Guidance for Developing Temperature Criteria for Nevada Waters

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Rainbow Trout (Photography courtesy of John Rupp)

NDEP

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Table of Contents

List of Tables

List of Figures

List of Acronyms

^oC	degrees Celsius
DMT	Daily Maximum Temperature
EPA	U.S. Environmental Protection Agency
LCT	Lahontan Cutthroat Trout
MDMT	Maximum Daily Maximum Temperature; highest DMT for a given time period (typically one year)
MLOE	Multiple lines of evidence
MWAT	Maximum Weekly Average Temperature; highest WAT for a given time period (typically one year)
MWMT	Maximum Weekly Maximum Temperature; highest WMT for a given time period (typically one year)
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
NDOW	Nevada Department of Wildlife
NRS	Nevada Revised Statutes
ODOW	Oregon Department of Wildlife
USFWS	U.S. Fish and Wildlife Service
WAT	Weekly Average Temperature; weekly (7-day) average of daily average temperatures
WMT	Weekly Maximum Temperature; weekly (7-day) average of daily maximum temperatures

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Introduction

Most of Nevada's current water quality criteria for temperature were established in the late 1970s and early 1980s. The Nevada Division of Environmental Protection (NDEP) has long recognized that the current temperature criteria are not well documented and in need of review. As part of an overall statewide strategy, NDEP is working to improve all existing water quality standards (including temperature) based upon scientifically defensible justifications.

NDEP in collaboration with local and regional fisheries biologist developed a methodology for defining thermal tolerance values for various fish species. Using this methodology, NDEP compiled thermal tolerance values for approximately 40 of the coldwater and warmwater fish species known to inhabit Nevada waters. This document provides guidance on the use of these thermal tolerance values in the development of regulatory petitions and rationales in support of future revisions to temperature criteria.

Background

Temperature Standards and Aquatic Life

Water temperature is an important factor that affects the health and survival of fish throughout all life stages. Specifically, water temperature can affect adult survival, juvenile growth, spawning success, and embryonic development. Temperatures that exceed above protective levels can have long lasting detrimental effects on the fish, fish populations and aquatic communities (Brungs and Jones, 1977; Washington Dept. of Ecology, 2002; Todd et al., 2008).

Federal regulations require that states adopt water quality criteria that will protect the designated uses of a given waterbody. For purposes of this guidance document, the interest is in setting temperature criteria for the protection of aquatic life uses in Nevada waters. States generally set temperature criteria based upon the needs of the fish, which also protects the broader aquatic life community in a waterbody.

In an EPA report, Brungs and Jones (1977) recommend establishing both chronic and acute temperature criteria for the protection of fish. Chronic criteria are intended to "*… maintain growth of aquatic organisms at rates necessary for sustaining actively growing and reproducing populations…*" Acute criteria are intended to protect fish from "*…short exposure to temperatures higher than those acceptable for reproduction and growth without significant adverse effects*." These criteria are not intended to protect fish from all effects, rather they are set to limit impacts to acceptable levels.

EPA's Recommended Thermal Tolerance Values

EPA guidance (Brungs and Jones, 1977; US EPA, 1986; NDEP, 2015) provides species-specific thermal tolerance values that are recommended as temperature criteria for several coldwater and warmwater fish, These thermal tolerance values are divided into two life stage groups: 1) adult and juvenile, and 2) spawning and incubation. However, EPA guidance provides thermal tolerance value recommendations for less than one-half of the some 40 coldwater and warmwater fish species selected by NDEP for thermal tolerance development.

For the adult and juvenile fish temperature criteria recommendations, EPA used a very prescriptive approach relying on mathematical equations for calculating chronic and acute temperature thresholds utilizing laboratory and field-derived thermal response values. EPA's approach for developing spawning and embryo survival thermal tolerance values was much less rigorous compared to the approach for juveniles and adults. For spawning and embryo survival, thermal tolerance values were not calculated, rather EPA relied on literature values derived using a variety of estimation methods, such as: 1) field observations, 2) laboratory experiments, and 3) hatchery operations.

NDEP's Recommended Thermal Tolerance Values

In 2015, NDEP formed a Temperature Work Group consisting of local and regional fisheries biologists to assist with the process of developing updated temperature criteria for Nevada's waters. After reviewing EPA's recommendations and prescriptive methodology, the group concluded that a Multiple Lines of Evidence (MLOE) approach in developing thermal tolerance values was more desirable (NDEP, March 2017). The MLOE approach allows for a wider range of information to be considered in the development process.

As part of the MLOE approach, NDEP compiled thermal tolerance information from over 500 published papers, reports and other references for approximately 40 species of coldwater and warmwater fish. Although other fish species are known to exist in Nevada waters, insufficient literature was found to justify recommending thermal tolerance values for these other species.

Adult and Juvenile Thermal Tolerance Values: NDEP's recommended values for chronic and acute thermal tolerances for coldwater and warmwater adult and juvenile fish (Tables 1 and 2) were developed using the MLOE. NDEP's approach was to accept the EPA chronic and acute recommendations unless the literature review provided a compelling reason to utilize other values. In all cases, EPA's recommended values were found to be appropriate for criteria development.

For those species not addressed in EPA guidance, best professional judgment was used to select recommended chronic and acute thermal tolerance values from within the range of acceptable values reported in the literature. NDEP's methodology document (NDEP, March 2017) provides a detailed discussion of the process of developing thermal tolerance values. Discussions of the MLOE that were considered during development of species-specific thermal tolerance values are provided in the individual documents (NDEP, May 2017) prepared for each of the fish species listed in Tables 1 and 2.

Spawning and Incubation Thermal Tolerance Values: Following careful consideration of the available information, NDEP concluded that a detailed review of EPA's spawning and incubation thermal tolerance recommendations was not necessary at this time (Tables 3 and 4). Use of these thermal tolerance values requires detailed knowledge of spawning and incubation locations and timing for the waterbody under consideration. In most cases, limited information on spawning and incubation location exists. NDEP is proposing an alternative approach for protection of spawning and incubation life stages for those waters with limited early life stage information.

Table 1. Summary of NDEP's Recommended Thermal Tolerance Values: Juvenile/Adult Coldwater, Summer

Fish Species	Thermal Tolerance Values	
	Chronic (°C)	**Acute (°C)**
Salmon and Trout Family - Salmonidae		
Bonneville Cutthroat Trout	17	22
Brook Trout	19*	24*
Brown Trout	17*	24*
Bull Trout (juvenile rearing)	None	12*[1]
Bull Trout (adult foraging and migration)	None	16*[1]
Kokanee (Sockeye) Salmon	18*	22*
Lahontan Cutthroat Trout	17	22
Mackinaw (Lake) Trout	16	21
Mountain Whitefish	17	22
Rainbow Trout	19*	24*
Redband Trout	19	24
Yellowstone Cutthroat Trout	17	22
Sculpin Family – Cottidae		
Mottled Sculpin	None	26

*Based upon EPA recommendation
[1]7-day average of daily maximum temperatures

Table 2. Summary of NDEP's Recommended Thermal Tolerance Values: Juvenile/Adult Coolwater/Warmwater, Summer

Fish Species	Thermal Tolerance Values	
	Chronic (°C)	Acute (°C)
Carp and Minnow Family – Cyprindae		
Bonytail Chub	29	33
Common Carp	32	37
Fathead Minnow	29	32
Northern Leatherside Chub	27	29
Woundfin	26	33
Live Bearers Family – Poeciliidae		
Western Mosquitofish	32	35
Northern American Catfish Family – Ictaluridae		
Brown Bullhead	30	33
Channel Catfish	32*	35*
White Catfish	32	None
Perch Family – Percidae		
Walleye	25*	30
Yellow Perch	29*	30
Sucker Family – Catostomidae		
Flannelmouth Sucker	29	32
Mountain Sucker	26	28
Razorback Sucker	29	33
Sunfish Family – Centrarchidae		
Black Crappie	27*	32
Bluegill Sunfish	32*	35*
Green Sunfish	31	34
Largemouth Bass	32*	34*
Pumpkinseed Sunfish	31	33
Redear Sunfish	29	31
Smallmouth Bass	29*	31
Spotted Bass	32	None
White Crappie	28*	31
Temperate Bass Family – Moronidae		
Striped Bass	30	32
White Bass	30	31
Wiper	30	31

*Based upon EPA recommendation

Table 3. Summary of EPA's Recommended Thermal Tolerance Values: Coldwater Spawning and Embryo Survival

Fish Species	Thermal Tolerance Values	
	Chronic (°C)	Acute (°C)
Salman and Trout Family - Salmonidae		
Brook Trout	9	13
Brown Trout	8	15
Bull Trout (juvenile rearing)	None	9[1]
Kokanee (Sockeye) Salmon	10	13
Mackinaw (Lake) Trout	9	14
Rainbow Trout	9	13

[1]7-day average of daily maximum temperatures

Table 4. Summary of EPA's Recommended Thermal Tolerance Values: Warmwater Spawning and Embryo Survival

Fish Species	Thermal Tolerance Values	
	Chronic (°C)	Acute (°C)
Carp and Minnow Family – Cyprindae		
Common Carp	21	33
Fathead Minnow	24	30
Northern American Catfish Family – Ictaluridae		
Brown Bullhead	24	27
Channel Catfish	27	29
Perch Family – Percidae		
Walleye	8	17
Yellow Perch	15	20
Sunfish Family – Centrarchidae		
Black Crappie	17	20
Bluegill Sunfish	25	34
Largemouth Bass	21	27
Pumpkinseed Sunfish	25	29
Smallmouth Bass	17	23
White Crappie	18	23
Temperate Bass Family – Moronidae		
Striped Bass	18	24
White Bass	17	26

Development of Appropriate Temperature Criteria for a Waterbody

NDEP proposed to incorporated updated temperature criteria into the water quality standards (Nevada Administrative Code [NAC] 445A) using the thermal tolerance values presented in Tables 1 through 4. The basic steps in establishing updated temperature criteria for a given waterbody are as follows:

STEP 1 - Identify the fish species and life stages that occur or are desired/potential with the waterbody

STEP 2 - Determine if detailed information exists to identify timing and locations of fish spawning and incubation

STEP 3 - Divide reach into subreaches as necessary to address differences in fish species and life stages, as well as their associated criteria

STEP 4 – Using the thermal threshold values, construct temperature criteria that protect the most sensitive fish species and early life stages, as appropriate

The following paragraphs discuss each of these four steps for determining thermal tolerance values and developing appropriate temperature standards that are protective of fish and aquatic communities in a given waterbody.

STEP 1 - Identification of Fish Species and Life Stages

Temperature criteria are typically set to protect the most sensitive fish species that occur in a given waterbody. Therefore, one must understand the main species that are present (or desired) or potentially present (in the case of threatened and endangered species) in each of the waterbodies targeted for updated/new temperature criteria. It is standard practice for NDEP to consult with Nevada Department of Wildlife (NDOW), US Fish and Wildlife Service (USFWS), and other organizations when identifying species of concern for a particular waterbody. Some other sources of information that are available include:

- NDOW Fishable Waters Maps (Figure 1) - these maps identify fishable waters and which coldwater and warmwater gamefish species can be expected in these waters. Always check with NDOW to verify this information. Introduction of and eradication efforts for different species may have changed the fish species currently present in some of these waters.

- Bull Trout Critical Habitat Designations (Figure 2) – this information identifies critical bull trout habitat for spawning/rearing and foraging/migrating/overwintering, as designated by the USFWS.

- Warren et al. (2014) compiled information on fish presence and absence from 5,156 fish surveys conducted by NDOW and Oregon Department of Wildlife (ODOW_ across multiple decades (1953-2010) in more than 500 streams in Nevada and Oregon. The survey information includes fish counts for brook trout, brown trout, Lahontan cutthroat trout (LCT), rainbow trout, and LCT x rainbow trout hybrids.

- Lahontan Cutthroat Trout (*Oncorhynchus clarki henshawi*) Recovery Plan – Appendix E (Coffin and Cowan, 1995) – Appendix E provides of list of streams in Truckee River, Carson River, Walker

River, Black Rock Desert, Quinn River, Humboldt River, and other interior Nevada basins which: 1) have current or recently existing LCT populations (as of 1995), and 2) represent other potential sites for recovery.

- Lahontan Cutthroat Trout Species Management Plan for the Upper Humboldt River Drainage Basin, Appendix A (Elliott, 2004) – Appendix A provides a list of streams and the status of fish (LCT and other trout, as well as nongame species) that may occupy these streams. Potential LCT streams are also identified.

- Lahontan Cutthroat Trout Species Management Plan for the Quinn River/Black Rock Basins and North Fork Little Humboldt River Sub-basin – Appendix A (Sevon et al., 1999). Appendix A provides a list of streams with existing LCT populations, along with streams that have the potential for re-establishment of LCT populations. The occurrence of other fish (game and nongame) in these waters is also identified.

- NDOW website provides a document entitled "Distribution of Native Trout Species in Nevada" which lists native trout species and their associated waterbodies: http://www.ndow.org/uploadedFiles/ndoworg/Content/Fish/Angler_Recognition/Native-Trout-water-list-Nevada.pdf

- Miscellaneous NDOW Progress Reports – NDOW produced a number of progress reports that typically include fish survey information for use in establishing presence of fish species in a given waterbody: http://www.ndow.org/Our_Agency/Divisions/Fisheries/Job_Progress_Reports/

STEP 2 – Identify Timing and Locations of Early Life Stages As Needed

In addition to protecting the most-sensitive fish species, temperature criteria should also protect the most sensitive life stages (spawning and incubation) that occur in the waterbody. Early life stages are generally more sensitive to temperature conditions than the juvenile and adult forms of fish, and may require more restrictive temperature criteria. Consultation with NDOW, USFWS and others will be needed to identify the appropriate early life stages occurring within a waterbody, as well as the location and timing of spawning and incubation. In many cases, little may be known about the timing and locations of fish spawning and incubation. Options for dealing with these situations are discussed later.

Some waters may not have self-propagating populations and are maintained solely by stocking. These waters would likely not need criteria to protect early life stages of the stocked species.

Lakes, reservoirs and large rivers (Colorado River) may present some challenges in setting appropriate temperature criteria and assessing compliance. With some fish species, spawning occurs in the shallower, littoral zones of these waters. In these cases, the spawning and incubation temperature criteria should only apply to these littoral zones. However, most temperature monitoring of lakes, reservoirs and large river is performed in the deeper (pelagic) region of the water, rather than the littoral zone, of these waterbodies. Therefore, monitoring data from the pelagic zone may only be comparable to the adult and juvenile temperature criteria, and not the spawning and incubation criteria.

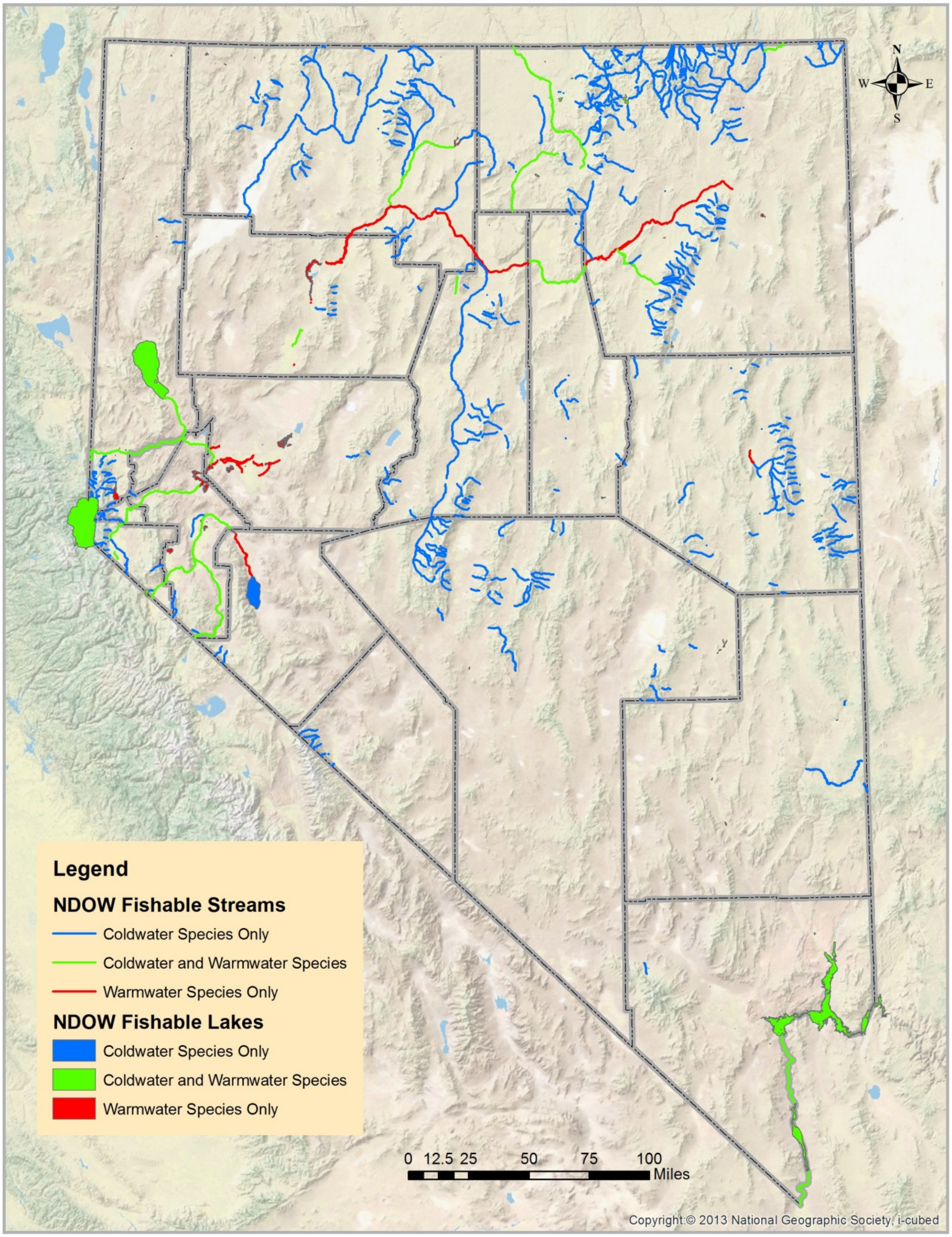

Figure 1. NDOW Fishable Waters

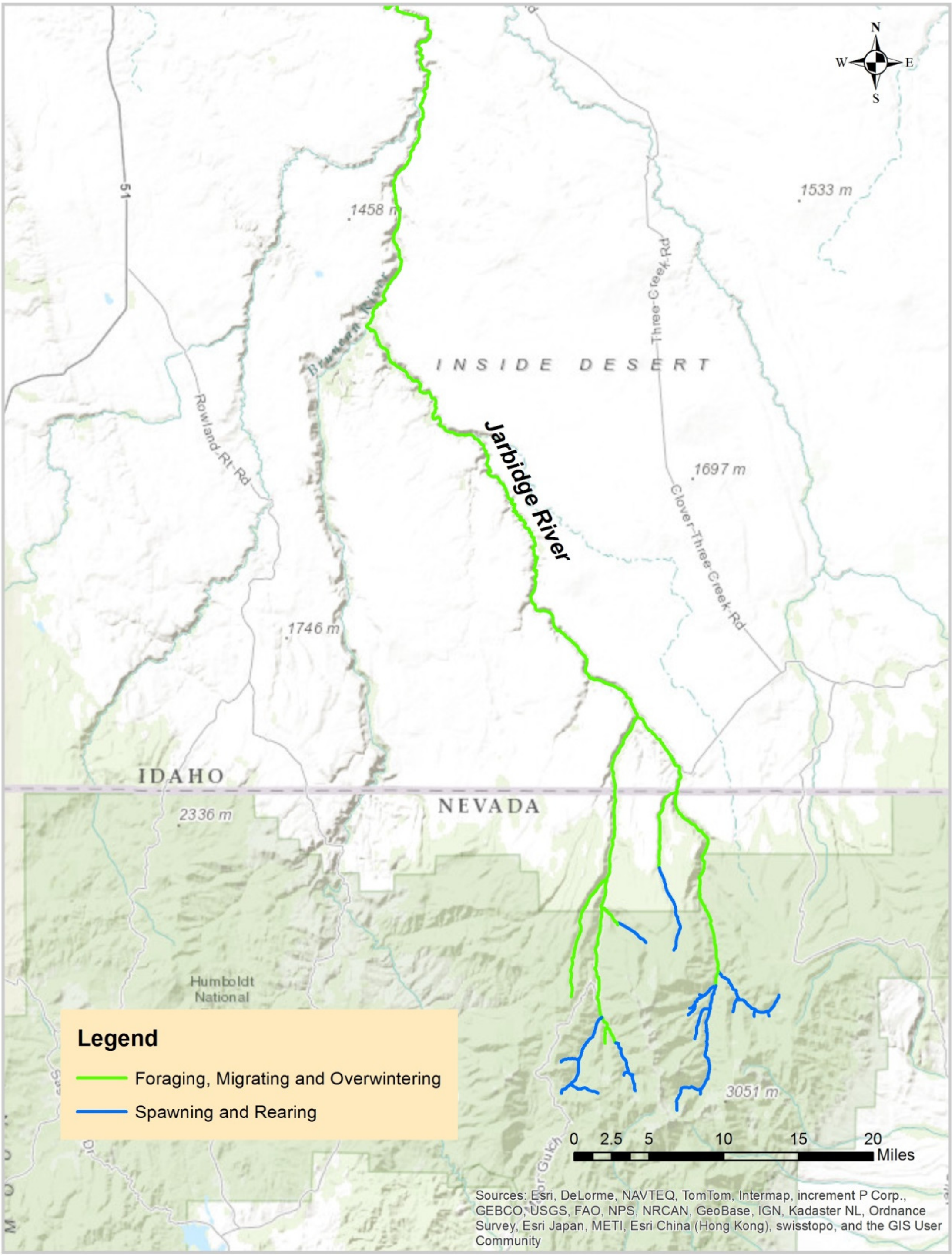

Figure 2. Bull Trout Critical Habitat Designations in Jarbidge River Watershed

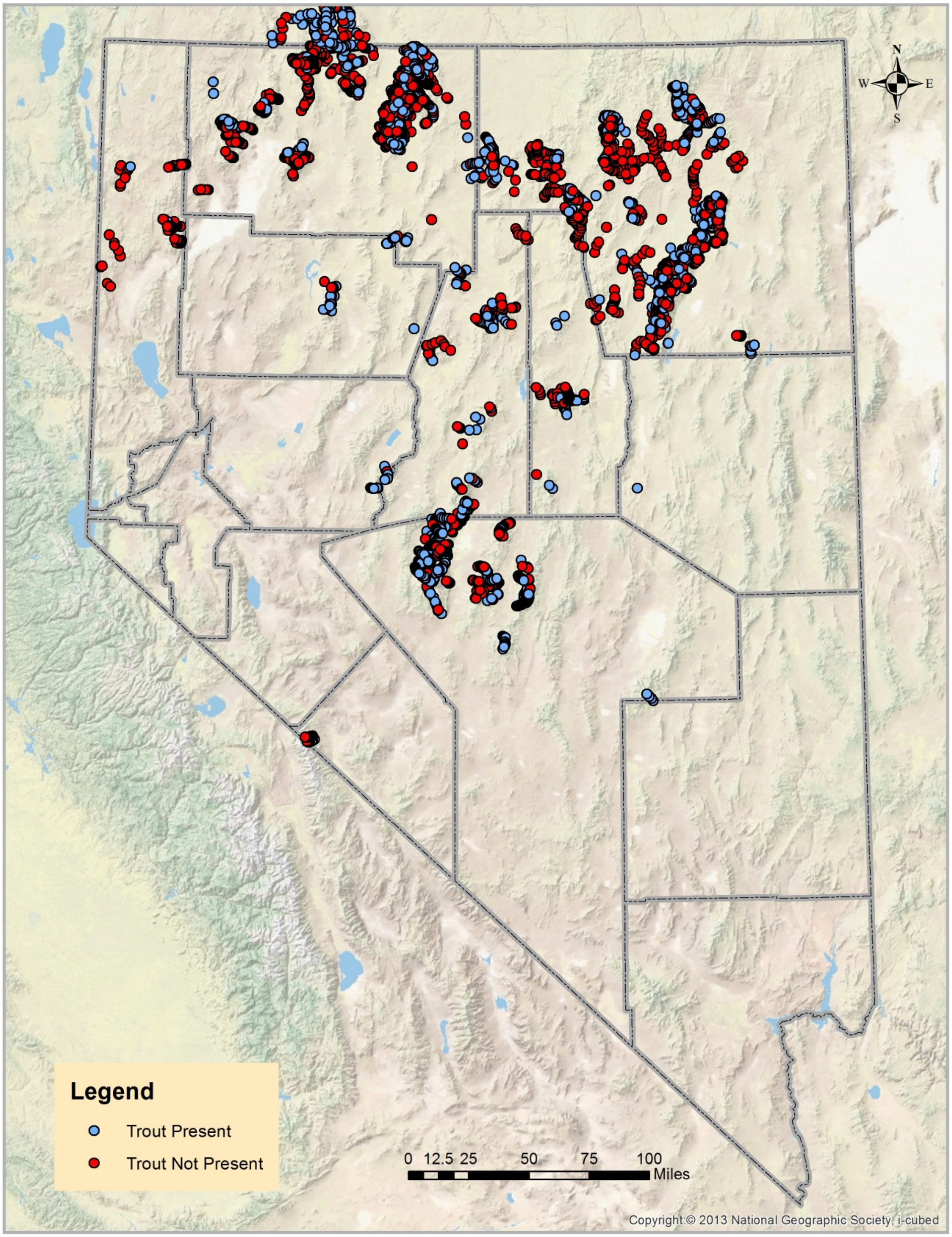

Figure 3. NDOW and ODOW Fish Surveys (1953-2010)

STEP 3 – Divide Waterbody into Subreaches As Needed

Within the NAC, the spatial limits of each waterbody reach or segment are defined to account for changes in conditions (e.g. transition from coldwater to warmwater fishery). However, there may be instances where new information indicates that the limits of a reach or segment need to be revised to better account for changes in fish species or in spawning and incubation areas throughout the waterbody. For waters newly added to the NAC, reaches and segments should be provided as needed to account for changes in fishery designations, based upon the most current information.

STEP 4 – Construct Temperature Criteria

The thermal tolerances of juvenile and adult fish are typically higher than those desired for spawning and embryo survival[1]. Therefore, the thermal tolerance values developed to support the growth and survival of juvenile and adult life stages (Tables 1 and 2) are not likely to provide adequate protection of all other life stages. To address this difference in tolerances, EPA guidance (Brungs and Jones, 1977) recommended numeric temperature criteria that protect both juvenile and adult fish, as well as spawning and survival of embryotic life stages. The development of seasonally variable temperature criteria that meet all life stages throughout the year is necessary to maintain viable fish populations (Todd, et al. 2008).

In accordance with the EPA guidance (Brungs and Jones, 1977), criteria are constructed by assigning thermal threshold values for spawning and incubation to the months when these life stages occur (for the most-sensitive species), and then assigning the values to protect growth and survival of juvenile and adult life stages to other months (again, for the most-sensitive species). Unfortunately, implementing EPA's approach to establish life-stage-specific temperature criteria may not be workable for most Nevada waters for one main reason: There is limited information available on spawning locations for most waterbodies in Nevada. Without such information, one would need to assume that spawning occurs throughout the waterbody; however, this could result in overly restrictive criteria for some reaches.

Perhaps the more difficult factor with EPA's seasonally variable is identifying the timing of spawning and incubation. Limited information is available on the timing of fish spawning in Nevada waters. One option could be to estimate spawning and incubation timing based upon a literature review, however, there are some significant problems with this strategy. Fish spawning is typically cued by certain environmental conditions, such as temperature, streamflow, and length of daylight (Whitehead et al. 1978; Bjornn and Reiser, 1991; Idaho Deparment of Environmental Quality, 2002); resulting in spawning for a particular species occurring at a different times in different streams located at different latitudes and elevations. For example, a diverse collection of streams in the Tennessee Valley was found to have spawning commencement dates varying by as much as 22 to 65 days (National Academy of Sciences, 1973). Idaho Department of Environmental Quality (2002) presents cutthroat trout spawning at starting dates ranging between March and May for streams in Idaho and the surrounding area, and spawning ending at dates ranging between May and July depending upon the characteristics of each stream.

Not only can spawning periods vary from stream to stream, spawning activity can also vary within a given waterbody from year to year due to annual variations in flow conditions and weather. An examination of temperature data for the East Fork Carson River near the Nevada-California stateline suggests that the time

[1] For those species in Nevada, EPA's acute recommendations for juvenile and adults are 1 to 11 °C higher than the spawning and embryo survival recommendations.

of year when rainbow trout spawning might be "triggered" (assuming a trigger temperature of 9°C as a weekly average per Brungs and Jones, 1977) can vary by as much as 100 days from one year to another.

Given the challenges with defining spawning locations and timing, two main methods are suggested for developing temperature criteria depending upon the information available for a given waterbody.

Method 1: Method 1 is applicable for streams with detailed knowledge of the location and timing of spawning and incubation. With Method 1, thermal threshold values from Tables 1 and 2 are used to develop acute and chronic temperature criteria for juvenile and adult stages. The thermal threshold values in Tables 3 and 4 are used to develop criteria specific to locations and dates of spawning and incubation. It is likely that Method 1 will rarely be used because most Nevada waters have limited information on the location and timing of spawning and incubation. In instances where Method 1 is applicable, it may be appropriate to perform a literature review to confirm (or revise as necessary) the thermal threshold values presented in Table 3 and 4, prior to their use.

Method 2: Method 2 is applicable for streams for which there is limited knowledge of the location and timing of spawning and incubation. With Method 2, acute and chronic temperature criteria for the protection of juvenile and adult fish are developed using thermal threshold values from Tables 1 and 2, and are assumed to apply throughout the year. To maintain a "natural" temperature regime throughout the year, a change in temperature (i.e., "delta T" or "ΔT") criterion should also be assigned to the waterbody reach or segment, as needed[2]. The ΔT criterion is often specified in discharge permits to minimize temperature changes due to permitted discharges into a waterbody.

For both of the above methods, the selected acute and chronic criteria are to be defined as daily maximum temperatures (also referred to as DMT) and weekly (7-day) average of daily average temperatures (also referred to as WAT), respectively. For bull trout, only acute criteria are to be set and should be defined as weekly average of daily maximum temperatures (also referred to as WMT) limits.

For either Method 1 or Method 2, the criteria for a waterbody segment are always driven by the most sensitive fish species. For instance if both rainbow trout and Lahontan cutthroat trout (LCT) both populate a given stream, the criteria should be set based upon the more sensitive needs of the LCT. The following footnote could be assigned to the LCT criteria for streams that lack an existing LCT population but have been identified as having the potential for reintroduction of LCT:

Criteria apply when Lahontan cutthroat trout are present.

Special Situations: Some special situations may need particular attention when developing appropriate acute and chronic criteria. For example, NDEP may wish to consider changes in the beneficial uses due to natural and anthropogenic causes (irrigation flow diversions, naturally higher temperatures for lower elevation sites, etc.). Criteria for waters with beneficial uses ranging from coldwater, seasonal coldwater to warmwater fisheries may be helpful to manage water quality in some waterbodies. However, it may be challenging to develop criteria for those coldwater-to-warmwater transition areas due to the lack of guidance.

[2] A majority of the waterbodies currently named in the NAC have ΔT criterion. New waters will need ΔT criterion to protect a natural temperature regime.

Some waters may be stocked with coldwater fish that are not expected to live throughout the summer. For these seasonal fisheries, judgment may be needed to assign appropriate summer maximum criteria that could differ from values in Tables 1 and 2. It may not be necessary to set chronic temperature criteria for put-and-take fisheries. Chronic criteria (WAT, weekly average temperature) are designed to support the growth of the fish. Put-and-take fisheries may be managed such that growth and long-term survival of the fish are not anticipated.

Attainability of Temperature Criteria

One of the issues often encountered when establishing water quality standards (i.e. criteria for specific beneficial uses) is the question of whether or not the proposed standards are reasonably achievable. In fact, Nevada Revised Statutes (NRS 445A.521(2)) require water quality standards be reasonably attainable:

> *The commission shall base its water quality standards on water quality criteria which numerically or descriptively define the conditions necessary to maintain the designated beneficial use or uses of the water. The water quality standards must reflect water quality criteria which define the conditions necessary to support, protect and allow the propagation of fish, shellfish and other wildlife and to provide for recreation in and on the water if these objectives are reasonably attainable.*

Attainment of temperature criteria may be challenging for some streams, due to irrigation diversions, natural variations in flow, natural gradients in temperatures from the headwaters to the downstream reaches, for example. It may not be possible to achieve the criteria throughout the full length of a stream; particularly the lower reaches of a stream. Although the mountain headwaters of a stream may have been identified as supporting trout species, the same temperature criteria are not achievable when the stream reaches lower elevations. Some stream reaches may contain both warmwater and coldwater fish; however, it may not be realistic to expect that the more restrictive coldwater temperature will be met in the lower elevation, downstream reaches.

Some general observations regarding attainability of temperature criteria can be made from the available data. An analysis of detailed temperature data for 240 monitoring sites on more than 120 stream segments across northern Nevada shows that Maximum Daily Maximum Temperatures (MDMT) and Maximum Weekly Average Temperatures (MWAT) generally decline as elevation increases (Figures 4 and 5). An analysis of NDOW fishable waters (Figure 1) indicates that approximately 75% of the streams identified as "coldwater species only" are located at 5,500 feet or higher (Figure 6). For those streams at and above 5,500 feet elevation, Figures 4 and 5 suggest that compliance with potential acute and chronic temperature criteria for brook, brown and rainbow trout is generally achieved. However, attainability of the recommended temperature criteria is highly variable from waterbody to waterbody, and is best determined on a site-specific basis.

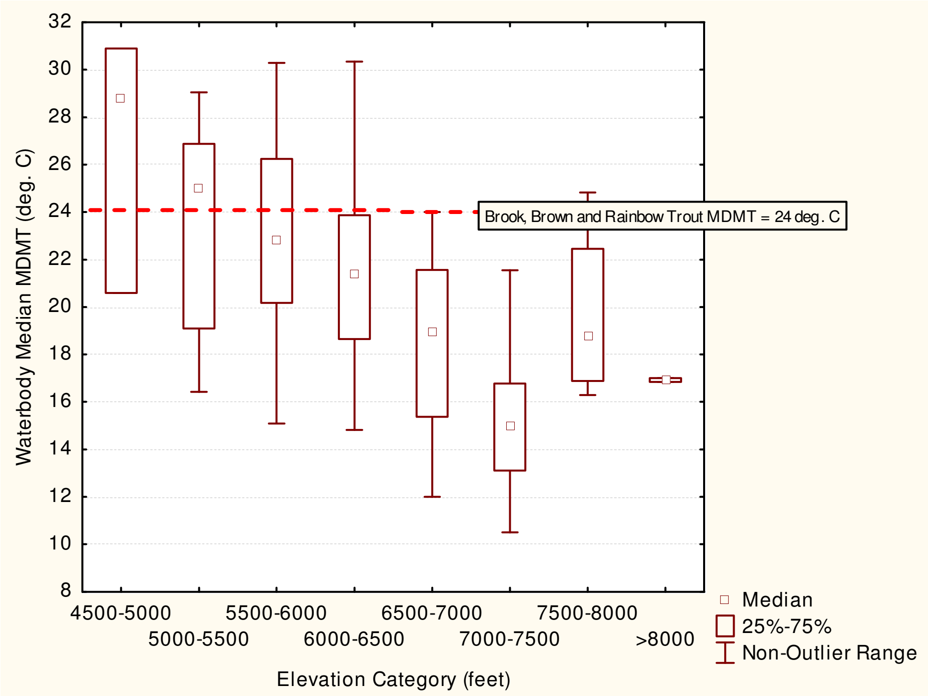

Figure 4. Waterbody Median MDMT and Elevation for Selected Streams

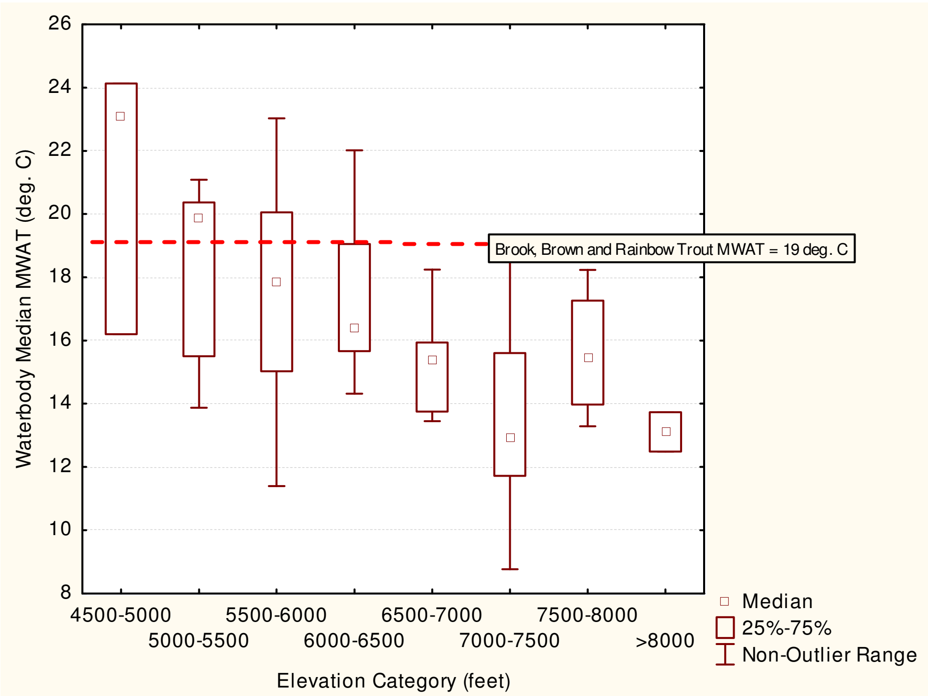

Figure 5. Waterbody Median MWAT and Elevation for Selected Streams

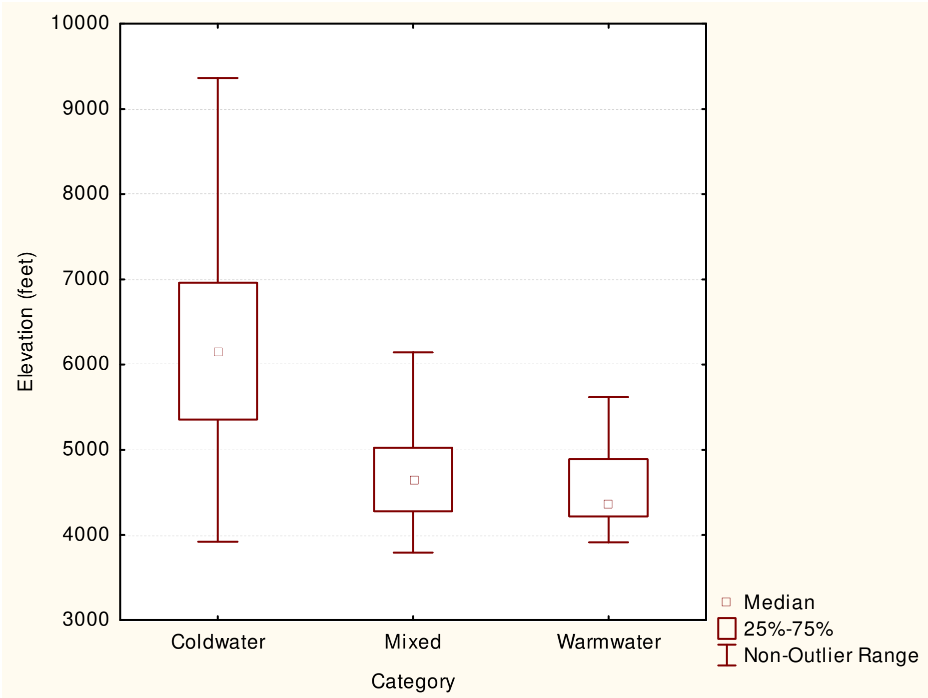

Figure 6. Elevation Distribution of Coldwater, Warmwater and Mixed Fisheries Streams Depicted on NDOW Fishable Waters Maps

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