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The Effects of Extreme Drought and Management Implications for Brook Trout (*Salvelinus fontinalis)* and Chinook Salmon (*Oncorhynchus tshawytscha)* for the Tuolumne River Watershed

California is experiencing an extensive drought from 2012 to present day, a notable increase in severity regarding dry, hot weather and drought conditions within the past few decades (Swain et al. 2016). Droughts can cause low-flow events in aquatic systems and are increasing in frequency due to anthropogenic alterations of flow regimes (Walters 2016). Alteration of dams and diversion of water can shift conditions native species are used to, directly or indirectly affecting both unaltered and altered systems (Barnett et al. 2008, Brown et al. 2013). In order to properly manage and conserve our watersheds, there needs to be a thorough understanding of conditions to which the system may be subject to. The recent extreme drought has prompted urgency with scientists and managers in recognizing how to best manage watersheds, especially the economically and intrinsically valued Tuolumne River.

In order to properly understand the system, the interdisciplinary fields of hydrology, ecology, geomorphology and more come together to influence management decisions. There is an emphasis placed on understanding the coupling of stream flow and fish population dynamics to appropriately manage fisheries and monitor fish response to low flows (Poff et al. 2010). Drought conditions can act as an abiotic stressor by decreasing stream flows, which ultimately affect fish by decreasing survival rates, body growth rates and abundance of the population size (Walters 2016). Drought is detrimental to a majority of stream salmonids, greatly decreasing their overall carrying capacity by altering natural habitat conditions, resource availability, and skewing reproductive cues (Elliott 1993, Walters 2016). Specifically, native fish have been seen to be less sensitive to decreased flow in areas with historic cycles of low flow events (Leprieur et al. 2006). For insight on the further management of the Tuolumne River watershed in extreme drought conditions, effects of drought on physical and biological components of Chinook salmon (*Oncorhynchus tshawytscha)* and brook trout (*S.f.)* are examined, in regards to species success. The model species, native Chinook salmon and non-native species brook trout (*Salvelinus fontinalis)* within the Tuolumne River watershed, both belong to the Salmonidae family.

Physical Effects

Areas and Refugia. Drought can have substantial effects on wildlife by altering the physical parameters of habitat in which they live (Walters 2016). Low flow events caused by drought conditions shift accessibility and habitat availability for fish and other taxonomic groups of interest (Hilderbrand et al. 1999, Boulton 2003). In addition, drought decreases stream depth, width, and water velocity within a system (Hilderbrand et al. 1999).

The geomorphological unit first to be affected and diminished are riffles (Freeman and Marcinek 2006, Kanno and Vokoun 2010). However, drought conditions all decrease overall flow in pools, riffles and runs. In addition, in times of drought, riffles reduce five times more frequently than pool areas (Hakala and Hartman 2004). Both juvenile and adult Chinook salmon and brook trout utilize riffles, and are therefore susceptible to habitat alteration by drought (Walters 2016). Therefore, species that utilize riffles are most likely to be detrimentally affected, while generalists and those that thrive in pools have a higher chance of survival and thriving in drought conditions (Walters 2016). Brook trout thrive in pools, and show a significantly similar preference for both deep and shallow pools, suggesting they would not be as vulnerable to decreasing pool levels (Mollenhauer et al. 2013). Although both species utilize riffles, brook trout have a higher likelihood of adapting to changing habitat conditions than Chinook, as they are stream and lake generalists (Robillard et al. 2011).

Drought can have a large impact on salmonid populations by decreasing local refugia. Stream juvenile salmonids, represented by both the non-native brook trout, and native Chinook salmon, suffer due to decrease in pool habitat, where juveniles take refuge (Kraft 1972, Elliott and Hurley 1998, Huntingford et al. 1999). Refuge is extremely important for fish species by decreasing overall predation and stress, while increasing abundance of juveniles which upkeeps population sizes. Diminishing refugia can increase mortality rates, decrease birth rates, and increase migration rates in population (Magoulick and Kobza 2003). Therefore, in cases of drought, refuge sizes decrease and pose a threat to species, regardless of nativity, for population persistence (Magoulick and Kobza 2003). In comparison, due to brook trout being stream and lake generalist, they have an advantage of utilizing different refugia types (Robillard et al. 2011). Thus, Chinook salmon are more sensitive to a decreased abundance of riffles and subsequent refugia relative to brook trout. However, in cases of extended drought conditions, both salmonid species, regardless of native or non-native, are at risk.

Fine Sediment. An important component to observe within watersheds, coupled with drought conditions, is the movement and impact of sediment load throughout the system. Fish may be susceptible to sediment alterations directly influenced by drought. Juvenile brook trout populations are predominantly affected by fine sediment, even under normal flow conditions (Hartman and Hakala 2006). Drought encourages deposition of fine sediment throughout the system, especially increasing river bed sedimentation (Collins and Walling 2007). Increased river bed sedimentation also affects the diets of brook trout by reducing invertebrate biodiversity (Wood and Petts 1999). Juvenile trout are thus vulnerable to drought conditions via decreased resource availability. An increase in stress and decrease in quality of trout juveniles can affect future health of adults, decreasing likelihood of returning to successfully spawn. Similarly, Chinook salmon are affected by fine sediment, as Chinook adults require coarse-bedded substrate in rivers for spawning (Overstreet et al. 2016). The increase of fine sediment deposition from drought can be detrimental for spawning areas, thus decreasing recruitment of native salmon populations (Overstreet et al. 2016).

Wildfires. Wildfires can affect wildlife on varying levels, and have been debated whether beneficial or detrimental to watershed ecosystems. Drought conditions increase occurrence and frequency of wildfires (Halofsky and Peterson 2016). Furthermore, wildfire increases habitat quality for native Chinook salmon adults and overwintering juveniles by increasing the amount of wood in streams (Flitcroft et al. 2016). However, wildfire also increases fine sediment load into the system, negatively affecting the quality of egg and fry habitat for Chinook (Flitcroft et al. 2016). Therefore, the balance and extent of frequency and magnitude of controlled wildfires is required to properly influence management.

Biological and Physiological Effects

Body size. Drought can also affect body size of an individual, with larger individuals generally being more susceptible and vulnerable to drought-induced low flow events (Li et al. 2010, McCargo and Peterson 2010). Larger individuals and bigger species, such as the Chinook salmon, have an increased risk of decreased survival due to lack of resources and space requirements from drought conditions (Li et al. 2010, McCargo and Peterson 2010). In addition, in low flow events and shallower waters, adults are more exposed to predation (McCargo and Peterson 2010). Although juvenile individuals of a population can be more sensitive to stress, adults are more at risk in regards to body size-specific effects from drought (Li et al. 2010, McCargo and Peterson 2010). Bigger individuals in a population are stronger, and have higher recruitment rates (Magoulick and Kobza 2003). If bigger individuals and adults are lost, we can see a decrease in population and recruitment. According to Hakala and Harman 2004, as a result of low flow conditions, adult brook trout not only decreased in abundance, but also in overall body health conditions, in comparison to normal precipitation years before (Hakala and Hartman 2004).

Temperature tolerance and flow. Juvenile Chinook in 21-24 °C water show significant decrease in overall health, specifically growth rate, impaired smoltification, and increased predation risk (Marine and Cech 2004). The ideal temperature for juvenile Chinook is within 13-16 °C water (Marine and Cech 2004). Therefore, with increased temperatures, juvenile fish are in detrimental conditions. Drought increases water temperature and due to requirements and timing of reproduction, winter and spring run Chinook are the most at-risk. When juvenile Chinook are confronted with differing stream flow, use of microhabitat does not significantly change and individuals will actively move to more suitable habitats, dependent on the extent of the stream flow change (Shirvell 1994). Chinook juveniles are able to adapt more quickly to onset drought conditions of differing flows than brook trout. However, Chinook juveniles have been shown to prefer faster water velocities either 30 cm above or laterally to their body, and drought conditions result in slower water velocities (Shirvell 1994).

Further Implications

Ultimately, the severity of drought conditions and low flow events are often unpredictable (Swain et al. 2016). Scientists, policy makers, managers, and other stakeholders can predict conditions based on historical data, but the unpredictable nature of droughts make it a multi-faceted and difficult issue to combat. There is another challenge to be added: the increase in frequency of drought due to anthropogenically induced changes in climate (Walters 2016). Many studies in the literature have conducted drought studies in their system of interest, but there may in lie substantial biases when transferring management tactics to the Tuolumne. For example, one study (Hakala and Hartman 2004) saw low flow events decreasing abundance and body condition of salmonid populations, but another (James et al. 2010), showed drought reduced abundance but did not significantly change in body condition, again in salmonid populations. Both studies also showed drastically differing results of flow reduction influencing water temperature and resource availability. Therefore, in order to properly and adequately manage the Tuolumne river watershed, there needs to be specific research done about the system. The potential effects of drought on native Chinook salmon and non-native brook trout is complex and research done on other systems may not suffice in transferability for management.

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