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Assessment of dam effects on streams and fish assemblages of the conterminous USA

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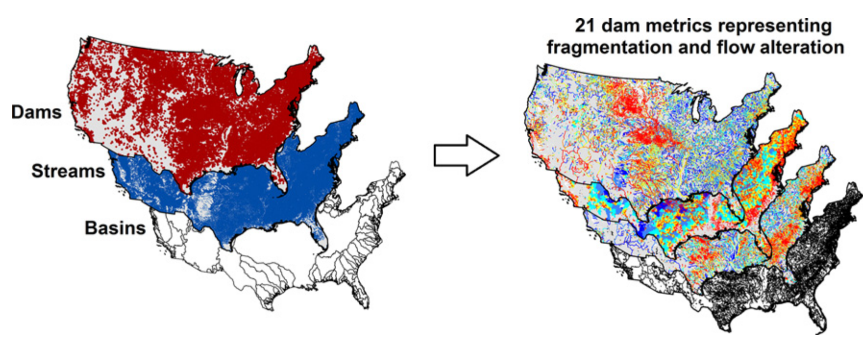
HIGHLIGHTS

- Developed 21 metrics of stream fragmentation and flow alteration by dams in the USA.
- Dams have increased stream fragments by 801% and significantly altered flows.
- Dam influences on streams and fishes differ by ecoregion and stream size.
- Dams have affected fishes as much or more than other anthropogenic stressors.
- Diverse dam metrics are needed to aid in dam policy and management decisions.

GRAPHICAL ABSTRACT



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ABSTRACT

Despite the prevalence of damming as a global disturbance to river habitats, detailed reach-based assessments of the ecological effects of dams are lacking, particularly across large spatial extents. Using data from nearly 50,000 large dams, we assessed stream network fragmentation and flow alteration by large dams for streams of the conterminous USA. We developed 21 dam metrics characterizing a diversity of dam influences operating at both localized (e.g., distances-to-dams) and landscape scales (e.g., cumulative reservoir storage throughout stream networks) for every stream reach in the study region. We further evaluated how dams have affected stream fish assemblages within large ecoregions using more than 37,000 stream fish samples. Streams have been severely fragmented by large dams, with the number of stream segments increasing by 801% compared to free-flowing streams in the absence of dams and a staggering 79% of stream length is disconnected from their outlet (i.e., oceans and Great Lakes). Flow alteration metrics demonstrate a landscape-scale disturbance of dams, resulting in total upstream reservoir storage volumes exceeding estimated annual discharge volumes of many of the nation's largest rivers. Further, we show large-scale changes in fish assemblages with dams. Species adapted to lentic habitats increase with dams across the conterminous USA, while rheophils, lithophils, and intolerant fishes decrease with dams. Overall, fragmentation and flow alteration by dams have affected fish assemblages as much or more than other anthropogenic stressors, with dam effects generally increasing with stream size. Dam-induced stream fragmentation and flow alteration are critical natural resource issues. This study emphasizes the importance of considering dams as a landscape-scale disturbance to river habitats along with the need to assess differential effects that dams may have on river habitats and the fishes they support. Together, these insights are essential for more effective conservation of stream resources and biotic communities globally.

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1. Introduction

Aquatic habitat degradation resulting from anthropogenic disturbances is a major source of freshwater biodiversity loss globally (Dudgeon et al., 2006), contributing to population declines in imperiled fishes (Jelks et al., 2008). Many studies have demonstrated how anthropogenic disturbances can operate both locally and over landscapes to change stream habitats, with local disturbances including those that directly change the stream channel (e.g., channelization and bank hardening) and landscape-scale disturbances including those that can operate throughout catchments (e.g., urbanization, agriculture, deforestation). Often, localized and landscape-scale disturbances can act in concert, having multiple, cumulative effects on aquatic habitat (Degerman et al., 2007; Schinegger et al., 2012). Dams are an example of a disturbance known to have a diversity of effects on streams, inducing localized changes that alter the continuum of stream temperature, water chemistry, energy, and sediment (i.e., serial discontinuity concept; Ward and Stanford, 1983) as well as having landscape-scale influences including stream network connectivity loss and system-wide changes in flow and temperature regimes (Nilsson et al., 2005).

Despite the prevalence of damming, few detailed reach-based assessments have been conducted investigating landscape-scale consequences stemming from the cumulative effects of dams over large spatial extents. This cumulative aspect is important as dams not only affect streams as individual disturbances, but also in conjunction with all other dams located throughout stream networks (Segurado et al., 2013). Because stream networks consist of longitudinally-connected fluvial habitat patches constrained within dendritic networks (Fagan, 2002), habitats as well as organisms therein are particularly susceptible to network-wide disturbances such as damming, which alter boundaries, size, quality, and connections among habitats. This is particularly true for stream fishes that use disparate habitats for reproduction, growth, and survival (Schlosser and Angermeier, 1995; Fausch et al., 2002), as dams can influence species assemblage structure, richness, and abundance (e.g., Cheng et al., 2016; Cooper et al., 2016). Further, dams can also affect macroinvertebrate communities (Van Looy et al., 2014), an important food source for many stream fishes. Due to these factors, studies focusing on dams that lack network-wide measurements for all streams or have only considered a single aspect of fragmentation provide a limited view of dam effects on river systems and aquatic biota throughout entire stream networks.

In the USA and globally, there is a need to understand the scale and magnitude of dams as a landscape-scale disturbance and to evaluate large-scale influences of dams on fish communities, particularly when compared to other prominent landscape disturbances. This study meets these needs. We first develop 21 dam metrics characterizing stream network fragmentation and flow alteration which we use to describe regional patterns in dam influences across the vast and heterogeneous region comprising the conterminous USA. Next, we evaluate relationships between fish assemblage traits and dam metrics, considering how these relationships vary by stream size and by ecoregion. Finally, we test the relative influence of dams on stream fishes in comparison with other major landscape-scale stressors to better understand the potential for dams to act as a landscape-scale disturbance to stream fish assemblages.

2. Methods

2.1. Describing dam conditions for the conterminous USA

2.1.1. Dam database

We utilized a comprehensive and spatially consistent large dam database for the conterminous USA, the National Anthropogenic Barrier Dataset (NABD; USGS, 2013). The NABD includes spatially-verified dam locations attributed to the 1:100,000 scale National Hydrography Dataset Plus Version 1 stream network (described below; NHDPlusV1; USEPA and USGS, 2005) as well as dam attributes including reservoir storage volume (Fig. 1). NABD dams were derived from the 2009 U.S. Army Corps of Engineers National Inventory of Dams (NID; USACE, 2009) and meet the following criteria: 1) dam hazard potential is considered either high or significant or 2) dams exceed 7.62 m in height and 1.85 hectare-meter of storage or exceed 1.83 m in height and 6.17 hectare-meter of storage (USACE, 2009). To create the NABD, we overlaid dams from the NID and the stream network of the NHDPlusV1 with satellite imagery from Google Earth™. We matched locations of dams from the NID with dam locations represented in Google Earth™ by conducting searches of reservoir or dam names and through visual verification based on Google Earth™ imagery to identify locations of dams in reference to the NHDPlusV1 stream network. Dams from the NID that fell directly onto the NHDPlusV1 stream network were linked to the appropriate spatial location. Dams from the NID that could not be associated with a location on the NHDPlusV1 stream network were not incorporated into the NABD database. This process resulted in 49,298 NID dams linked to the NHDPlusV1 that were used in this study from the NABD database. To ensure that large dams were not missing from the resulting dataset, dams greater than 7.62 m from the USFWS Fish Passage Decision Support System (USFWS, 2008) were checked against NABD dams. This process identified 170 dams that we added to NABD that were not included in the 2009 NID. The final dam data layer includes 49,468 dams linked to the NHDPlusV1 streams throughout the conterminous USA (Fig. 1).

2.1.2. Stream network dataset

The 1:100,000 scale National Hydrography Dataset Plus Version 1 (NHDPlusV1; USEPA and USGS, 2005) was the stream network used

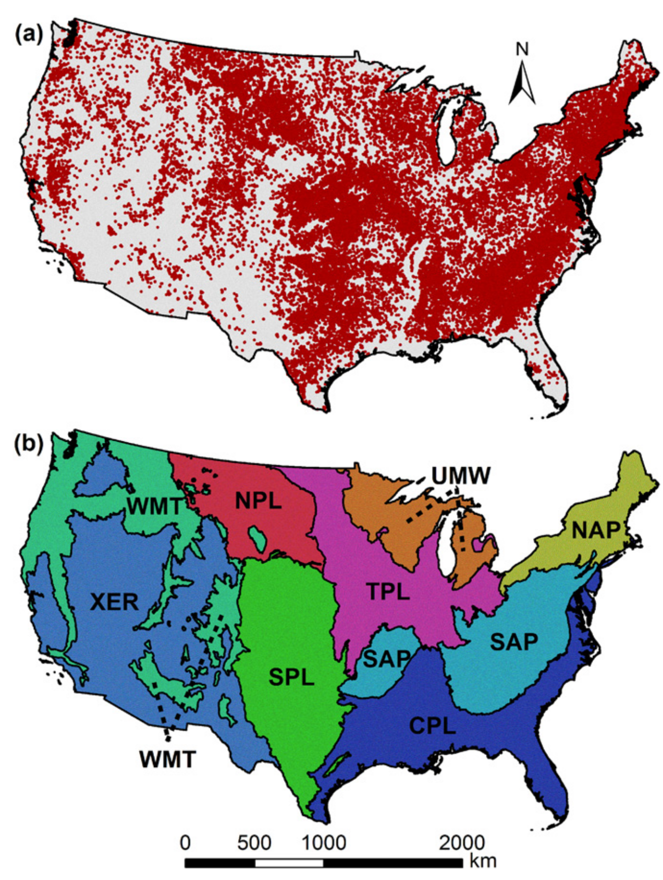

Fig. 1. Distribution of large dam locations (a; $n = 49{,}468$) and nine ecoregions (b) for the conterminous USA. Ecoregions include: Northern Appalachians (NAP), Southern Appalachians (SAP), Upper Midwest (UMW), Coastal Plains (CPL), Temperate Plains (TPL), Northern Plains (NPL), Southern Plains (SPL), Western Mountains (WMT), and Xeric (XER) (USEPA, 2006).