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Management Brief

The importance of trimming National Hydrography Dataset streamline networks when delineating potential habitats and species distributions for fish and amphibians in broad geographical applications

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ABSTRACT

Objective: Digital representations of stream networks are integral components of spatial analyses to describe species distributions and habitat extents, but users should understand their strengths and weaknesses. Here, we used two resolutions of the publicly available and widely applied National Hydrography Dataset (NHD) with large fish and amphibian occurrence data sets to highlight patterns of habitat occupancy relative to availability as described by the NHD.

Methods: Data sets consisting of 37,318 occurrences for 10 species were linked to NHD reaches, attributed with reach slope and mean flow values that represented major habitat gradients, and used to develop cumulative distribution curves describing habitat use and species-specific habitat threshold values for networks in the northwestern USA.

Results: The 10 species rarely, and usually never, occurred in headwater reaches with the smallest flows and steepest slopes, although these reaches composed significant portions of the NHD. Application of species-specific habitat threshold criteria within a single river basin indicated that of its 25,797 km, only 16–55% of this length was likely to be occupied by one of four native species. At a broader scale encompassing the state of Idaho, the medium-resolution NHD network depicted 141,902 km of streams, but this figure was reduced by 52% to 68,586 km once 16% reach slope, 0.2-ft^3/s mean flow, and intermittency criteria were applied that excluded most species from portions of the statewide network.

Conclusions: Our results suggest that the NHD often overestimates the network extents used by many aquatic vertebrates and could be trimmed to improve accuracy in species-specific applications that involve estimating range extents, developing sampling designs for data collection, and applying predictive biological models in unsampled areas. Descriptors of reach slope, flow magnitude, and other attributes useful for representing habitat conditions are available for the NHD and are straightforward to apply.

KEYWORDS: geographical information system, National Hydrography Dataset, species distribution, stream network

LAY SUMMARY

Digital stream networks are components of many geographically broad fisheries applications but may inaccurately portray species distributions and potential range extents. These networks can be customized using reach habitat descriptors to improve their accuracy in many species-specific applications.

INTRODUCTION

Description of fish species range extents is important for status assessments that guide conservation and management (Kruse et al., 1997; Muhlfeld et al., 2015; Wenger et al., 2011), estimating population sizes to assess demographic risks and responses to habitat improvements (Cooper et al., 2020; Hilderbrand & Kershner, 2000), and designing efficient sampling strategies (McKelvey et al., 2016; Stevens & Olsen, 2004; Young et al., 2022). Within the river networks that comprise the ranges of lotic species, strong gradients occur in stream size, flow velocity, channel slope and morphology, temperature, and other physicochemical factors from headwater reaches downstream to large

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rivers (Montgomery & Buffington, 1997; Vannote et al., 1980). These gradients interact with species traits in thermal tolerance, diet, body size, and swimming and leaping abilities to create filters that limit species to subsets of drainage networks (Jackson et al., 2001; Poff, 1997). Large-bodied adult Chinook Salmon *Oncorhynchus tshawytscha*, for example, are precluded from accessing and occupying small streams that sculpin *Cottus* spp. can occupy due to body size differences spanning two orders of magnitude. Similarly, trout species such as Bull Trout *Salvelinus confluentus* and cutthroat trout often extend further upstream than sculpin because of greater cold tolerance (Isaak, Wenger, & Young, 2017; Parkinson et al., 2016) and leaping abilities that enable passage of larger physical obstacles (Gibson-Reinemer & Rahel, 2015; Lemoine et al., 2020). Even the most vagile or smallest fish species, however, are likely to be excluded from the uppermost portions of drainage networks, where limited flows, steep channels, or barriers posed by other physicochemical conditions become insurmountable (Adams et al., 2000; Fransen et al., 2006; Platts, 1979).

The capacity for fisheries biologists to represent river networks and biological phenomenon within them has advanced significantly in the previous decade with increased availability of geospatial data sets and analytical tools for streams (Amatulli et al., 2022; Fisher, 2013; Simley, 2018), large databases of species occurrence and abundance surveys (Comte et al., 2021; Tedesco et al., 2017; Young et al., 2018), greater training and expertise with geographical information systems (GIS) (Eder & Neely, 2013), and the rise of species distribution modeling as a subdiscipline (Elith & Leathwick, 2009; Franklin, 2013). It is now routine for species status and trend assessments or sampling campaigns to be conducted across thousands of stream kilometers or throughout the full extents of species ranges (Iacarella & Weller, 2023; Young et al., 2022). Fundamental to the accuracy of such endeavors are digital renderings of streams that at a minimum represent the basic topological elements of drainage networks, such as discrete channel reaches, their locations, planforms, and tributary confluences (Amatulli et al., 2022; Simley, 2018). Digital networks fall into one of two basic categories, synthetic or raster-based networks and vector or line-based networks. Synthetic networks are derived from elevation models represented by raster grid cells (10-, 30-, and 90-m grid resolutions are common) and are initiated in headwater catchments based on user-defined criteria for minimum watershed area, terrain slope, and other geomorphic factors, after which channels are propagated downslope along the lowest elevation grid cell path until a confluence with another stream or the edge of the analytical domain is reached (Amatulli et al., 2022; Tarboton et al., 1991). Vector networks, in contrast, are derived by digitizing streamlines from existing map sources or orthographically corrected photographs (Fritz et al., 2013). These networks are based on observed rather than modeled characteristics of landscapes but may be subject to potential cartographer biases and inaccuracies that stem from channel movements over time (Leopold, 1994), although it should be noted that synthetic networks also suffer from inaccurate channel depictions, particularly in low-gradient areas (Kenny et al., 2008; Li & Wong, 2010).

Vector networks are frequently used in broad geographical fisheries applications because of their sufficiency for many tasks and wide availability. Of these, the National Hydrography Dataset (NHD) networks developed jointly by the U.S. Geological Survey and Environmental Protection Agency are most commonly used within the USA (Simley, 2018). The NHD networks were developed with adherence to rigorous quality control and cartographic mapping standards to provide a nationally consistent depiction of stream drainage networks and are available in two resolutions (Cooter et al., 2010; Dewald & Roth, 1998). The medium-resolution version corresponds to a 1:100,000 map scale, whereas the high-resolution version, which includes many additional first-order channels, is 1:24,000 scale (Cooter et al., 2010). Both are the digital equivalents of the blue streamlines depicted on U.S. Geological Survey paper topographic maps of the same scales (Fritz et al., 2013). A significant enhancement of these NHD versions, the NHD-Plus (NHD-PlusV2 for the medium-resolution and NHD-PlusHR for the high-resolution), added catchment characteristics and other stream reach attributes to facilitate hydrologic modeling throughout the coterminous USA (Moore & Dewald, 2016; Viger et al., 2016). Of interest to fish biologists, many of these attributes are also relevant descriptors of habitat conditions and gradients within networks, such as reach slope, flow volume, water velocity, and stream order. Attribute values are cross-referenced to individual NHD reaches and can be used to query, summarize, or filter networks and thereby tailor them for project-specific applications (McKay et al., 2012; Moore et al., 2019).

Despite the breadth of NHD applications (Fisher, 2013; Simley, 2018) and potential utility of reach attribute descriptors, these attributes are rarely used to improve the accuracy of range estimates or other fisheries applications at broad geographical scales. Moreover, a general perception exists that NHD networks are often inadequate for representing the habitat extents available to fish species and usually provide underestimates. These underestimates are believed to stem from two sources, those due to vector line smoothing of stream meander patterns (Dauwalter et al., 2022; Firman & Jacobs, 2002; Isaak et al., 1999) and those due to the omission of some streams and conservative portrayals of network extents in headwater areas (Leach et al., 2017; Meyer et al., 2014; Shepard et al., 2005). The goal of this management brief is to highlight the utility of NHD reach attributes in assessing the validity of the latter type of underestimate, which outside of a few anecdotal observations has rarely been examined quantitatively in the fisheries literature. More specifically, our objectives were to (1) examine the range of habitat conditions available within the NHD-PlusV2 network based on gradients in two reach attributes that are likely to affect species distributions (stream size and steepness), (2) describe patterns in fish and amphibian habitat use by linking large species occurrence data sets to reaches in the NHD-PlusV2 network, (3) compare stream network extents before and after application of reach attribute criteria that appeared to delimit species distributions, and (4) assess the adequacy of NHD-PlusV2 coverage by determining how frequently species occurred outside it and on reaches in the more extensive NHD-PlusHR network.

METHODS

A species occurrence data set derived from 23,025 stream electrofishing and snorkeling surveys at 13,769 unique reaches

Table 1. Species occurrence observations from electrofishing and snorkeling surveys used to examine patterns associated with reach attributes in the medium-resolution NHD-PlusV2.

Species name	Occurrences
Mountain Whitefish *Prosopium williamsoni*	2,026
Cutthroat trout	11,543
Rainbow Trout[a] *Oncorhynchus mykiss*	3,977
Chinook Salmon *Oncorhynchus tshawytscha*	1,728
Brown Trout[b] *Salmo trutta*	1,228
Bull Trout *Salvelinus confluentus*	2,809
Brook Trout[b] *Salvelinus fontinalis*	7,036
Rocky Mountain tailed frog *Ascaphus montanus*	957
Pacific Lamprey *Entosphenus tridentatus*	325
Idaho giant salamander *Dicamptodon aterrimus*	593

[a]Nonnative to some streams within the study area.
[b]Nonnative to all streams within the study area.

(Isaak, Wenger, & Young, 2017) was downloaded from the Dryad data repository (https://datadryad.org/stash). These surveys were conducted by state and federal agency fish biologists primarily in Idaho and western Montana, although small numbers of surveys were from northern Utah and western Wyoming. The data set contained information on 14 species, but we only used data for the eight species (seven salmonid fishes and one amphibian) that were most common to increase the likelihood that occurrences spanned the range of conditions a species would occupy (Table 1). These data were supplemented with large occurrence data sets for Pacific Lamprey *Entosphenus tridentatus* (Young et al., 2022) and Idaho giant salamander *Dicamptodon aterrimus* (Isaak et al., 2025) to increase taxonomic diversity and the potential extent of the NHD-PlusV2 network that was occupied by at least one species. The region where stream surveys were conducted is topographically complex and encompasses environments ranging from midelevation steppe grasslands to mountainous areas, forests, and alpine zones that exceed 4,000 m in elevation. Climate is characterized by cold winters with moderate to heavy snow accumulations at high elevations and warm, dry summers. Stream hydrographs are dominated by snowmelt runoff, with high flows during spring and early summer and low flows throughout the remainder of the year. The species occurrence surveys were conducted during late summer and early fall months, when logistical considerations allowed access to streams (Isaak, Wenger, & Young, 2017).

Spatial coordinates and stream names provided by fish biologists with the occurrence surveys were used to link survey sites to reaches in the NHD-PlusV2 network. If site coordinates did not coincide directly with a stream reach, sites were snapped to the nearest reach on the stream identified by the contributing biologist in GIS software. The species occurrences and reaches throughout the network were then attributed with reach slope (field name = Slope in the ElevSlope data table described in McKay et al., 2012), mean August flow (field name = AugQ1E in the EROM_MA0001 data table), and intermittency code (field name = FCode: < > 46003 in the NHDFlowline data table) values in the GIS based on the NHD ComID reach identifier. The Slope values were converted from proportional values (i.e., rise/run in meters per meter) provided in the NHD-PlusV2 to percentages by multiplication with 100. To describe interspecific differences in occurrence, cumulative distribution curves (CDCs) were calculated for the reach slope and flow values associated with each set of species occurrences and these were compared to CDCs describing availability throughout the NHD-PlusV2 network. The 1st and 100th percentiles of the species CDCs were determined and used to delimit potential network extents for four native species that had contrasting preferences based on stream size and reach slope (Rocky Mountain tailed frog *Ascaphus montanus*, Pacific Lamprey, Bull Trout, and Mountain Whitefish *Prosopium williamsoni*) within the Salmon River basin of central Idaho. To provide a broader perspective concerning potential differences between fish distributions and the stream network depicted by the NHD-PlusV2, we also examined the network for the state of Idaho. In this instance, the statewide extent of the NHD-PlusV2 network was treated as a baseline for comparison with networks that were trimmed by applying a series of reach criteria that appeared to exclude fish species from many portions of the NHD-PlusV2 network.

Because species occurrence surveys compiled for the Isaak, Wenger, & Young (2017) study were collected in the 1990s and 2000s, when location estimates were less accurate prior to the broad availability of global positioning systems (GPS), we supplemented our analysis using more recent environmental DNA (eDNA) data sets collected from 2016 to 2023, which are publicly available from the eDNAtlas project website (https://research.fs.usda.gov/rmrs/projects/ednatlas#overview; Young et al., 2018). The eDNA samples were collected and processed following consistent field and laboratory protocols at the National Genomics Center for Wildlife and Fish Conservation (Carim et al., 2016; Wilcox et al., 2018), and we had access to the field site coordinates recorded with GPS receivers. The greater locational accuracy of these data decreased potential errors in spatial assignment to stream reaches, which provided an opportunity to assess the adequacy of the NHD-PlusV2 by determining how frequently species occurred outside this network and on reaches in the more extensive NHD-PlusHR. The eDNA data were collected for many different reasons but were often associated with projects designed to document unknown populations in headwater areas or determine the upstream limit of fish distributions (McKelvey et al., 2016; Young et al., 2022). The number of species with large samples from the eDNAtlas was limited in comparison to the Isaak, Wenger, & Young (2017) data set, but five species had hundreds to thousands of occurrences within the study area and were used for analysis (Pacific Lamprey, Rainbow Trout *Oncorhynchus mykiss*, Bull Trout, Brook Trout *Salvelinus fontinalis*, and cutthroat trout).

RESULTS

Cumulative distribution curves indicated that the eight fish species occurred in stream reaches with higher flows and lower slopes than were generally available in the NHD-PlusV2 network (Figure 1). Pacific Lamprey were particularly extreme in their selection of low-slope areas and larger streams, as 100% of their occurrences were in <3.5% reach slope or flows >5 ft^3/s. At the other extreme, the 100th percentiles of three trout species often associated with headwater

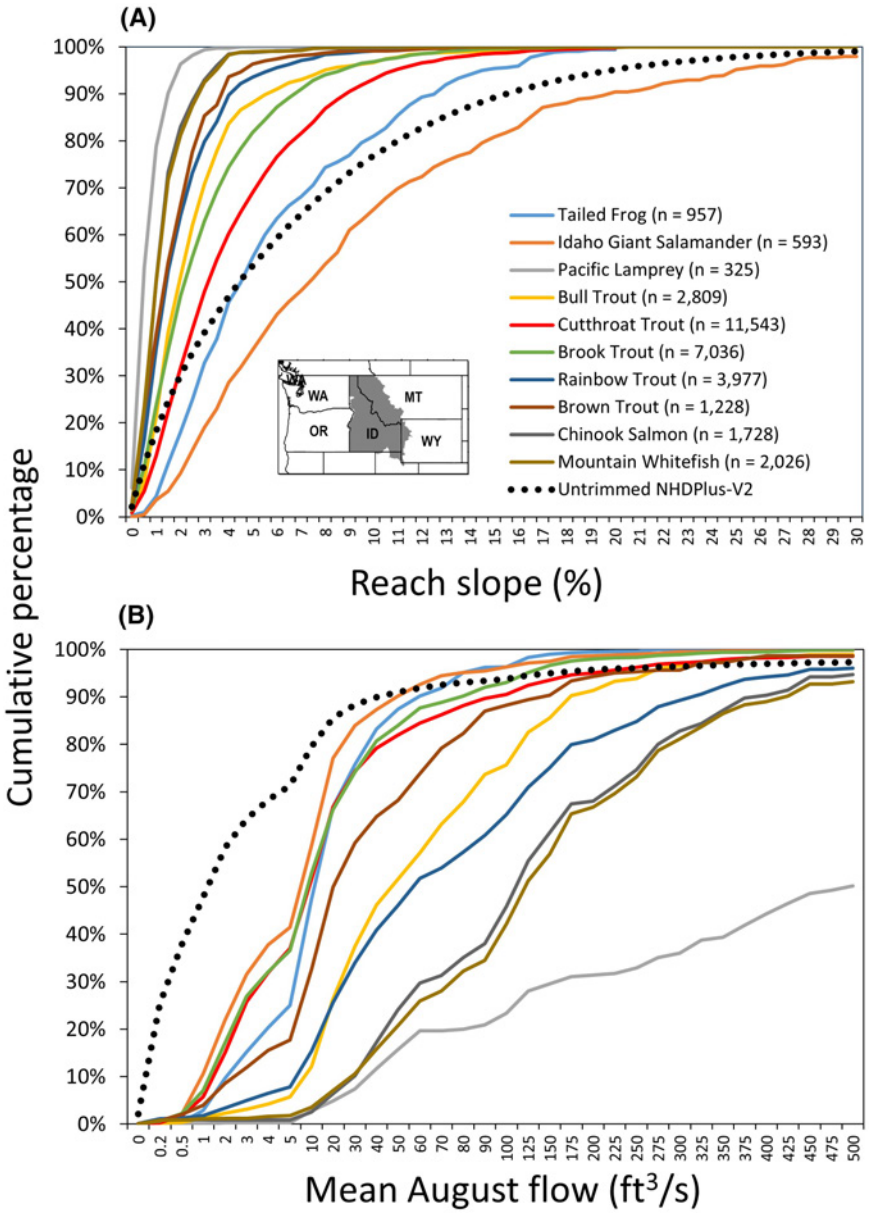

Figure 1. Cumulative distribution curves for species occurrences associated with (A) reach slope and (B) mean August flow versus the availability of stream reaches in the untrimmed medium-resolution NHD-PlusV2 network based on length for the drainages where the stream surveys were conducted in the northwestern USA.

areas—cutthroat trout, Bull Trout, and Brook Trout—were in slopes as high as 13–16% and flows as low as 0.20.5 ft^3/s. Despite greater upstream penetration of the network by these species, significant portions of the NHD-PlusV2 extended beyond these limits. For example, 10–25% of the reaches in the network were steeper than that slope range and 20–35% had smaller flows. The two amphibian species were less constrained by steep slopes, with Rocky Mountain tailed frog occurring in reach slopes at percentages similar to their network availability, whereas Idaho giant salamander selected for especially steep reaches.

In the Salmon River basin, where the NHD-PlusV2 depicted 25,797 km of stream, application of species-specific 1st and 100th occurrence percentile values associated with the two habitat gradients highlighted differences in potential distributions among four species native to the basin (Figure 2). Rocky Mountain tailed frog and Bull Trout network extents were similar (Figure 2B, 2C), although the distribution of the former was shifted further upstream through steeper reaches with an absence of occurrences in large rivers. Pacific Lamprey and Mountain Whitefish network extents, in contrast, were limited to downstream subsets of the overall NHD-PlusV2 network by the preferences of these species for larger streams and lower reach slopes (Figure 2D, 2E). Notably, the species networks exhibited varying degrees of fragmentation (Figure 2), a portion of which stemmed from areas with natural subsurface flow conditions and the lack of NHD channel depictions. But most fragmentation related to differences in the criteria that were used to trim the network. For a species like Rocky Mountain tailed frog that was not captured in the

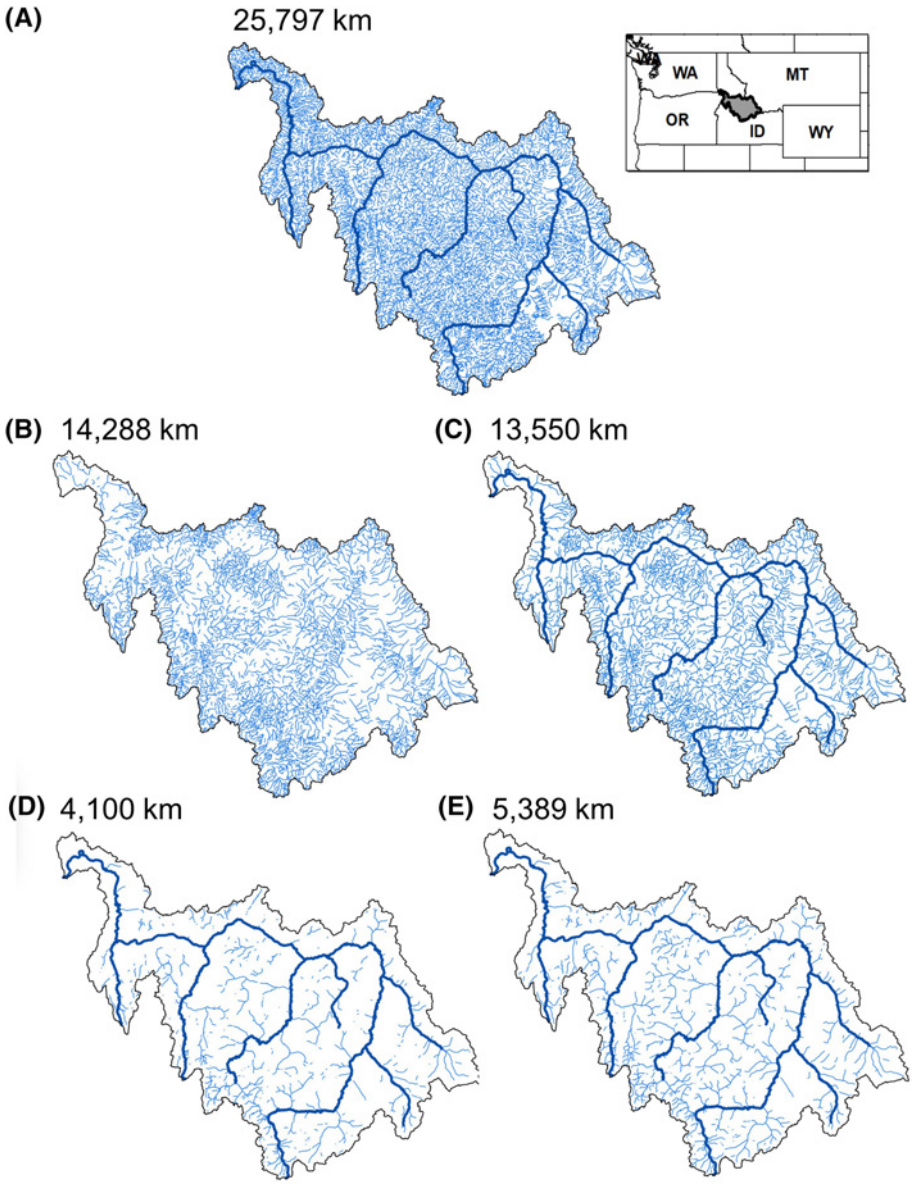

Figure 2. Stream network extents within the Salmon River basin of central Idaho based on (A) the untrimmed medium-resolution NHD-PlusV2 network and subsets trimmed by applying species-specific occurrence criteria associated with reach slope and mean August flow for (B) Rocky Mountain tailed frog, (C) Bull Trout, (D) Pacific Lamprey, and (E) Mountain Whitefish. Thick blue lines denote main rivers.

larger streams that constitute the trunks of networks, excluding these areas isolated many headwater networks. However, fragmentation was also apparent for species like Mountain Whitefish and Pacific Lamprey that occurred in downstream areas. In these instances, reaches that exceeded slope criteria were interspersed between flatter reaches along stream profiles. These exceedances may have been small, in which case the excluded reaches could remain navigable but elsewhere may have been large enough to create movement barriers that precluded access to otherwise suitable habitats further upstream. An example of this may have occurred along the northern border of the Salmon River basin, where a series of streams were separated from the main-stem river by long sections of stream that exceeded 20% slope (Figure 2D, 2E).

At a statewide scale, the NHD-PlusV2 depicted 141,867 km of streams in Idaho (Figure 3). However, if this network was trimmed by applying the reach slope (16%) and flow (0.2 ft^3/s) criteria that appeared to preclude the eight fish species from occupying upstream areas, the network extent was reduced considerably to 97,161 km (Table 2). Because Idaho also contains extensive areas where channels are dry most years (e.g., Snake River plain) due to low annual precipitation and incompetent underlying geologies, excluding intermittent reaches from that total may also be warranted. Doing so eliminated another 28,575 km of the NHD-PlusV2 network and suggests that only 48% of the baseline network was likely to serve as habitat for at least one fish species.

The eDNA-based comparison of occurrence surveys on the NHD-PlusV2 and NHD-PlusHR networks suggested that the former encompassed the large majority of sites where species occurred (Table 3). Pacific Lamprey never occurred in an NHD-PlusHR reach that was not also represented by

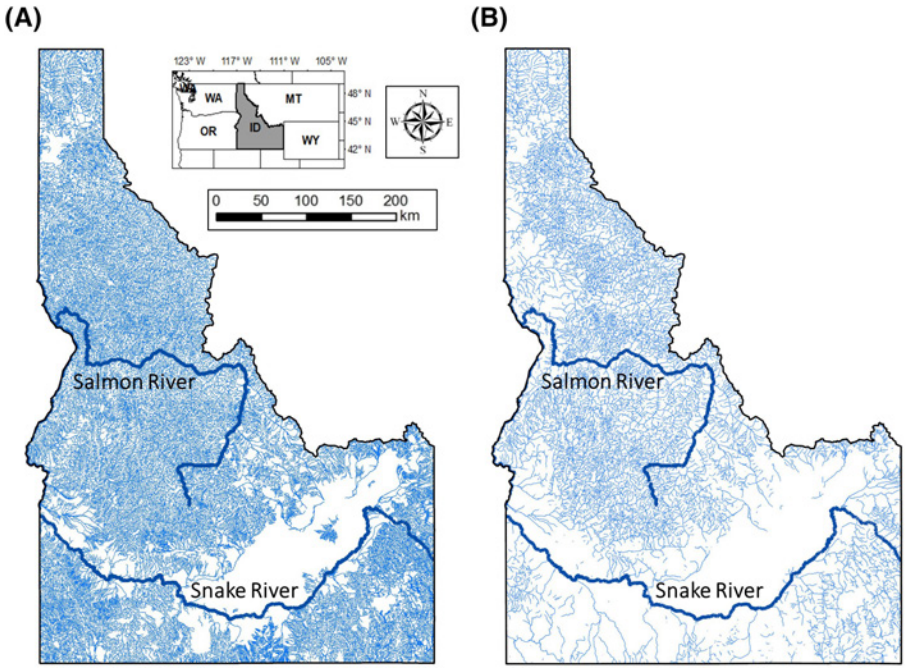

Figure 3. Comparison of the (A) untrimmed (141,902 km) and (B) trimmed (68,586 km) medium-resolution NHD-PlusV2 networks for Idaho after exclusion of intermittent streams and application of 0.2-ft^3/s minimum stream flow and 16% maximum reach slope criteria.

Table 2. Stream network extents and characteristics of constituent reaches for Idaho in the NHD-PlusV2 when the network is trimmed by application of reach slope and flow criteria.

Network trimming criteria	Network length (km)	Number of reaches	Reach slope (%)				August flow (ft^3/s)			
			Min	Max	Median	SD	Min	Max	Median	SD
None	141,902	78,738	0.01	217	3.83	8.38	0.01	29,829	1.22	1,510
Exclude reach slopes >16%	123,401	68,260	0.01	16.0	2.79	4.41	0.01	29,829	1.58	1,619
Exclude reaches with mean August flow <0.2 ft^3/s	113,480	62,870	0.01	217	4.01	8.25	0.20	29,829	2.52	1,709
Exclude reaches >16% slope and flow <0.2 ft^3/s	97,161	54,033	0.01	16.0	2.87	4.49	0.20	29,829	3.61	1,835
Exclude >16% slope, flow <0.2 ft^3/s, and intermittent reaches[a]	68,586	41,450	0.01	16.0	2.54	4.44	0.20	29,829	6.49	2,067

[a]Intermittent reaches in the NHD-PlusV2 data set are labelled 46,003 in the Fcode field. See McKay et al. (2012) for details.

Table 3. Frequencies of eDNA species occurrences on reaches in the high-resolution NHD-PlusHR that were not represented in the medium-resolution NHD-PlusV2 network. Values in parentheses are percentages of the total number of occurrences.

Species	Total eDNA occurrences	Occurrences on NHD-PlusHR
Pacific Lamprey	179	0 (0%)
Brook Trout	1,073	27 (2.5%)
Bull Trout	2,559	10 (0.39%)
Rainbow Trout	548	5 (0.91%)
Cutthroat trout	737	9 (1.22%)

NHD-PlusV2 as might be expected for a species associated with larger streams and low slope reaches. At the other extreme, 2.5% of Brook Trout occurrences, a nonnative species that has been widely introduced to headwater streams across the study area, fell solely in NHD-PlusHR reaches, while about 1% of the other trout species occurrences were in these areas.

DISCUSSION

Our results counter the perception that NHD streamlines significantly underestimate the network extents available to many lotic vertebrates and support the view that environmental gradients along stream profiles act as faunal filters to differentially restrict species distributions (Jackson et al., 2001; Poff, 1997). This is not surprising, as these networks were not developed originally for ecological applications but were described as landscape elements by cartographers interested primarily in depicting channel locations regardless of perennial flow or other attributes relevant to aquatic biota (Fritz et al., 2013; Moore & Dewald, 2016). For many fisheries projects done at broad geographic scales, therefore, trimming NHD networks based on species-specific criteria may be a means of achieving greater accuracy. Not doing so risks overestimation of potential habitat extents, species ranges, and abundances within those ranges. Broad abundance estimates, for example, are usually derived as the product of average observed densities within a small number

of sample reaches and the length of streams across a larger unsampled domain (Cooper et al., 2020; Isaak, 2017; Toepfer et al., 2000; Wyatt, 2003), thereby requiring accurate estimation of both elements. Similarly, species status assessments often include range size estimates as a means of highlighting risk and the amount by which occupied habitats may have changed from prior periods. These assessments are particularly common for salmonid species within their native ranges, as is the practice of using untrimmed NHD layers in derivation of range estimates (DeWeber & Wagner, 2015; Meyer et al., 2014; Wenger et al., 2011). An important corollary is that when contemporary species distributions, which are often known with fair accuracy due to large amounts of modern sampling, are compared with what may be inflated historical estimates, the magnitude of declines and range contractions may also be overestimated. That said, because declines in many species of conservation concern are so large, it is unlikely that better historical range estimates would change the conservation status of these species, but it is an area where improvements are possible.

Specifically how an NHD network is trimmed requires judgement and a consideration of species-specific habitat thresholds. Threshold values could be derived using expert opinion, obtained from response curves in species distribution models, or, as was the case here, by matching NHD reach attributes with large species occurrence data sets, which are increasingly common throughout the USA (Troia & McManamay, 2017; Young et al., 2018). The latter technique ensures consistency between criteria derivation and application but likely yields values that are most reliable for small headwater streams and rivers, where sampling efficiency is high and false absence rates (i.e., a species is present but not detected) are low. However, these types of streams are also where the NHD-Plus networks appear to be most liberal and exclusion of reaches that were too steep or small to provide habitat would be most beneficial. The utility of trimming networks by eliminating reaches from larger streams in downstream areas is less certain for two reasons. First, habitat threshold criteria in these areas could be less precise due to lower sampling efficiencies or habitat use patterns wherein species are seasonally absent from larger streams due to life history or behavioral requirements. Second, trimming downstream areas heavily fragments networks for species that occur primarily in headwater areas and larger streams must occasionally, even if only rarely, be used for dispersal and movements among continuously occupied areas.

Regardless of how NHD-Plus networks are treated, they will remain imperfect representations of stream networks, and users should understand potential trade-offs when choosing whether to trim a network and which NHD resolution to use. For example, there are instances when perennial streams or reaches within streams that are used by target organisms are not depicted by the NHD as noted by previous authors (Leach et al., 2017; Shepard et al., 2005). Our findings regarding eDNA-based species detections outside the NHD-PlusV2 network suggests that these instances are relatively rare, but the number of such omissions could be exacerbated by network trimming and must be weighed against the potential for improved accuracy. It could also be the case that stream omissions and species occurrences outside the NHD-PlusV2 are more common outside our study area in wetter regions, where higher channel densities or more extensive tree cover presented greater challenges to cartographers when inferring the presence of streams. In these areas, the 1:24,000-scale NHD-PlusHR and its more liberal portrayal of networks may be a better option (Moore et al., 2019; Viger et al., 2016). That said, the large majority of additional streams depicted in the NHD-PlusHR relative to the NHD-PlusV2 are small, first-order channels of the type least likely to be occupied by many fish species. In the state of Idaho, for example, the NHD-PlusHR depicts 293,000 km of stream, more than twice the extent of NHD-PlusV2, but this figure was reduced to 79,876 km when the same three criteria previously applied to this statewide network were used for trimming (D. J. Isaak, unpublished analysis). In addition to both resolutions of the NHD-Plus, the U.S. Geological Survey has recently undertaken a lidar-based remapping of national hydrography in the 3D National Hydrography Program that may yield stream networks useful for fisheries applications (Anderson et al., 2024; https://www.usgs.gov/3DHP). Networks delineated as part of this program are even more extensive than those in the NHD-PlusHR but were available for only a subset of U.S. watersheds in 2024 because the program was recently initiated.

Another important consideration in choosing among NHD networks is the availability of reach attribute descriptors that are needed to customize. For heuristic purposes, we focused on reach slope and streamflow to represent environmental gradients that constrained species distributions, but there are many other potentially limiting physicochemical gradients. The NHD-PlusV2 has the largest number of reach attributes because it has been available for the longest period and the original set of reach attributes developed by McKay et al. (2012) has been supplemented with additional data sets created by research groups within the NHD user community. These auxiliary data sets were designed for compatibility with NHD-PlusV2, can be used consistently throughout the coterminous USA, and include hundreds of metrics describing flow regimes (Miller et al., 2018; Wenger et al., 2010), thermal regimes (Isaak, Wenger, Peterson, et al., 2017; McManamay & DeRolph, 2019; Siegel et al., 2023), water chemistry (Olson & Cormier, 2019), and surficial watershed features and morphology (Hill et al., 2016; McManamay & DeRolph, 2019). The more recently developed NHD-PlusHR has a basic set of reach descriptors (e.g., reach slope, flow volume, water velocity, and stream order; Moore et al., 2019), but few auxiliary data sets have been developed to further enhance its utility. Moreover, with the ongoing development of networks from the 3D National Hydrography Program, it is unclear whether incentives exist to further enhance the NHD-PlusHR. The 3D National Hydrography Program networks will also have a basic set of reach descriptors (Anderson et al., 2024), but their utility will be limited by geographic availability until program completion. Given the relative dearth of reach attributes available for the newer networks, work-around solutions may be useful and include adapting NHD-PlusV2 attributes or using a GIS to develop novel reach attributes (Peterson & Pearse, 2017), although these options typically require advanced GIS skills.

Rather than trimming NHD networks through application of reach attribute habitat criteria, an alternative involves developing models to predict the distributions of target organisms. Doing so is more involved, as it requires field surveys of a

response variable (e.g., occurrence or abundance of an organism), linking the response to habitat descriptors that serve as model covariates (often these are NHD-Plus reach attributes), fitting a statistical model to describe the relationships between the response and covariates, and using the model equation to predictively map the response variable throughout the domain of interest. In several instances, researchers have developed models specifically to predict the upstream limits of fish distributions (Fransen et al., 2006; Latterell et al., 2003; Penaluna et al., 2022). To date, however, these efforts have been undertaken at relatively limited spatial extents and where commercial timber harvest is a priority to understand which streams host fish and require wider riparian buffer protections. More common are species distribution models that are parameterized to predict and interpolate spatial patterns in abundance or occurrence probability (Bond et al., 2011; Buisson et al., 2008; Olden & Jackson, 2002). These models generate continuous maps and are frequently applied throughout large portions of species ranges but generally make no distinctions within networks regarding the locations where distributions end (DeWeber & Wagner, 2015; Iacarella & Weller 2023; Wenger et al., 2011). Instead, threshold values of occurrence probability or abundance are chosen by the modeler and applied to prediction maps, which are then classified prior to calculation of range extents (Elith & Leathwick, 2009). Developing and applying a species distribution model requires careful evaluation of the covariate ranges at observation sites and the areas where predictions are made to avoid extrapolation errors (Rousseau & Betts, 2022; Yates et al., 2018). It is commonly the case, for example, that fish species distribution models include parameters for stream size, slope, and other network habitat gradients (Fausch et al., 1988; Isaak, Wenger, & Young, 2017), which if applied in areas significantly outside the range of observations, as many headwater NHD reaches are for some species, could result in anomalous predictions.

CONCLUSIONS

The famous quote, "All models are wrong, some are useful" by the statistician George Box seems apropos of NHD stream networks. These digital representations of networks are imperfect models given cartographic and surveying errors associated with their original depictions, as well as the propensity of channel planforms to evolve over time. Nonetheless, NHD networks remain valuable tools given their national availability and functionality for many broad-scale fisheries applications, and our goal here was to examine their adequacy for representing potential habitat extents by comparison to large species occurrence data sets. In our study area within the northwestern USA, it appeared that the NHD networks often overrepresented the extent of headwater areas that many aquatic vertebrates occupy. The amount of bias in the NHD varied among species likely due to differences in traits and habitat thresholds that mediate upstream penetration of networks. Using reach attribute descriptors that were developed as part of the NHD-Plus enhancement program, it is possible to trim and customize these networks, thereby improving accuracy for many species-specific applications. Whether and how to customize NHD networks are choices that investigators must make based on the goals of individual projects, but NHD-Plus user guides provide extensive documentation (Anderson et al., 2024; McKay et al., 2012; Moore et al., 2019) that practitioners with basic GIS skills will find accessible.

DATA AVAILABILITY

No new data were collected for this work. Data sets used in the examples were obtained from previous studies and websites associated with the NHD-PlusV2 (https://www.nhdplus.com/NHDPlus/NHDPlusV2_home.php) and the NHD-PlusHR (https://www.usgs.gov/national-hydrography/nhdplus-high-resolution).

ETHICS STATEMENT

The authors confirm that this research meets the ethical guidelines and legal requirements of the United States.

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CONFLICTS OF INTEREST

The authors do not report any conflicts of interest.

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