table 1, for larger unionid species. Note that only three of the Klamath River reaches revealed the presence of these species.

TABLE 1.—Sampling observations of Unionid bivalves, Klamath River, Oregon and California, September 2003. River kilometers (RK) measured from mouth of Klamath River.

River Reach	Station ID and Location (RK)	Species	Number sampled/density (#/m²)/ Size range (mm)	Habitat Characteristics / Field Notes
Keno Reach (KR)	KR–1 (375)	*A. oregonensis*)	79/14.6/52 – 126	Soft sediments associated with bulrush and cattail patch just below Keno Dam. Low velocity water, depth 45 cm. *A. oregonensis* semi-buried. No other species noted.
	KR–2 (367)	*G. angulata*) and *A. oregonensis*	*G. angulata*: 6/6/43 – 84 *A. oregonensis*: 35/35/37 – 93	Coarse sand with silt associated with bulrush patch in mid-channel, just above Boyle Reservoir. Generally, smaller *G. angulata* than other sites; mostly- to completely buried. Low velocity water. Water depth 45 cm. *G. angulata* dominant species, though few *A. oregonensis* noted
JC Boyle Peaking Reach (PR)	PR–1 (330)	*G. angulata*	16/1.8/37 – 100	Coarse sand in pool below rock chute. Water depths varied, depending on release flows, from 0.7 to 1.5 m. Low velocity. No associated vegetation. *G. angulata* mostly to totally buried. No other species noted.
Full-Flow Reach (FFR)	FFR–1 (305)	*A. oregonensis*	37/2/56 – 96	Cobble substrate downriver of Iron Gate Fish Hatchery bridge over Klamath River. Slow water velocity in countercurrent noted. Water depth 1-1.3 m. Unidentified hydrophyte associated. No other species noted.
	FFR–2 (299)	*G. angulata* and *A. oregonensis*	*G. angulata*: 20/0.5/57 – 96 *A. oregonensis*: 4/0.1/66 – 77	Coarse sand substrate between cobbles and boulders. Just upstream of footbridge at Klamath River County Estates. Swift water. No associated vegetation. Water depth to 0.7 m. *G. angulata* dominant species, though few *A. oregonensis* noted.
	FFR–3 (291)	*G. angulata* and *A. oregonensis*	*G. angulata*: 142/6.8/53 – 100 *A. oregonensis*: 4/0.3/58 – 79	Coarse to fine sand substrate between cobbles in slow moving section of water (depth to 0.6 m.). Unid. hydrophyte associated (same as FFR-1). *G. angulata* dominant species, though few *A. oregonensis* noted.
	FFR–4 (289)	*G. angulata*	62/16.5/21 – 103	Coarse to fine sand with some silt substrate just upstream of I-5 bridge over Klamath River. Moderate water velocity. *G. angulata* mostly to totally buried in approx. 45 cm of water. Unid. hydrophyte associated (same as FFR-1). Four vacant shells of fresh-dead to long-dead adults to young of *A. oregonensis*, and one vacant shell of long-dead adult *Anodonta californiensis* (California floater) collected.
	FFR–5 (287)	*G. angulata*	41/14.9/47 – 94	Coarse sand substrate between cobbles. Just downstream of I-5 rest stop. Moderate velocity water, 30 - 45 cm. deep. No associated vegetation. No other species noted.

The major changes in substrate composition are longitudinal and elevation related with dominance by boulder and bedrock in higher elevations (Keno Reach 1-2, PJ. C. Boyle Peaking Reach 1), grading to cobble and gravel in the middle and lower elevation reaches (Full-Flow Reach 1 - 5).

The distribution of large bivalves within the study area is patchy and is strongly related to the patchy distribution of suitable habitat (Table 1). Low-energy areas where finer sediments accumulate and where hydrology is consistent were most suitable for A. oregonensis. While these types of habitats also supported Gonidea angulata, this latter species appeared to prefer faster waters and, consequently, coarser substrates such as medium- and coarse sands. Even areas with boulder and bedrock substrates had pockets of finer materials in which G. angulata were aggregated.

Both species could be locally dense in number and were highly variable in relation to burial in the substrate (Table 1). Some were completely isolated below the riverbed surface. Commonly, G. angulata were found buried to depths of 15 cm and often stacked atop one another. Presumably intergravel flow in the areas of faster moving water provided enough oxygen and food to support the completely buried animals with no apparent connection to the overlying water column (Unionid mussels lack siphons). As a general characteristic, G. angulata were always buried at least 80%, with only the tops of shells visibly evident. In contrast, A. oregonensis were less buried and sometimes found laying atop the substrate. While others were buried slightly, they were never buried as deeply as G. angulata.

It is unlikely that the Peaking Reach, with its highly variable reservoir-discharge flows, supports broadly distributed populations of unionid bivalves. In contrast, selected microhabitats within the Keno Reach and Full-Flow Reach appear to support extensive populations of both A. oregonensis and G. angulata (Table 1). Of the two, the latter appears more broadly distributed, possibly reflecting the relative abundance of preferred habitat (faster water, coarser substrate) and relative scarcity of slower, nutrient enriched habitats (e.g., near eutrophic lakes).

Several locations were searched without the discovery of mussels and were therefore not reported in Table 1. These areas include the boulder-dominated Bypass Reach (RK 357), the Peaking Reach (RK 330), the Bypass Reach (RK 318), and the Full-Flow Reach (RK 297) and a location with too few G. angulata to establish a sampling site at RK 294 (but presence noted).

Our findings of unionid bivalve distribution and diversity are in agreement with the findings of Howard (2010) and Howard et al. (2015) (both as part of her 2008/2009 statewide mussel survey that included Klamath River locations) in that we did not document the presence of *Margaritifera falcata*, although that species was historically present in our study area. In other studies, *M. falcata* has been described as extirpated from eastern California streams (Hovingh 2004). Howard's study reach of the Klamath River started at our most downstream boundary and progressed downstream, whereas our study area progressed upstream from that site (I-5 rest stop and Hwy 96 crossing of the river, FFR-4) and therefore our study locations on the Klamath River were only in overlap at that one location. We found only *Gonidea* in the river at this location and immediately upstream, confirming the Howard et al. (2015) results that both *A. oregonensis* and *M. falcata* have apparently disappeared from this section of the river, at least as early as 2003 (our result) and 2008 (Howard et al. 2015). We also confirm the Howard et al. (2015) reports that *M. falcata* were not present in our Klamath River study reaches although they had been present (at least in the lowest elevation portions of our study) historically (Howard 2010; Howard et al. 2015) and are still present at downstream locations, outside our study area (Howard 2015).

We note only a single, individual dead shell of *A. californiensis*, at station FFR-4, indicating it was present in the river in that general area or possibly upstream (Table 1). Regardless, no living individuals were found in our survey and it must be considered to be very rare throughout our study reach. Historically, it was known from the lower Klamath and Shasta rivers, which includes the general area of our collection (T. J. Frest, Deixis Consultants, unpublished report). Taylor (1981) stated that most natural populations of *A. californiensis* have probably been eliminated from California.

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