Article

The impact on coldwater-fish populations of interpretative differences in the application of the United States Clean Water Act 1972 by individual State legislatures

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Abstract

The United States Clean Water Act (CWA) is one of the key legal means in the USA to 'restore and maintain the chemical, physical and biological integrity of the nation's waters'. Given the pervasive influence of human development and associated climate change in increasing water temperatures in streams of the USA, salmonids are particularly susceptible to reduction in productivity and geographic distribution. Native and introduced, self-sustaining salmonid populations can be found in most of the 50 States of the US. Despite this commonly shared resource, the highly similar temperature sensitivity among salmonids, and the legal imperative under the CWA to provide full protection to the most sensitive uses, the States supporting these thermally sensitive species have adopted a wide range of standards. As these standards are so divergent, even though the protection goal under the CWA applies uniformly to all States, it is clear that water temperature standards have been developed under conflicting interpretations of the best science available or there is a misunderstanding of the level of protection needed. The current EPA Gold Book guidance for development of protective standards, dating from 1973, still recommends the use of MWAT (maximum weekly average temperature) as a means of assigning protective chronic temperature standards to coldwater fisheries. MWAT, applied according to EPA guidance, is typically used in conjunction with an acute upper limit. From its inception, evidence was available to show that MWAT was inadequate to protect against chronic thermal impairment. This review of temperature standards, applied across the 50 States, collectively reveals a set of ecologically based principles that can be extracted from available standards and would provide a better measure of protection. It is deduced that standards might better apply to optimum temperatures for each life-history stage to protect against chronic thermal effects. These should include: geographic identification of core spawning and rearing areas; recognising cumulative warming from multiple sources; a limit on rate of warming or cooling; special standards for salmonids with exceptionally lower specific temperature requirements, requiring natural thermal patterns on a daily, seasonal, and annual cycle; and regulating

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the frequency of exceedence of standards on a multi-year basis. The diverse temperature standards found in the statutes of individual States to protect fish species with highly similar biological requirements are indicative of the failure of States to provide consistently high levels of protection and of the EPA to ensure State application of the best science through its standards approval process. In addition to appropriate standards, monitoring, listing of streams as water quality impaired, and development of restoration plans are essential to the success in protecting the coldwater fish resource.

Keywords: Water temperature standards; US Clean Water Act; salmonids; maximum weekly average temperature; chronic temperature; incipient lethal; balanced indigenous population; natural thermal potential; growth optimum; biocriteria.

Introduction

The United States Clean Water Act (CWA) is one of the key legal means in the USA for the protection and restoration of water quality on all US waterbodies. Among its most commonly cited goals is to 'restore and maintain the chemical, physical and biological integrity of the nation's waters' (33 USC §1251); to provide full protection of the existing uses (40 CFR §131.12, see EPA, 2010); and to direct protection to the most sensitive use (40 CFR §131.11). Implementation of the CWA has progressed from monitoring merely the chemical and physical properties of water to full biotic monitoring. Initially, there was an implicit assumption that provision of suitable chemical and physical water-quality conditions would support high quality biotic communities and allow them to flourish. It was then recognised slowly that sub-lethal biotic effects from chronic water-quality conditions, effects of combinations of water-quality stressors, or intermittent acute effects that are overlooked in periodic sampling, can all lead to impaired community structure and loss of sensitive members of the community, despite the apparent suitability of the chemical and physical conditions. This situation led to the inclusion of biomonitoring with conventional water-quality monitoring as a means of ensuring that pollution from point and non-point sources does not impair aquatic resources and dependent terrestrial natural resources (Environmental Protection Agency, 2002). Biotic indices make sense as an integrative standard because they reflect the bottom-line issue – the health of the ecosystem revealed through the cumulation of all spatial and temporal water quality and environmental effects. In terms of the water temperature aspect of water quality, States may have some combination of quantitative water temperature standards, narrative (qualitative) standards, or associated criteria such as biocriteria, presumed to be closely linked with water temperature.

A review of Behnke's (1992, 2002) excellent books on the distribution of North American native trout species provides a clear demonstration of the widespread occurrence of salmonids within the USA. In addition, the advent of the Endangered Species Act (ESA) listings of salmon in the Pacific Northwest in 1991 has prompted a heightened awareness of the influence of anthropogenic effects of all types, and water temperature in particular, on increasing the risk to maintenance of these fish species in California and the Pacific Northwest. Urban and industrial development and land use in watersheds provide a ubiquitous thermal effect on streams and challenge the continued survival of coldwater fish (native and introduced) in the USA. This threat is common to these species in all developed watersheds within their worldwide ranges.

Regulation of water temperature in each member of the United States is a State responsibility that comes about via development and implementation of each State's water-quality statutes, which lay out specific standards. The US Environmental Protection Agency (EPA) delegates this authority to individual States but retains its authority to approve State standards as they are proposed and ensure that they meet or exceed the EPA federal standards

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(33 USC §1313). The EPA sets the goals for water temperature protection and provides guidance for how to achieve these goals, but allows States to apply the advice as is appropriate in each case. This situation is similar to the federalist structure presented by the European Union where EU directives are converted to national laws that are enforced by individual member countries (Rechtschaffen, 2007). The European Union Water Framework Directive (European Commission, 2000) has goals similar to those of the CWA. The goals of this framework can be summarised as calling for good ecological status of surface waters of EU member countries by 2015 (European Commission, 2008).

The level of protection provided to salmonid populations varies among States. For example, common scenarios are that State water temperature standards are now out of date and need revision, or have recently been revised but are not necessarily based upon the best available science, or they are based on criteria that do not aim to achieve high levels of protection. A State might adjust its forest or agricultural practice rules to be consistent with the intent to achieve water temperature standards. Despite this, there can be inconsistencies between effectiveness of BMPs (best management practices) for forestry or agricultural practices, and water temperature standards in either the predicted recovery endpoint to be achieved (i.e. failure to apply those scientifically based practices adequate to meet standards) or the length of time needed to achieve the endpoint at the rate of planned restoration (failure to implement effective controls in a timely, comprehensive manner). The implication of these two failures in applying BMPs is that endangered fish may be subject to inadequate water temperatures for decades before either qualitatively or quantitatively sufficient BMPs are applied.

Each State is challenged by the CWA to conduct reviews of its water quality regulations to ensure that the intent of the CWA is met. What is clear, however, from my experience in monitoring or aiding the development of water quality (especially water temperature) standards, is that there are very different interpretations among practitioners about what is required by the law. Given the latitude allowed by individual States to develop their own standards and the vagaries of federal oversight and approval in this process, it is little wonder that State standards become inconsistent in application of best science and adherence to goals of the law. This situation suggests that because most States of the USA are charged with protecting coldwater fish, there is a need to review key technical and legal aspects of this challenge.

The objectives of this paper are to:

1. review the history and goals of the CWA;
2. highlight key problem areas in the application of the CWA to coldwater fish protection and future consequences of these weaknesses;
3. examine the extent of the coldwater fish distribution across the USA and the consequent need for protecting coldwater fish;
4. assess the diversity of water temperature standards provided by each of the 50 States for protection of the coldwater-dependent fish;
5. assess whether the goals of the CWA to protect sensitive species are addressed uniformly.

It seems likely that thermal degradation of streams supporting coldwater species would result in a marked effect to overall fish distribution patterns because of downstream cumulative thermal effects. Consequently, a review of the technical and legal basis for protecting coldwater fish species and maximising their natural distribution range should provide a window to human effects on distribution patterns of the full range of fish communities in-stream systems.

Methods

Fish distribution

Mapping of the coldwater fish distribution for the USA was based principally upon the USGS (2007) NAS (Nonindigenous Aquatic Species) database. This database provides maps of native and non-native species distributions by State, HUC (Hydrologic Unit Code) 2, 6 and 8, and tabulated for specific waterbodies. Tabulated data for non-native introductions listed the waterbodies stocked, the date, and whether the stocking resulted in 'established populations'. Reported entries stating that

a species was collected since 1975 or that the species was established since 1975 were taken as evidence that stocking resulted in a self-sustaining population. Because this review is focused on lotic coldwater species, stocking activities in lakes alone were not taken as evidence of a successful introduction, except when spawning would typically be assured in streams flowing into or out of the lake (e.g. coho, sockeye). Coldwater species that are typically associated only with lakes were not considered (e.g. lake trout). Supplemental fish distribution information was obtained from a variety of sources, including: Behnke (1992) and Behnke (2002) for North American trout; EBTJV (2006) and Hudy et al. (2005) for eastern brook trout; Osburn et al. (1930); Argent et al. (2002); Alaska Department of Fish and Game (2006); and Hocutt & Wiley (1986). If a coldwater fish species was native to a State and an existing use by 1975, the species was recorded as native and no introductions were considered. However, if the species is not native but species introductions occurred via stocking programmes, those cases were recorded where there was evidence of a self-sustaining population in stream habitats that had been in established use since 1975.

GIS (Geographic Information System) mapping of land use

Geographic Information System technology was used to characterise watersheds, often considered as reference sites with regard to thermal conditions and fish distribution, in order to estimate the potential influence of land uses, such as road development, on water temperatures. Calculations of road densities were made by the CRITFC (Columbia River Inter-Tribal Fish Commission, Portland, Oregon) GIS staff, using the highest resolution hydrography layers available (1:100 000 or 1:24 000), stored at StreamNet Library (www.streamnet.org), Portland, Oregon. Road layers for the Clearwater River and Salmon River were also compiled from the combination of Tiger roads layer (US Census Bureau, obtained from Environmental Systems Research Institute (ESRI)) and road data from the Nez Perce and Clearwater national forests of Idaho (both forest roads and unclassified roads), which provided the most extensive road network available. Watershed boundaries were obtained from USGS HUC 5 or 6 mapping. ArcMap (ESRI) and XTools were used as the GIS computer programs for computing road density, watershed area and stream lengths.

State water quality standards

Water quality standards (WQS) for each of the 50 States of the United States were obtained from the respective State water quality agencies in December 2009. Data were compiled from these documents, which provided the quantitative or narrative standards for maximum temperature limits for coldwater fish species. In addition, standards were recorded on a spreadsheet for any criteria that pertained to spawning, rearing, adult migration, special standards for highly sensitive coldwater fish, allowable temperature increases, whether criteria exist for cumulative temperature increase, rate of change permitted and whether criteria exist for natural thermal regimes (diel or seasonal fluctuation patterns). EPA's 305(b) reports for each State, which are accessible on the Internet (EPA, 2011), were used to compile a picture of the effort applied by States to water quality monitoring and water temperature monitoring, specifically. Data were extracted from each individual State report, covering in each case the total mileages of streams, the total mileage surveyed, the total mileage threatened or impaired and the total with temperature impairment. These data were then used to calculate the percentages of river lengths surveyed and impaired in each State. The comparisons may be misleading because the methods used by individual States to extrapolate water quality are dissimilar. If a State uses very small assessment units and does not expand the impairment to upstream units, there would be an apparent small degree of impairment. In addition, the 303(b) reports submitted to EPA by States every two years can vary by presentation of stream survey data either cumulatively or as a summary of the past two years. The 303(b) report summaries were compiled by selection of the reports carried out in 2002, 2004, 2006 or 2008 that had the greatest

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amount of miles surveyed and also recorded water temperature impairment, if observed.

The Clean Water Act

Purpose of the CWA

Protection of coldwater fish species via application of WQS, as well as the protection of all other aquatic biota, takes place under the CWA. Under this Act, each State is required to develop and implement State statutes for the full protection of the beneficial uses designated for each stream in the State. Water quality criteria for protection of aquatic resources have been characterised as the basis for maintaining streams to be 'fishable and swimmable'. In recent years, application of physical/chemical criteria has often been supplemented with biocriteria for aquatic resource protection (Karr et al., 2003). This addition was due to recognition of aquatic community health as a significant concern (Karr, 1981, 1990, 1991, 1995). Various biotic indices have been developed to identify reference conditions against which to contrast the current condition of aquatic communities in developed streams. Not all effects on water quality are attributable to modified water temperature. Widespread effects have occurred in streams in the USA from headwaters to downstream zones from cumulative actions of all combined sources of perturbation. The aquatic communities often reflect the effects of regional levels of acid rain, lead or mercury deposition, fire suppression and other effects, even in streams that have been minimally entered directly. Livestock grazing in western wilderness areas is common and is likely to have established new template conditions (i.e. those that are considered reference conditions for highest quality waters). Invasion of streams by exotic species often alters the native fish community composition. Consequently, identification of unperturbed reference states is often simply a matter of selecting the best or least perturbed (Mebane et al., 2003; Hughes et al., 2004; Van Sickle et al., 2006) of what remains in any particular ecoregion to provide a relative comparison. For this reason, as useful as biotic indices are for establishing biotic expectations of high quality streams, it remains important to maintain use of quantitative temperature criteria for protection of fish communities and restoration of the template upon which historic communities can be re-established. If temperature records are unavailable for historic conditions, but we are aware of historic fish distributions to some extent, we can employ optimum temperatures for life stages to establish biological targets. More site-specific targets can be suggested by use of state-of-the-art temperature models, such as that by the Oregon Department of Environmental Quality (ODEQ) (Boyd & Kasper, 2003; ODEQ, 2004).

Full protection of the beneficial use

It is often indicated that the beneficial uses will be fully protected. Each State 'shall assure water quality adequate to protect existing uses fully. Furthermore, the State shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable BMPs for non-point-source control' (40 CFR §131.12, see EPA, 2010). This statement raises the question of what is actually meant by full protection. The EPA (1985) stated that 'no activity is allowed that would 'partially or completely eliminate any existing use whether or not that use is designated in a State's WQS.' Species must be protected even if they 'are not prevalent in number or importance'. In order to provide full protection, the 'water quality should be such that it results in no mortality and no significant growth or reproductive impairment of resident species' (EPA, 1994). When designating uses of a waterbody, each State is required to 'ensure that its water quality standards provide for the attainment and maintenance of the water quality standards of downstream waters' (40 CFR §131.10, accessed April 2009). The species present do not need to qualify as sport or commercial fish in order to receive full protection (EPA, 1994). In fact, the protection of aquatic invertebrates or plants is a sufficient justification for the full protection of the water quality needed to achieve full protection of the 'aquatic life'. In addition, Federal Water Pollution Control Administration Section 304(a)(1) (FWPCA, 2002) states that the EPA 'shall develop and

publish criteria for water quality accurately reflecting the latest scientific knowledge: (A) on the kind and extent of all identifiable effects on health and welfare including, but not limited to, plankton, fish, shellfish, wildlife, plant life…and (C) on the effects of pollutants on biological community diversity, productivity and stability…'. These statements imply a broad concern for biotic integrity and maintenance of high levels of survival and fitness.

A history of water quality criteria

Water quality standards for the USA have their origin in the Water Pollution Control Act of 1948, followed by a modification to this Act in 1956. The 1948 Act was designed to reduce water pollution in this nation's rivers, primarily through the construction of water treatment plants. It was the primary responsibility of States themselves to establish standards. The Ohio River Valley Sanitation Commission (ORSANCO, 1956; as cited by Brungs & Jones, 1977) prepared some of the first temperature criteria for aquatic life. They recommended simple upper temperature limits that were applicable to all locations and seasons. They also called for no allowable temperature increases in trout waters. The Water Quality Act of 1965 directed States to develop WQS for interstate waters. In 1967 ORSANCO improved its criteria to include specific temperature recommendations by season. For example, for trout protection it recommended a maximum of 20 °C in summer and of 12.8 °C during the fall to early spring spawning and incubation seasons (Brungs & Jones, 1977).

After publication of the ORSANCO criteria, the NTAC (National Technical Advisory Committee) was constituted by the FWPCA (Federal Water Pollution Control Administration) to develop new water quality criteria under the Federal Water Quality Act of 1965 (PL 89-234). These criteria were published in 1968 as the Green Book and established criteria as thresholds, below which designated uses are considered to be protected. These criteria were the first to suggest that seasonal temperature cycles must be maintained, that changes must be gradual and that temperature extremes must be within high and low bounds to protect population composition. It was further recommended that trout streams should not be warmed and that no heated effluents should be discharged in spawning areas (Brungs & Jones, 1977). The suggestion that heat increments be limited to the extent that the temperature increase at minimum daily flow for each month is no greater than 2.8 °C (meaning that at higher daily flows the temperature increment would be lower) was misconstrued to imply that a 2.8 °C increment could be assumed to be always unharmful (Brungs & Jones, 1977).

The FWPCA recommended these new criteria to ORSANCO in 1969 for protection of mainstem Ohio River fish, giving consideration to survival, activity, final preferred temperature, reproduction and growth. Daily mean temperatures and hourly maxima were recommended by month to protect the most sensitive species. By 1970, all States had adopted standards to protect intrastate waters, as directed by the Water Quality Act (EPA, 2006a).

On 2 December 1970 the EPA was formed, replacing the FWPCA. In 1971 the EPA created a Committee on Water Quality Criteria under the NAS/NAE (National Academy of Sciences/National Academy of Engineering) to revise and update the 1968 NTAC report. The NAS/NAE committee produced its Water Quality Criteria 1972, which was released in 1973 as the Blue Book (EPA, 1973). The chapter on Heat and Temperature, authored by Coutant, became the temperature criteria for this document (Brungs & Jones, 1977). This new publication brought together the seminal works of Fry and Brett and new research on thermal biology. It developed techniques for maintenance of growth rates (chronic effect index), reproductive function, winter survival and protection against short-term exposure to extreme temperatures (critical effects). Chronic effects, under these new guidelines, were reportedly prevented by application of the MWAT (Maximum Weekly Average Temperature) calculation. The FWPCA Amendments of 1972 added end-of-pipe TBELs (Technology-Based Effluent Limitations) to protect water quality to the pre-existing ambient in-stream WQS (BLM, 2008). However, in the process of writing an NPDES (National Pollutant Discharge Elimination System) permit, if it is determined that the TBELs will

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be insufficient to meet the criteria, then a WQBEL (water quality-based effluent limit) is imposed (EPA, 1996).

In 1976 the EPA published its Red Book, entitled *Quality Criteria for Water* (EPA, 1976), which incorporated into its temperature control criteria the recommendations of the NAS/NAE temperature panel. These temperature criteria were soon amplified in an EPA document entitled *Temperature Criteria for Freshwater Fish: Protocol and Procedures*. This document is commonly cited as Brungs & Jones (1977). It repeats the Heat and Temperature chapter of the EPA (1973) report as Appendix A and the thermal tables for individual fish species from the same report as Appendix B.

The FWPCA Amendments of 1972 (P.L. 92-500) formed the basis of our existing water quality criteria. These amendments established a national goal of restoration and maintainance of the chemical, physical and biological integrity of the nation's waters. The Act also required point-source limits, identification of non-point-source (NPS) pollution and a water quality inventory (305(b) report). The CWA of 1977 (P.L. 95-217) and the Water Quality Act of 1987 (P.L. 100-4) significantly enhanced the FWPCA criteria. Section 316(a) expresses the intent that any point-source thermal discharge should be required to ensure protection and propagation of a balanced, indigenous population (BIP) of shellfish, fish, and wildlife on the water body. However, the legislative intent for the CWA expressed by Senator Muskie was one of restoration of aquatic ecosystems that existed prior to the introduction of pollution from human activities (EPA, 2003a). Maintaining the BIP, as required in CWA Section 316(a), is also not consistent with allowing a community shift from thermally sensitive to thermally tolerant species (EPA, 2008). One might think that this emphasis would confirm the need to prevent the cumulative upward shifting of thermal regimes by an endless series of variances, whereby each new increment can be argued to be *de minimis* with respect to all prior cumulative effects. Such a deviation in thermal characteristics of a waterbody would lead to a progressive shift in the balance between tolerant and sensitive species. Unfortunately, Section 316(a) is essentially a variance provision in the CWA that permits thermal discharges by thermoelectric facilities and sidesteps TBELs and WQBELs provided they simply ensure protection of the BIP. Cross-purposes, such as this expressed in the CWA, emphasise how the Act often provides a conflicting intent that thwarts its central ambitions (see McCullough, 2010).

Section 304(a) (1) of the CWA requires the EPA periodically to update its water quality criteria. A recent revision to the Red Book was released by EPA as the Gold Book, under the title *Quality Criteria for Water, 1986*. The Gold Book (EPA, 1986) incorporates the same temperature section as the Red Book despite the requirement to periodically update its guidance to reflect the most recent science. The EPA (2006b) provides citations to the current guidance on all water quality criteria. Its guidance on water temperature states that the Gold Book provides current suggested criteria and supplements this information by reference to the Red Book and Brungs & Jones (1977). Given that the Gold Book guidance on temperature effects is still the existing national guidance, it has not been revised to incorporate new science for nearly 40 years.

The CWA specifies in Section 303(c) that States will designate uses for all waterbodies. Designated uses can either be existing uses or higher quality uses. These may include recreational use, coldwater fisheries, agriculture or numerous other uses. Existing uses are those uses attained on, or after, 28 November 1975 (EPA, 1994). Antidegradation requirements were imposed on all States under EPA regulations (40 CFR § 131.12, see EPA, 2010) and are based on the CWA goal to 'restore and maintain the chemical, physical and biological integrity of the Nation's waters' (EPA, 1994). States have applied Tier 1 protection as the minimum level protection to all waters, whereby existing uses are expected to be fully protected. If these waters are already somewhat impaired, there is a presumption that existing uses will be maintained, but that waters can also be restored. Tier 2 protection is to be applied to high quality waters. If water quality under Tier 2 is higher than necessary to protect the existing uses, a *de minimis* reduction in water quality would be permitted only after a review that showed that development was necessary, the existing uses would be fully supported, and the highest regulatory controls for point sources and cost effective and reasonable BMPs for nonpoint sources

are applied. Unfortunately, it is a State prerogative to apply either mandatory or voluntary NPS controls (EPA, 1994). Tier 3 waters are Outstanding National Resource Waters (ONRW) and receive the highest level protection under the antidegradation policy (EPA, 1994). In general, no lowering of water quality is permitted under Tier 3.

Water quality standards define the water quality goals of a waterbody by designating its use(s), the criteria necessary to protect the use(s) and the means of ensuring that the use(s) may be maintained. The standards are designed to meet the 'purposes of the Act', in which it is interpreted to mean:

1. restore and maintain the chemical, physical and biological integrity of State waters;
2. provide, wherever attainable, water quality for the protection and propagation of fish, shellfish and wildlife and recreation in and on the water ('fishable/swimmable');
3. consider the use and value of State waters for public water supplies, the propagation of fish and wildlife, recreation, agricultural and industrial purposes and navigation (EPA, 2006a).

Water quality standards are needed in:

1. setting water quality goals for waterbodies;
2. calculating TMDL (Total Maximum Daily Load), waste load allocations for point sources and load allocations for non-point sources;
3. permitting by federal agencies (e.g. FERC or Federal Energy Regulatory Commission, NRC or Nuclear Energy Regulatory Commission) where a Section 401 water quality certification is produced for actions that may result in discharge with a potential to affect water quality;
4. developing water quality management plans necessary to attaining water quality goals for a waterbody;
5. calculating NPDES WQBELs for point sources (EPA, 2006a).

In addition, Section 303(c) requires that standards '*enhance* the quality of water and serve the purposes of this Act' (FWPCA, 2002).

Under existing law, correction of point source and non-point source thermal pollution should be prescribed by each State setting the standards relevant to the protection of biota in its waterbodies and these standards being approved subsequently by EPA; in the case of a waterbody having water quality not adequate to support its designated use, it is considered to be of impaired quality under the 303(d) provision of the CWA and requires a TMDL analysis to be conducted to establish permissible thermal load allocations (LA). Thermal restoration under a TMDL is designed to address both point-source waste load allocations (WLA) and non-point source LA (EPA, 1996).

Numerous weak links exist in the current State processes that thwart the sequence of steps in developing technically adequate water temperature standards for the development of TMDLs. For example, even though required to review its WQS only every three years (CWA §303(c)(1)), a State typically chooses only some selected standards to revise. If water temperature standards do not exist or are not part of a current triennial review, the EPA does not have the opportunity to rule on the adequacy of a standard to protect the use. For example, Idaho retains its old standard for bull trout protection because it has not reviewed its water temperature standard, despite the fact that Oregon and Washington adopted a more sensitive standard that was preferred by EPA Region 10 for its technical adequacy (McCullough, 2010). Of more concern, many States, such as Maine, never established water temperature standards in the first place. Other States have standards that are particularly ill-advised for coldwater fish protection. This paper will review the diversity of responses to coldwater fish protection through quantitative water temperature standards. The wide range of standards used to protect the same, or highly similar, species indicates a discrepancy between best available science and standards used in fish protection.

Protection of existing ONRWs (Outstanding National Resource Waters) under Tier 3 antidegradation can theoretically compel maximum protection against degradation and serve to protect high quality salmonid waters. Unfortunately, such designations are most often reserved by States for waters that are already named as

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Wild and Scenic, or are designated as wilderness or critical habitat for ESA-listed species. Wild and Scenic waters may have more value for scenic or recreational use, or maintenance of water quality for downstream uses, than for fisheries. A high level of protection is typically given to federally owned waters designated as critical habitat under the ESA, although habitat and water quality protection and restoration on private lands has been weak and primarily reliant on voluntary conservation efforts that are slowly being supported by incentives (Bean, 1998; Buck et al., 2010; Paulich, 2010). Full protection of beneficial uses is typically assumed under general State water quality regulations, but this situation always involves a higher level of protection afforded to federal and State lands vs. private lands with regard to non-point-source thermal effects. Idaho has considered ONRW status for several high quality waters of the State, but has never legislatively designated any (IDEQ, 2007). The EPA has also never clarified what constitutes an ONRW (BLM, 2008) and States are afraid that if they designate a waterbody as an ONRW, the strict provisions against lowering water quality will be unacceptable at some point in the future (EPA, 1991). Unfortunately, the EPA does not see its legal authority as requiring it to designate an ONRW if a State fails to do so.

Under the water quality statutes of Oregon and Washington, temperature regulation in non-point source water on non-federal forested lands rests with State forestry practice laws that specify practices designed to meet WQS. It is assumed that by implementing these practices (BMPs), standards are met by definition or will be met provided the forest practice is continued for an indefinite period of time. This assumption carries with it the dilemma that once a basin management plan is implemented, no actual temperature violation might be reviewed for remedial action, because it can be assumed that the existing BMPs have not been employed for a long enough period of time. This process, therefore, allows a plan to comprise a set of ineffective actions that might generate stakeholder acceptance but will merely delay the rate of restoration from that known to be feasible. The effectiveness of the actions might not be fully evaluated prior to approval of the plan and might not apply best scientific knowledge. The actions also might not be adequately monitored after implementation, thereby limiting the usefulness of planning and adaptive management. Oregon provides a useful example of forest-practice effectiveness monitoring as a means of evaluating forestry BMP efficacy in meeting WQS (ODF & ODEQ, 2002).

In addition to weak links in State processes, the CWA has weaknesses that thwart it from achieving the Act's own goals. There is confusion in different parts of the CWA concerning the intended target species for a temperature standard and, consequently, the most meaningful biological monitoring program to confirm protection of water quality and attainment of the Act's goals (see above). Brungs & Jones (1977) indicated that balance in the fish community can be strongly influenced by the effects of temperature on reproduction, recruitment and growth. However, assessment of this 'balance' remains subjective. Consideration of a balance for selected indicator fish species representing coldwater to warmwater species in the same stream does not necessarily result in the same level of protection as afforded by addressing the thermal needs of the most high-temperature-sensitive components of the community (McCullough, 2010). Lethal effects were also cited by Brungs & Jones (1977) to be capable of shifting a coldwater fishery to a warmwater fishery. At the level of individual species, the biological significance of sub-lethal temperatures on population viability, through effects on specific metabolism, respiration, behaviour, distribution and migration, feeding rates, growth and reproduction, should be the guiding principle for protecting the most sensitive species in the community (Brungs & Jones, 1977). Brungs & Jones (1977) also noted that maximum temperatures should not exceed 20.0 °C during the summer months, in order to protect trout habitat. This comment appears to treat a coldwater fish community at the level of a guild.

In the CWA §316(a), there are provisions for variance-based thermal discharge limits in which a discharge permittee is required to demonstrate that their thermal effluent will assure protection and propagation of the BIP of fish, shellfish and wildlife in and on the receiving water.

EPA (2010, CFR or Code of Federal Regulations) regulations define the terms BIP and BIC (balanced indigenous community) as follows:

'[A] biotic community typically characterized by diversity, the capacity to sustain itself through cyclic seasonal changes, presence of necessary food-chain species and by a lack of dominance by pollution-tolerant species. Such a community may include historically non-native species, introduced in connection with a program of wildlife management and species whose presence or abundance results from substantial, irreversible environmental modifications. Normally, however, such a community will not include species whose presence or abundance is attributable to the introduction of pollutants that will be eliminated by compliance by all sources with section 301(b)(2) of the Act; and may not include species whose presence or abundance is attributable to alternative effluent limitations imposed pursuant to section 316(a).' 40 CFR.§ 125.71(c)

The 1977 guidance (EPA, 1977) further defines RIS (representative important species) as follows:

'Representative important species are those species which are: representative, in terms of their biological requirements, of a [BIC] of shellfish, fish and wildlife in the body of water into which the discharge is made. Specifically included are those species which are:

1. *Commercially or recreationally valuable (i.e. within the top 10 species landed by dollar value);*
2. *Threatened or endangered;*
3. *Critical to the structure and function of the ecological system (e.g. habitat formers);*
4. *Potentially capable of becoming localized nuisance species;*
5. *Necessary in the food chain for the well-being of species determined in 1–4; or*
6. *Representative of the thermal requirements of important species but which themselves may not be important.'*

RIS were intended to be a collection of species whose presence at a site could ensure protection of other species at the site (Coutant, 1975) and adequately represent an entire ecosystem or fish community. The problem with this viewpoint is that few aquatic communities are purely occupied by a single, narrow thermal guild. For example, most aquatic ecologists would agree that the Columbia River, in the Pacific Northwest, represents a coldwater habitat, but it is inhabited by numerous exotic species representing coldwater, coolwater and warmwater habitat preferences. Nonetheless, warmwater species, such as smallmouth bass, can be designated as desirable sport fish at the discretion of State fish agencies and managed as such, as in the Connecticut River (McCullough, 2010). In this case, warmwater species could become RIS according to State preference under EPA rules, which could result in attempts to 'balance' the needs of salmon and smallmouth bass. At a minimum, monitoring would be required to follow trends in bass populations with the intention of assessing the 'balance'. No quantitative indices of such balances between warmwater and coldwater species are given in EPA methodology, so in 316(a) demonstration projects conducted by power plant operators discharging heated effluent into rivers, the technical arguments supported by preferences for RIS and associated population monitoring can be highly subjective and open to broad interpretation. In reality, there is no way to select a single temperature standard that would fully protect both coldwater and warmwater species simultaneously. Adopting an average temperature spanning this range might support coolwater species fully and provide marginal support to coldwater and warmwater species, but this direction does not appear to be the intent of the CWA.

In 2001, The National Research Council recommended the use of biocriteria in conjunction with physical and chemical criteria to meet WQS. Biocriteria have great utility in assessment of the highest attainable use (EPA, 2003b) and act as a broad-based index to reference communities that represent physical habitats and water qualities that underpin high biointegrity. Karr's (1981) original work stimulated a continuing development of biocriteria (e.g. IBI or index of biointegrity) and eventual adoption of biocriteria into WQS in many States, with the EPA promoting adoption of biocriteria in water quality monitoring from 1990 (EPA, 1990, as cited by Karr et al., 2003). The development of biocriteria in the USA can be overviewed via an EPA Internet link (http://www.epa.gov/

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bioindicators/index.html) and in EPA (2003b). Even though many States are in the process of developing biocriteria, current levels of application to water quality standards vary considerably. IBI methods have been applied predominantly to small, wadeable streams (Hughes et al., 1998, Hawkins et al., 2000, Mebane et al., 2003). There have also been notable applications of IBI methods in large rivers (Simon & Lyons, 1995, Yoder & Kulik, 2003). The principal difficulties arising in the development of large-river IBIs include the problems inherent in sampling biota from large rivers and the almost complete lack of reference conditions pertaining to large rivers (Simon & Lyons, 1995).

IBIs are tailored for streams on a regional basis. Regions have been classified on the basis of the EPA ecoregion, watershed, geology, stream size, regional-level species diversity, or other features (Simon & Lyons, 1995, Hawkins et al., 2000). IBIs are composed of a set of metrics with regional expectations of a high-level fish community performance (i.e. high biotic integrity) typically associated with high habitat quality. These metrics express species richness and composition, indicator species, trophic function, reproductive function, abundance and fish condition (Simon & Lyons, 1995).

Karr et al. (2003) emphasised that fish IBIs are essential components of State water quality standards because mere compliance with State physical/chemical water quality criteria does not ensure protection of all fish life functions. Use of biocriteria would indicate watershed condition and provide early warning of community degradation linked to habitat degradation. Because streams can often meet WQS and yet have a degraded community condition detected by IBI, it is important to add biocriteria to the toolbag of standards to ensure effective restoration and maintenance of the chemical, physical and biological integrity of this nation's waters (Karr et al., 2003). One important reason for using biocriteria indices, such as IBI, is that pollutants can include biological pollution (e.g. exotic fish introductions) as well as physical and chemical pollution (Karr et al., 2003).

In 1986, the State of Maine was the first in the USA to adopt statutorily narrative aquatic life standards for each classified stream type by the Department of Environmental Protection (DEP) (Maine DEP, 1999). Numeric biocriteria have been refined over the period as they were first adopted by expansion of the aquatic life reference base within that State. Biological assessment is used to monitor attainment of narrative aquatic life goals for stream classes, status and trends in water quality, effects of point and non-point activities, and CWA §401 water quality certification. For Maine's class-AA waters, the goal is for high quality water for recreational and ecological interests, with a biological standard of 'aquatic life as naturally occurs', which means having 'the same physical, chemical and biological characteristics as found in situations with similar habitats, free of measurable effects of human activity'. Class-A waters have limited human interference and also the biological standard of naturally occurring aquatic life. Class-A waters permit some impoundment and very restricted discharges, so the risk of degradation, while quite small, may increase through modest human intervention in managing the ecosystem. The classes of freshwater rivers provide a hierarchy of degradation risk (Maine DEP, 2007). Quantitative indices of the responses of aquatic life in monitored streams are based on linear discriminant comparisons against communities of macroinvertebrates in reference streams set by the State (Maine DEP, 1999).

Maine has developed a programme of water quality standards based primarily on biocriteria, dissolved oxygen and toxic chemical levels (Maine DEP, 1999). Temperature standards do not exist for Maine and, consequently, no streams have been placed on the 303(d) list for temperature violations. The Maine DEP (2006) lists various factors used in the State to assure protection of aquatic life: biomonitoring numeric criteria, dissolved oxygen, ambient water quality criteria (which do not include temperature criteria), support of indigenous species, wetted habitat and general provisions (e.g. floating/settleable solids, pH, radioactive substances). Aquatic life concerns are often cited as a reason for listing (Maine DEP, 1998). It appears that Maine DEP assumes that elevated temperature is a factor fully subsumed by biotic indices. There is an apparent presumption in Maine's WQS that macroinvertebrate IBI criteria and dissolved oxygen assessment are sufficient to identify streams with degraded habitat conditions. However, despite the linkage between macroinvertebrate

community integrity and fish community integrity (Karr et al., 2003), one must ask the question whether community response indices are sensitive enough to register rapidly changing water temperatures that threaten to exceed thresholds of degradation. Specifically, is the linkage between community IBI value and water temperature precise enough to act as an early warning of irretrievable habitat degradation? In a region with a shifting reference community baseline or in a large river with no reference conditions for minimally perturbed status, it is important to know what the most direct indicator is of optimal conditions for the most sensitive species known to inhabit the stream. Oddly, Maine DEP (1999) considers traditional WQ standards as 'indirect' indicators. Yet biocriteria, in reflecting the integrated quality of physical habitat and water quality, do not discriminate causes of community response. Consequently, low IBI scores could reflect either poor temperature conditions or optimum temperature conditions, with other habitat factors causing the impairment. It seems perfectly sensible to include IBI metrics or multivariate analysis techniques for macroinvertebrates and fish in a comprehensive water quality criteria programme, but not to ignore obvious biological requirements for appropriate water temperatures and dissolved oxygen regimes. Given that water temperature can be measured precisely, it should be a criterion of first resort in protection of beneficial uses. If temperatures match the site potential, it follows that there should exist much of the required biological potential for full expression of site potential communities.

Interaction among land uses, water temperature and other aquatic habitat effects

When violations of water temperature standards lead to 303(d) listing of streams as impaired and subsequently to the TMDL process, a plan is then devised to address point and non-point-source thermal degradation at a basin scale. Basin-scale restoration of thermal regimes to protect fish populations can be modelled on estimates of natural thermal potential (NTP: thermal regimes distributed in the stream network simulating no anthropogenic degradation) or it can incorporate an allowable thermal increment above the NTP to accommodate human use. Uniformly distributed increments of allowable temperature increase on a river continuum naturally result in shrinkage in the distribution of targeted coldwater fish species (McCullough, 2010). The more conventional alternative is to apply a biologically based temperature standard, such as MWAT, in judging whether a particular temperature regime at a point in the stream will avoid chronic effects. A thorough evaluation of this scheme, however, reveals that maintenance of a fish population across a basin, taking account of historic species range requires meticulous modelling and monitoring of cumulative temperature increases, rather than application of a simple criterion such as MWAT on a site-specific basis. For instance, in order to meet a criterion such as MWAT in the historic downstream portion of a species' range, it will likely prove problematic to simultaneously adjust land uses in the upstream portion of the range to maintain the biological MWAT there as well.

Application of a basin plan to address basin-scale point and non-point-source thermal increases requires a full understanding of the linkages between land uses and water temperature alteration. The setting and monitoring of water temperature standards address this linkage directly. Land uses are also associated with habitat and water chemistry effects that can impair biological function. These effects can be modelled or monitored via a combination of water temperature models, habitat quality-population dynamic models, bioassessments that link biotic indices to overall habitat health, or comprehensive physical habitat status and trend monitoring coupled with comparison to reference stream habitat condition.

Fish populations in the USA are widely threatened by numerous causes of water quality degradation nominally considered under the CWA. These threats have been well documented in the scientific literature and can be associated with massive effects on riparian vegetation across the USA (NRC, 2002). They include agricultural developments, which represent the leading cause of riparian degradation across the country (NRC, 2002) and whose BMPs for water temperature protection are being addressed only slowly.

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Forest timber harvest, likewise, is a spatially extensive perturbation that frequently includes riparian harvest, especially in forested headwater areas that may be fish free, but are nevertheless tributaries to trout or salmon streams. Most timber harvest operations that do have rules concerning shade retention usually aim to retain some established minimum level that is claimed not to result in significant water temperature increases. However, resulting riparian stands on private or federal land managed in accordance with State forest practices rules, which permit widely varying riparian buffer zones and leave tree requirements, take on some characteristics that diverge from an unmanaged, site potential condition (Gregory, 2000). The forestry rules can result in a lower canopy height, a lower basal area, a smaller diameter LWD (large woody debris), lower volumes of LWD and a reduced shading of all stream sizes than would be typical of local potential. Small fish-bearing and fish-free streams that are tributary to fish-bearing streams across the USA tend to have lower targets for protection of riparian function, including shade protection, than do larger streams (e.g. Pollock et al., 2009). Large streams, however, have typically had a longer history of past degradation that resulted in significant species conversion and diminished function (NRC, 2002).

Mining activities often contribute sediment and toxic runoff that degrade fish populations and, in the process of filling primary pools with sediment, contribute to stream warming. Road building in watersheds provides access for all sediment producing watershed activities. Roads in riparian areas increase solar warming of the stream system by eliminating streamside vegetation, increase the rate of pool infilling from surface erosion, lead to loss of channel volume in the process of channelisation and rip-rapping to protect road beds, and increase the rate of interception of shallow groundwater and route it as warmed surface flows to stream channels. These processes all contribute to the finding that elevation of water temperature above natural potential temperatures in drainage water is related to road density (km km^{-2}) (Nelitz et al., 2007) and also the general level of forest or total riparian harvest within the past 40 years (Pollock et al., 2009).

Livestock grazing contributes to stream warming through bank damage, channel widening and shallowing, local sedimentation leading to pool filling and prevention of re-growth of riparian vegetation having the potential to provide significant shading (Rhodes et al., 1994). Water abstraction for irrigation poses a significant threat to US fish populations due to its dewatering of streams. Reduced flows lead to decreased buffering of thermal loading, decreased food production and supply, and an increased population density of fish competing for limited resources. Wetland elimination frequently reduces sources of cold groundwater supply to streams, while groundwater pumping in aquifers with subsurface connection to the hyporheic zone of stream channels can also cause stream dewatering, and consequently the stream might receive warmed return flows instead of receiving cold groundwater inputs.

Urban runoff from sewage systems and storm drains can contribute large volumes of heated water to streams (Poole & Berman, 2001) as can hydroelectric developments, through creation of reservoirs with extensive surface areas that collect high thermal loads. Lateral expansion of reservoirs into former floodplain areas can lead to broad zones where shallow, ponded water mixes less freely with flows along the thalweg and consequently heats up beyond the tolerance of fish species or age classes that typically relied on rearing in channel margins (Coutant, 1999). Lastly, power plants that use river water for electrical generation and cooling, discharge large volumes of heated effluent into US rivers.

The numerous sources of stream heating have caused significant, widespread deviations from historic thermal regimes. Such historic thermal regimes, reflecting conditions prior to significant human disturbance, have been termed the NTP (Poole et al., 2001a, b; Poole et al., 2004). The NTP constituted the thermal regime under which the native fish populations evolved. Given that air temperatures were relatively stable in the Pacific Northwest over the past 1000 years (IPCC, 2007), one can conclude that the water temperature regimes in streams in unmanaged watersheds provided a dynamically stable evolutionary environment until up to five decades ago, after which time

rapid air temperature increases have occurred. In the USA, fish populations are conceived of as occurring in distinct lengths of the river continuum (Vannote et al., 1980; Li et al., 1987) where they are arrayed typically longitudinally from cold headwater populations, mid-level coolwater populations, to downstream warmwater populations. Replacement of species along this continuum follows common patterns that are linked to individual thermal tolerance limits as well as species-specific adaptations to current velocity, substratum grain-size composition, water depth and food availability (type and abundance). Stream continua in the Pacific Northwest range typically from only cold water to cool water; those in other parts of the USA range from coldwater to warmwater zones although typical warmwater species introduced to western streams from the eastern USA have proliferated under conditions at the warmer end of the available spectrum. In the coldwater zone, the typical fish guild can be represented by numerous species. In the western USA it is common for this guild to be represented by bull trout in the coldest headwater areas, followed by associations with cutthroat trout, rainbow/steelhead, spring Chinook, summer Chinook and fall Chinook/chum/pink salmon in a longitudinal, overlapping succession downstream (Li et al., 1987). In the northeastern USA, the coldwater zone typically supports native brook trout and Atlantic salmon, while non-native coldwater species, are often represented by rainbow trout and brown trout (Behnke, 2002).

The species most sensitive to anthropogenic warming are best protected on a site-specific basis by maintaining optimal temperature conditions to the greatest extent feasible through regulation of point-source thermal discharges and restoration of natural processes affected by land use changes. Native fish communities at a basin scale arrayed on a river continuum can be best protected by adjusting thermal regimes to meet those typical of NTP. Basin-scale thermal management was implied in the 1973 guidance from the NAS/NAE (EPA 1973), although this critical management step is often overlooked when deferring to site-specific criteria such as MWAT.

The current EPA national guidance for water temperature criteria

Current EPA national guidance (EPA, 2006b) for water temperature still defaults to the EPA Gold Book (EPA, 1986). This guidance had its origin in a National Academy of Sciences methodology (EPA, 1973) for acute, time-dependent exposures and chronic or weekly average temperatures (i.e. MWAT) for various seasons, including the growth (summer) and reproductive (spring and fall) periods adjusted to local conditions. This guidance was later repeated in the Red Book (EPA, 1976) and then the Gold Book (EPA, 1986). The short-term acute temperature is time dependent. For a short-term exposure, the acute temperature recommended by the EPA Gold Book approach, as reflected in the paper by Brungs & Jones (1977) and by the EPA (1973), is equal to the UILT (Upper Incipient Lethal Temperature) minus 2 °C. The 2 °C figure is applied as a safety factor, but its efficacy is debatable if multiple exposures to thermal spikes are considered.

Chronic thermal effects were assumed to be protected against by ensuring that the physical MWAT measured in a stream did not exceed the calculated, biological MWAT (McCullough, 2010; also see below). Although the weaknesses in MWAT make it unsuitable as a means of setting a protective standard (McCullough, 2010), there are other parts of the Gold Book (EPA, 1986) that reflect the EPA (1973) content and that represent protective guidance. The EPA (1986) recommended that baseline thermal conditions be measured at a site that has no unnatural thermal additions from any source, while still being near the discharge in question, and having similar hydrography to the stream that receives a discharge. This situation indicates that there should be a greater emphasis on natural thermal conditions rather than simply ambient (potentially altered) conditions, which could allow each new point source to be additive to all other upstream sources. Among the biological functions needing thermal protection, the EPA (1973) cited various criteria for freshwater water temperatures (paraphrased):

1. maximum sustained temperatures that permit desirable levels of productivity;

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2. prevention of thermal shock;
3. regulation of exposure time to prevent mortality at high and low temperature extremes;
4. restricted temperature exposure for protection of reproduction, gametogenesis, spawning migration, release of gametes, embryo development, first feeding, juvenile development and behaviour, and fry emergence;
5. protection of entire aquatic communities;
6. thermal requirements of downstream aquatic life.

These criteria are all excellent and important considerations for full, comprehensive protection of freshwater fish resources, but are not often observed in State standards in any explicit or holistic sense.

The EPA (1986) literature regarding temperature indicates that the most sensitive life stages for each species vary by month. This ecological emphasis is also reflected in statements that note that thermal alterations to streams can cause shifts from coldwater to warmwater fisheries, because of direct lethal effects or indirect effects on growth, activity and reproduction (EPA, 1986). Small increases in temperature were attributed to the potential to advance spring spawn timing and delay fall spawn timing. Recently, clear confirmation of this type of effect has been established for sockeye and Chinook (Hodgson & Quinn, 2002, Robards & Quinn, 2003). The timing of migration and of arrival at the spawning grounds may affect productivity via reproductive success (Seamons et al., 2004). Despite the need to give special attention to the most sensitive life stages, the EPA (1986) noted that data are typically inadequate to assess quantitatively those organisms most affected by temperature. Such uncertainty should ideally lead to application of safety margins in any assessments, as sublethal thermal effects can impair a species' viability at many points during their life cycle.

The biological concepts that form the basis for current EPA guidance and that address the thermal needs of coldwater fish and aquatic communities are still robust. In contrast, the criteria for prevention of chronic thermal effects are in a serious need of revision. Maximum Weekly Average Temperature is still identified as the key means of addressing summer growth period sub-lethal effects, as suggested by the EPA (1973). The next section of this review evaluates MWAT further before reviewing the approach taken by all 50 States to the problem of implementing EPA guidance in development of their own water temperature standards.

Origin of MWAT

The EPA's current Gold Book is based on use of MWAT to protect species against chronic thermal effects. This criterion is the default recommendation to States that are faced with development of their own temperature standards. If MWAT is faulty technically and provides inadequate protection, then States that have elected to develop alternative, but equivalent, standards to MWAT would have based these standards on a flawed criterion as a benchmark. Nevertheless, it is of interest to compare the diversity of standards developed by States for coldwater fish populations with one another and also to assess them against the level of protection provided by MWAT.

The biological MWAT was considered by the EPA (1973) to be a temperature that is equal to the optimal temperature (OT) plus one-third the difference between the ultimate upper incipient lethal temperature (UUILT) and the OT or growth optimum (GO). The formula for this standard, expressed as an MWAT, is:

$$MWAT = GO + (UUILT-GO)/3.$$

An alternative measure of MWAT uses the average of OT and the temperature of ZNG (zero net growth: Armour, 1991). Either formula for MWAT was supported by EPA (1973) as an in-stream target. The EPA (1973) states that '[t]he maximum temperature at which several species are consistently found in nature ... lies near the average of the optimum temperature and the temperature of zero net growth)'. This statement appears to be the sole biological justification for MWAT. The EPA (1973, p. 154) states further that MWAT 'would be a useful estimate of a limiting weekly mean temperature for resident organisms, providing the peak temperatures do not exceed values recommended for short-term exposures. Optimum growth rate would generally be reduced to no lower than 80 % of the maximum, if the limiting temperature is as

averaged above. This range of reduction from optimum appears acceptable, although there are no quantitative studies available that would allow the criterion to be based upon a specific level of impairment'. Worryingly, these statements imply that a degree of impairment associated with MWAT was anticipated from its inception. However, MWAT has been the default recommendation of the EPA for full protection (i.e. zero impairment) of the designated beneficial use by fish species (EPA, 1986).

The ZNG temperature is a temperature at which the instantaneous growth rate and mortality rate of a population are equal (Armour, 1991). The ZNG temperature would be slightly lower than that producing zero individual growth because, under field conditions, increased mortality that results from chronic effects is already active at a lower temperature than that leading to zero individual growth. Even at temperatures at which mean individual growth rate is not quite zero, the loss of biomass from the portion of the population that is succumbing to loading stresses can result in a ZNG for the entire population. Specific knowledge of temperatures that result in population ZNG is even rarer than knowledge of those temperatures that cause zero individual growth.

Proponents of the biological MWAT consider that this index is defensible physiologically as a means of limiting exposure to chronic high temperatures. Chronic high temperature exposure includes those temperatures between the OT and UILT at which loading stresses (see Elliott, 1981) accumulate in line with temperature increase. This is the same zone in which MWAT is placed in accord with EPA (1973) methodology. Chronic high temperatures are defined as sustained constant or cyclic temperatures that result in a combination of physiological and behavioural impairments that increase the probability of mortality progressively due to cumulative stress. Constant high temperatures that produce 50 % mortality in a test group within either 1000 min or 7 d, depending upon convention, identify the upper incipient lethal temperature (Elliott, 1981). Data on percentage mortality vs. duration of exposure to a series of temperatures can also be used to compute the exposure times needed to kill smaller percentages (e.g. 10 %) of a test population. All acute temperatures that result in statistically significant mortalities due to direct thermal load are considered to be within the resistance zone (McCullough, 1999). Fish in this temperature zone have variable success in resisting acute effects of temperature, depending upon their prior temperature history, level of nutrition, size, age and species. Because temperature exposure history during the summer can be highly variable, with periods of chronic exposure interspersed with irregular acute exposures and variable-length recovery periods (Bevelhimer & Bennett, 2000), the response to acute exposures is prone to vary with differing prior chronic exposure and acclimation temperature history. For example, if chronic exposure leads to restricted food intake and low growth rates plus initiation of warmwater disease in early summer, a subsequent period of acute exposure could cause a greater than anticipated mortality under field conditions than might be expected based on laboratory studies that use healthy and unstressed fish.

In terms of the exposure to temperatures above optimum in a fluctuating temperature environment, Hokanson et al. (1977) convincingly showed, subsequent to the NAS/NAE report (EPA, 1973), that MWAT could lead to a greater than 20 % reduction in rainbow trout yield. In a 1979 review, Thurston et al. (1979) expressed the opinion that the new Red Book guidance was inadequate for both short-term (acute) and long-term (chronic) protection against thermal effects. Thurston et al. (1979) further pointed out that the chronic temperature criterion (MWAT) was inadequate due to the potential for variation in physiological GO attributable to size, age, state of sexual maturity and assumptions about food availability.

EPA's assessment of the inadequacy of MWAT for protection of salmon in the Pacific Northwest

The EPA & NMFS (1971) published results of a major survey of thermal effects on Columbia River salmon that summarised the state of knowledge for all life stages. This landmark report was followed by another report (EPA, 1973) that provided mathematical formulas for

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estimating the critical and chronic thermal exposures that were presumed to result in protection of a wide range of fish species. The EPA & NMFS report summarised the understanding at that time of thermal effects on juvenile and adult migration timing, blockages or delay to migration, thermal resistance, spawning, egg incubation, predation, disease, food-chain organisms and indications of synergistic effects (dissolved oxygen (DO) and gas supersaturation). Studies of diseases stimulated by high temperatures received significant coverage, but the magnitude of effect by disease on fish productivity has only recently been realised. The NAS/NAE report (EPA, 1973) further clarified differences in thermal sensitivity between adults and juveniles. Unfortunately, the presumption that MWAT was a useful index for avoiding chronic effects of temperature was never tested adequately, either at the time of publication (Thurston et al., 1979) or at any time since. Nevertheless, implementation of the use of MWAT at least provided a starting point for tightening the regulation of water temperatures.

In the 40 years since publication of the EPA & NMFS (1971) report, the body of literature on thermal effects on fish has substantially supported previous conclusions, but additional aspects of thermal biology have also been studied since then. For example, recent research has contributed knowledge on genetic variation in thermal sensitivity; bioenergetic effects, including power available for burst activities such as swimming; swimming speed and recovery rate; distribution of fish in the field relative to temperature maxima; influence of high temperatures on disease outbreaks and prediction of time to death after infection; importance of competition and predation effects on determining species occurrence or community composition; importance of food availability to growth rate and optimum temperatures; synergistic effects of temperature and other water quality factors such as DO or heavy metal concentrations; thermal shock and heat shock proteins; susceptibility to predation after thermal shock; gamete viability from pre-spawning thermal exposure; egg development rates and thermal compensation; importance of lipid storage on overwinter survival and potential for smolt migration; effect of multiple exposure to thermal peaks in thermocycles; ability to feed; ability to hold territories and maintain social dominance; effect of fluctuating temperature regimes on growth rates; and the relationship between thermal preference and GO (for reviews see McCullough, 1999; McCullough et al., 2001).

The EPA (Region 10) concluded in 2003, after its own review of significant advances in understanding of temperature effects and especially the multitude of chronic thermal stressors, that the temperature criteria available in the Gold Book (EPA, 1986), which had been published originally as EPA (1973), no longer reflected the best available science. The relevant EPA report (EPA, 2003c) stated:

> *'Based on extensive review of the most recent scientific studies, EPA Region 10 and the Services* [i.e. NOAA (National Oceanic and Atmospheric Administration) Fisheries and USFWS (United States Fish and Wildlife Service)] *believe that there are a variety of chronic and sub-lethal effects that are likely to occur to Pacific Northwest salmonid species exposed to the maximum weekly average temperatures calculated using the current 304(a) recommended formulas. These chronic and sub-lethal effects include reduced juvenile growth, increased incidence of disease, reduced viability of gametes in adults prior to spawning, increased susceptibility to predation and competition, and suppressed or reversed smoltification. It may be possible for healthy fish populations to endure some of these chronic impacts with little appreciable loss in population size. However, for vulnerable fish populations, such as the endangered or threatened salmonids of the Pacific Northwest, EPA and the Services are concerned that these chronic and sub-lethal effects can reduce the overall health and size of the population.'*

Based upon the numerous chronic and sub-lethal effects that occur between the optimum growth temperature and the optimum plus one-third the difference between the UUILT and the optimum, in which this value is expressed as a physical average temperature, the EPA (2003c) rejected the use of MWAT calculated by this formula as a protective standard for the many ESA-listed species of salmon, steelhead and bull trout in the Pacific Northwest. Several case studies described in McCullough (2010) indicate clearly that MWAT is ineffective in protecting any target

fish species when used as a chronic standard across the geographic range of the species. A more practical means of implementing protective temperature criteria is suggested by EPA (2003c) in which they propose application of optimum temperature (monitored as a 7DADM or 7-day average of the daily maximum temperature, not an MWAT) (see Glossary) in the core rearing zone. Most of the remaining historic rearing habitat (i.e. non-core) for the major tributaries to the Columbia River was set at a temperature 2 °C above the GO (monitored as a 7DADM).

What is the distribution of coldwater fish in the USA?

Comparison of native distribution with introduced distribution in streams

The distribution of native coldwater fish in the USA encompasses 34 of the 50 States (Fig. 1). Native coldwater fish were not found extensively in the Mississippi River or its tributaries. 'Native coldwater fish' typically implies the Salmonidae, which includes salmon, trout and char (i.e. Salmoninae), whitefish (Coregoninae) and grayling (Thymallinae). However, in this paper the focus is restricted to the distribution and protection of lotic,

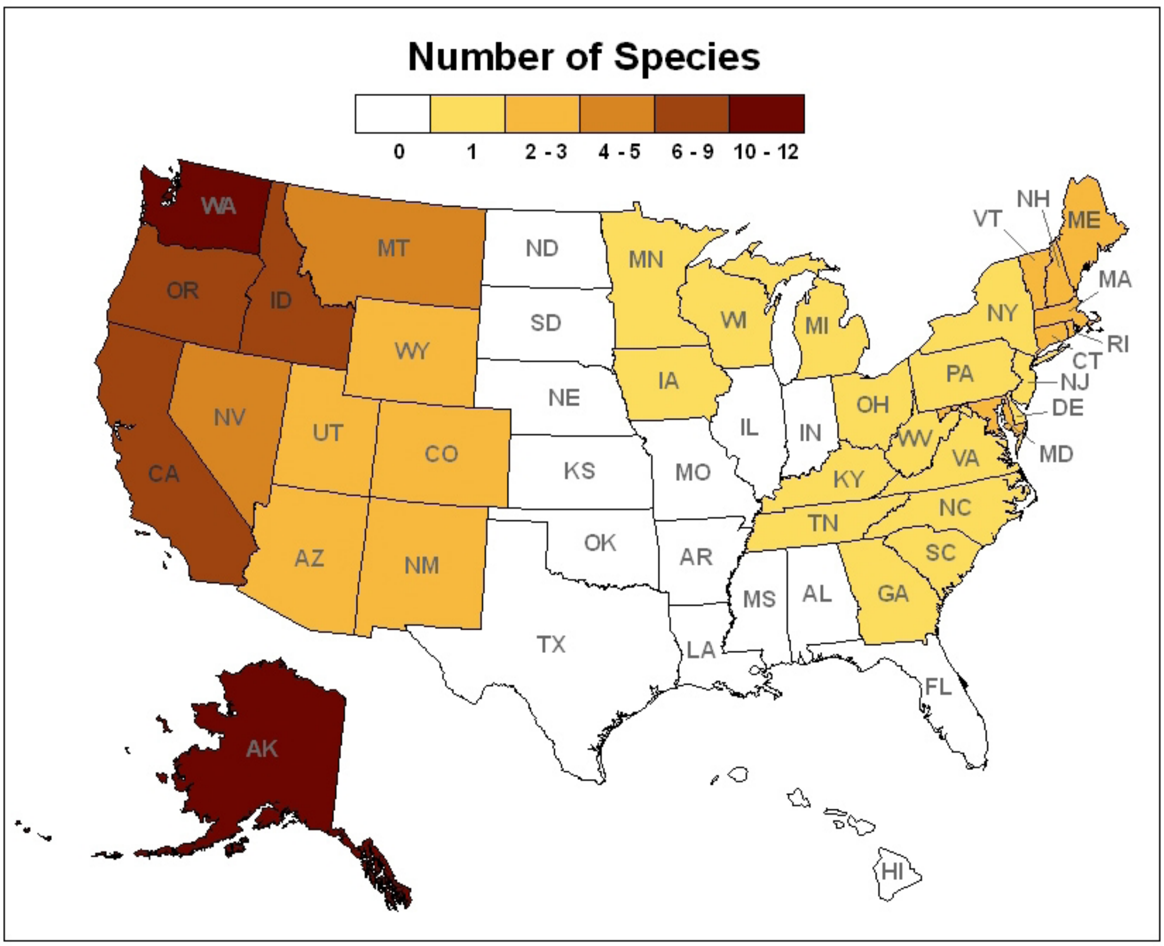

Fig. 1. Distribution of native, lotic coldwater fish species in the USA.

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Table 1. Coldwater fish species (Salmonidae) found in streams of the United States.

Scientific Name	Common Name
Oncorhynchus tshawytscha	Chinook salmon
O. kisutch	coho salmon
O. gorbuscha	pink salmon
O. keta	chum salmon
O. nerka	sockeye salmon
O. mykiss	rainbow trout/steelhead trout
O. gilae	Gila trout
O. apache	Apache trout
O. clarki	cutthroat trout
Salmo salar	Atlantic salmon
Salmo trutta	brown trout
Salvelinus fontinalis	brook trout
Salvelinus confluentus	bull trout
Salvelinus alpinus	Arctic char
Salvelinus malma	Dolly Varden
Thymallus arcticus	Arctic grayling
Prosopium williamsoni	mountain whitefish

coldwater fish (the Salmonidae of stream systems, not exclusively lakes; see Table 1). The mountain whitefish is the only whitefish species considered here as a member of the lotic fish community. The documented distribution of these species from 28 November 1975 to the present is emphasised because of the importance this date holds in the CWA (40CFR §131). The greatest numbers of native salmonid species are found in the States of Alaska (AK) (12), Washington (WA) (10), Oregon (OR) (9), Idaho (ID) (8), California (CA) (8), Montana (MT) (5) and Nevada (NV) (4) (Fig. 1; for State abbreviations, see Table 2). Other States with native salmonids have from one to three species each.

Considering the distribution of native plus non-native salmon, trout, grayling and whitefish species in the 50 States of the USA, it was determined that self-sustaining populations of lotic, coldwater species are found in all but four States ((Kansas (KS), Oklahoma (OK), Louisiana (LA) and Florida (FL); Fig. 2). States of the Pacific Northwest (OR, WA, ID), along with CA, MT and AK had the most numbers of native or non-native coldwater species (i.e. nine to 14 species) per State. If a species was tabulated as being native in a State, then non-native occurrences of the same species in that State were not recorded. The New England, interior West and mid-West States support four to nine native/non-native species each. The remaining States, except for the four without any coldwater species, support one to five native/non-native species.

Table 2. Abbreviations used to designate each of the 50 US States.

State	Acronym	State	Acronym
Alabama	AL	Montana	MT
Alaska	AK	Nebraska	NE
Arizona	AZ	Nevada	NV
Arkansas	AR	New Hampshire	NH
California	CA	New Jersey	NJ
Colorado	CO	New Mexico	NM
Connecticut	CT	New York	NY
Delaware	DE	North Carolina	NC
Florida	FL	North Dakota	ND
Georgia	GA	Ohio	OH
Hawaii	HI	Oklahoma	OK
Idaho	ID	Oregon	OR
Illinois	IL	Pennsylvania	PA
Indiana	IN	Rhode Island	RI
Iowa	LA	South Carolina	SC
Kansas	KS	South Dakota	SD
Kentucky	KY	Tennessee	TN
Louisiana	LA	Texas	TX
Maine	ME	Utah	UT
Maryland	MD	Vermont	VT
Massachusetts	MA	Virginia	VA
Michigan	MI	Washington	WA
Minnesota	MN	West Virginia	WV
Mississippi	MS	Wisconsin	WI
Missouri	MO	Wyoming	WY

Rainbow trout (*Oncorhynchus mykiss*) and cutthroat trout (*O. clarki*) are only found as native species in the western USA, with the greatest number of rainbow and cutthroat subspecies occurring in OR, CA and NV (eight to nine subspecies each). Subspecies of these lotic salmonids found in the USA are listed in Table 3. The northern tier of western States (WA, ID, MT and Wyoming (WY))

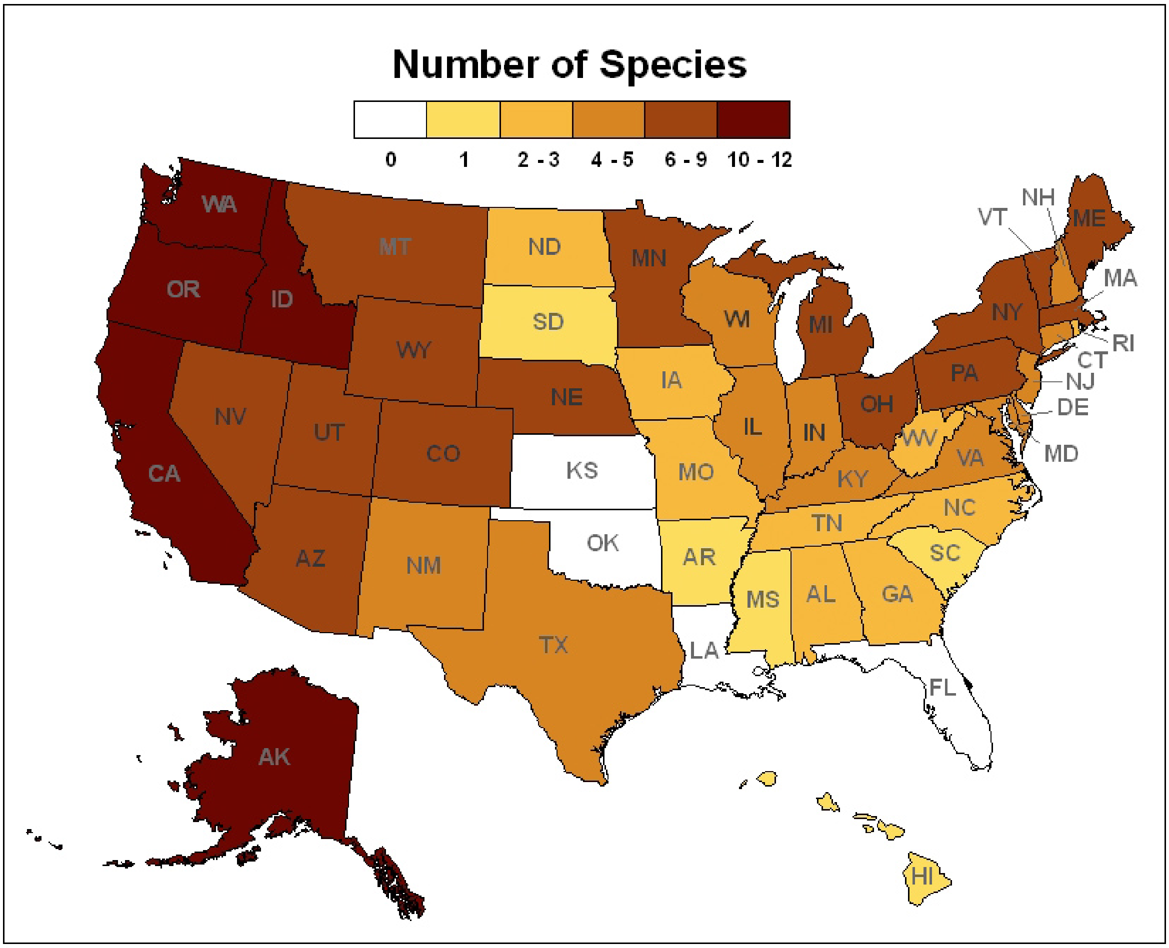

Fig. 2. Distribution of native and self-sustaining non-native, lotic coldwater fish species in the USA.

supports four to six subspecies each, while AK, Utah (UT) and Colorado (CO) have two to three and Arizona (AZ) and New Mexico (NM) have one or two each.

Salvelinus species of the USA include *S. fontinalis*, *S. malma*, *S. arcticus* and *S. confluentus*. One or more of these species are native in the western and eastern States and the upper mid-west States. Alaska supports three of these species, the Pacific Northwest States and upper New England (Maine and Vermont) have two each, and the remainder of the included States (CA, CT, DE, GA, IA, KT, MD, MA, MI, MN, MT, NV, NH, NJ, NY, NC, OH, PA, RI, SC, TN, VA, WV, WI) have one species each.

Given the wide distribution of native and non-native coldwater fish in streams of the USA, the number and distribution of unique subspecies of rainbow and cutthroat trout in the western States, and the ability of at least some streams of most of the USA to sustain populations of salmonids, it is effectively a national management issue to develop water temperature standards that will protect these species. Salmonids are widely listed by the ESA as threatened (T) or endangered (E), for instance in CA, OR, WA, MT, NV, ID, AZ, NM, UT, CO in the western USA and Maine (ME) in the east. Oregon, Washington, California, and Idaho have four, four, three, and three salmon or steelhead taxonomic species, respectively, listed as T or E, that spawn in the streams of these States. In OR, WA, CA, and ID there are a total of six, five, six, and four listed taxonomic species/subspecies, respectively, of fluvial salmonids that spawn in each State (NOAA, 2011). In AZ, CO, NM, ME, MT, NV, and UT there are one or two

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Table 3. Coldwater fish subspecies (Salmonidae) found in streams of the United States. These subspecies are members of rainbow trout and cutthroat trout. From Behnke (1992, 2002), USGS (2007).

Scientific Name	Common Name	States
Oncorhynchus mykiss irideus	coastal rainbow trout	AK, CA, MT, OR, WA
O. mykiss gairdneri	redband trout-Columbia River	ID, MT, OR, WA
O. mykiss newberrii	redband trout--Northern Great Basin	CA,NV, OR
O. mykiss stonei	redband trout-Sacramento River	CA
O. mykiss aguabonita	golden trout	CA
O. mykiss whitei	Little Kern River golden trout	CA
O. mykiss gilberti	Kern River rainbow trout	CA
O. clarki clarki	coastal cutthroat	AK, CA, OR, WA
O. clarki lewisi	westslope cutthroat trout	ID, MT, OR, WA, WY
O. clarki bouvieri	Yellowstone cutthroat trout	ID, MT, NV, UT, WY
O. clarki behnkei or *carmichaeli*	Snake River finespotted cutthroat	ID, WY
O. clarki utah	Bonneville cutthroat trout	ID, NV, UT, WY
O. clarkii pleuriticus	Colorado River cutthroat trout	AZ, CO, NM, UT, WY
O. clarki viriginalis	Rio Grande cutthroat trout	CO, NM
O. clarki stomias	Greenback cutthroat trout	CO, WY
O. clarki seleniris	Paiute cutthroat	CA, NV
O. clarki henshawi	Lahontan cutthroat trout	CA, NV, OR
O. clarki alvordensis	Alvord cutthroat trout	NV, OR
O. clarki spp.	Whitehorse Basin cutthroat trout	NV, OR
O. clarki spp.	Humboldt cutthroat trout	NV

species/subspecies each that are ESA-listed (USFWS, 2011). In OR, WA, CA and ID five salmonids (*O. nerka*, *O. tshawytscha*, *O. kisutch*, *O. keta* and *O. mykiss*) are represented by 22 threatened ESUs and five endangered ESUs, in which ESU typically denotes genetically and ecologically differentiated sets of populations that represent a unique evolutionary legacy of the species, with limited interaction with other ESUs (NOAA, 2011). Individual populations within an ESU are reproductively isolated relatively from one another. In this review, salmonid taxa distribution is mapped only at the taxonomic species or subspecies level.

In the east, Atlantic salmon are listed in Maine (NOAA, 2011). The extirpation of Atlantic salmon in many historic habitats prevents their listing in more New England States, but great interest in restoration exists (e.g. Atlantic salmon re-introduction in the Connecticut River) despite the substantial cumulative effects that have occurred. Brook trout populations have been impaired significantly in most New England States, although they have not been listed under the ESA (USFWS, 2011). The health of brook trout throughout its distribution in east coast States has been evaluated in 5563 subwatersheds within their former range (EBTJV, 2006). Wild brook trout currently occupy only 5 % of these subwatersheds to an occupancy rate in those subwatersheds of between 90 % and 100 % of the historical level. They are extirpated in 21 % of the subwatersheds, greatly reduced in 27 % and reduced in 9 %, and 19 % have an unclear history or status. A joint venture among State and federal fish and land management agencies, conservation groups and academic institutions is leading an effort to restore the brook trout habitat (EBTJV, 2006). Poor land management, bank erosion and sediment associated with agriculture are listed as the greatest influences on brook trout population integrity (EBTJV, 2006). However, elevated stream temperatures invariably accompany stream channel widening and riparian vegetation

loss, despite that fact that water temperature is often overlooked in the New England States as a limiting factor.

Thirteen different salmonid taxonomic species or subspecies have been ESA listed in the States noted above combined. These species include *Oncorhynchus tshawytscha* (Chinook salmon), *O. keta* (chum salmon), *O. kisutch* (coho salmon), *O. nerka* (sockeye salmon), *O. mykiss* (steelhead), *O. apache* (Apache trout), *O. gilae* (Gila trout), *O. clarki stomias* (greenback cutthroat), *O. clarki henshawi* (Lahontan cutthroat), *O. aguabonita whitei* (Little Kern golden), *O. clarki seleniris* (Paiute cutthroat), *Salvelinus confluentus* (bull trout), and *Salmo salar* (Atlantic salmon) (NOAA, 2011; USFWS, 2011). Only native species become listed, but the act of listing a species should bring with it an increased recognition of the thermal requirements of these species and an increased intensity of supportive management.

What are the temperature standards by State for the coldwater species?

Temperature standards were compiled for each of the 50 States of the USA to evaluate the level and kinds of protection that have been enacted in State statutes for coldwater fish (salmonids) from lotic habitats (Table 4). Standards were reviewed most recently on December 2009 from the Internet online surface WQS presented by each State's water quality agency. Acronyms for the common temperature statistics that have been used in thermal ecology and standards are listed in the Glossary. Among the States that have native salmonids, the general temperature maxima (i.e. a maximum applied specifically to general coldwater fish, or the most sensitive standard the State offers when there is no explicit standard for coldwater fish) range from 15 °C (daily max., AK), 16 °C (7DADM or 7-day average of the daily maximum, OR, WA), 18.2 °C (MWAT, CO), 18.9 °C (daily max., PA), 18.9 °C (daily mean, WV), 19 °C (max. daily average, ID), 19.2 °C daily max. MT), 20 °C (daily max., IA, MA, MI, NV, NC, NM, RI, TN, UT, VA, WY), 20 °C (max. seasonal average, NJ), 21.1 °C (daily max., IN, NY, WV), 22 °C (daily max., ID), 23.8 °C (daily max., CO), 23.9 °C (daily max., MD), 23.9 °C (daily mean, DE), 26.7 °C (daily max., IL), 29.4 °C (daily max. CT), 31.7 °C (daily max., KY), to 32.2 °C (general daily max., GA). Of the States with native salmonids, several have no quantitative water temperature standards at all (i.e. not for either cold- or warmwater fish). These States include: AZ, CA, ME, MN, NH, SC and VT. CA does have a few site-specific coldwater standards, such as 21.1 °C on specified reaches of the Sacramento River. Otherwise, it deals with salmonids simply on a case-by-case basis via TMDLs that identify riparian vegetation restoration as a key response in a basin plan. CA relies currently on judgement of natural temperature conditions for a site and assessment of whether the combination of existing anthropogenic increases plus new proposed increases would impair the designated beneficial use. This assessment is done with reference to salmonid and amphibian temperature requirements. CA has nine regions that operate semi-independently to develop standards. CA Water Board Region 1 is the most advanced region with respect to the development of temperature TMDLs in the State, yet has no quantitative rearing, spawning, or migration water temperature standard to date for protecting salmonids (up to March 2011).

Most States with native salmonids have standards for maximum allowable increases (Table 4). The maximum allowable increase for States with native salmonids ranges from 0 °C above natural (e.g. GA, KY, OH, NH, NV, RI, SC), to 0.5 °C, 0.6 °C and 0.8 °C above ambient (NC, NJ and MA, respectively), to 0.56 °C when temperature exceeds 18.9 °C (VT), to 1 °C above natural (VA), to 1.0 °C above ambient (AZ), to 1.1 °C above natural when T > 15.6 °C (WY), to 1.1 °C above natural (IN, MI), to 1.7 °C above natural (IL), to 2 °C and 2.2 °C above ambient (IA, UT), to 2.2 °C above ambient (CT), to 2.7 °C above ambient (NM), to 2.8 °C over natural (WI, WV, DE, CA), to 3.0 °C above ambient (TN).

Some States describe the allowable increase as an increment that exceeds the stated quantitative standard. For example, increases that are allowable when the standard is reached include: 0 °C (NY), 0.28 °C (MT), 0.3 °C (OR, WA), 0.5 °C (ID), 0.56 °C (UT). WI, which has no maximum allowable temperature standard for coldwater fish protection, states that there will be

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no significant increase from natural background that would cause an adverse effect, but also has a statewide standard that allows an increase of 2.8 °C at the edge of the mixing zones. It also allows a variance if the thermal polluter can demonstrate to the State that its discharge will not endanger the propagation of a BIP of fish. Such standards appear to carry an implied responsibility to know the NTP of each waterbody. Also, protection of the BIP raises questions of whether the State will restrict its consideration to only the historic native species, the methods for identification of 'balance', and the actual level of effect to fish productivity that has been incurred. Several States have no standard for allowable increases (AK, CO, ME, MD and PA).

Few States reference cumulative effects on water temperature control as an issue. OR frames this 0.3 °C allowable increase above ambient temperature as the cumulative increase at the point in the river of greatest thermal effect and 0.3 °C above the applicable criteria (0.3 °C from point sources prior to completion of a TMDL (Total Maximum Daily Load; calculation of the maximum amount of pollutant that can be received in a waterbody and still meet water quality criteria) and 0.3 °C from point and NPS after the TMDL is in place). WA frames this as a 0.3 °C increase above the criterion, and when the ambient temperature is lower than the criterion the allowable increase from a single point source is 28/(t+5) where t is the temperature at the edge of a mixing zone, and the allowable increase from combined non-point sources is 2.8 °C. VT recently adopted a 0.56 °C allowable increase over ambient 'due to all discharges and activities'. It is unclear whether this cumulative effect assessment can be implemented to prevent ratcheting upwardly of temperatures above natural, but the reference to ambient (in which ambient is the temperature at a point above the discharge) gives no indication that the State is interested in improvement in temperatures from those that already exist.

Among States with no native salmonids but which host introduced non-native species, the temperature standards for coldwater fisheries range from maxima of 18.3 °C (SD), 20 °C (AR, MO), 22 °C (NE), 29.4 (ND), 30 °C AL), 32.2 °C (MS), to 26.7–35 °C (TX). SD has the most sensitive comprehensive treatment of trout waters among this group, with a maximum temperature of 18.3 °C, a maximum allowable increase of 2.2 °C over ambient and a maximum rate of increase of 1.1 °C h^{-1}. However, application of the allowable increase above ambient temperature presents conflicts with the control of continued increases after 18.3 °C is exceeded. HI has no quantitative temperature standard. Increase in the temperature that is allowed for these States for non-native, reproducing salmonids are: 1 °C above ambient (HI), 2.8 °C above natural (AR, MS, ND), 2.2 °C above ambient (SD) and 2.8 °C above ambient (AL, TX), and 3.0 °C above natural (NE). OK has no native salmonids and based on the methodology detailed in this review, has no non-native salmonids that have a self-sustaining population, but the State does have seasonal trout fisheries. Its standard to protect these fish is highly sensitive relatively, with a maximum temperature of 20 °C and a 0 °C allowed increase when the temperature limit is reached.

Several States enforce standards for maximum rate of temperature change. Allowed rates of change range from 0.5 °C h^{-1} (AK, VA), to 1.0 °C h^{-1} (IA), to 1.1 °C h^{-1} (SD, PA), to 2 °C h^{-1} (TN). These standards are meant to cover a rate of temperature increase caused by human influence. It is not clear how the natural daily rate of temperature increase is differentiated from the anthropogenic rate of increase.

Several States have documented the special requirement that natural daily and seasonal fluctuations do occur. Included in this group of States are CO, IL, IN, IA, KS, KT, MA, NY, OK, OR, WA and WI. OR interprets this fluctuation as a natural temperature pattern that is linked to the timing of annual increases and to decreases in temperature in the Columbia and Snake rivers. WA legislation assumes that its spawning standards protect the natural seasonal thermal pattern, except in cases in which there is direct human influence.

It is fairly common for States to have standards that allow exemptions for extremely high air temperatures or extremely low streamflows. CO and OR have exemptions for extreme high air temperatures. Under these rules, standards do not apply when air temperatures exceed the 90th percentile air temperature computed from annual

Table 4. Most sensitive temperature standards provided by each of the 50 US States. *Note: For States with coldwater fish standards, standards are listed for spawning, rearing, and adult migration of the principal coldwater species. Some States have temperature standards for salmonids requiring higher levels of protection. For States with no coldwater fish standards, standards listed are the most sensitive available.*

State acronym	Spawning		Rearing		Adult migration			Super coldwater fish			Allowed temp. increase in rearing area (°C)	Max. ΔT (°C)/h
	Daily*	7-d**	Daily*	7-d**	Seasonal	Daily *	7-d**	Daily *	7-d**	Species		
AL			30/–								2.8	
AK	13/–		15/–			15/–						
AZ			None								1 OA	
AR			20/–								2.8 ON	
CA			None								0 ON (interstate); 2.8 ON (intrastate)	
CO	13/–	–/9	23.8/–	–/18.2				21.2/–	–/17	Cutthroat	3 over 4 h, lasting 12 h	1
CT			29.4/–								2.2	
DE			–/23.9								2.8 ON	
FL			32.2/–								2.8 OA	
GA			32.2/–								0 ON	
HI			None								1 OA	
ID	13/9		22/19						13/–	Bull trout	0.5 (bull trout)	
IL			26.7/–								1.7 ON	
IN	18.3/–		21.1/–								1.1 ON	
IA			20/–								2	1
KS			32/–								3 ON	
KY			31.7/–								0 ON	
LA			32.2/–								2.8 OA	
ME			None								–	
MD			23.9/–								No value specified	
MA			20/–								0.8	
MI			20/–								1.1 ON	
MN			None								No material increase	
MS			32.2/–								2.8 OA	
MO			20/–								1.1	
MT			19.2/–								[a]	
NE			22/–								3 ON	
NV			20/–								0 ON	
NH			None								0 ON	

NJ			20/–		20				0.6 ON	
NM			20/–						2.7 OA	
NY			21.1/–						[b]	
NC			20/–						0.5	
ND			29.4/–						2.8°C ON	
OH			None						0 ON for trout waters	
OK			20/–						2.8 OA; 0 when 20°C is reached	
OR		13/–		16/–		20/–	12/–	Bull trout	0.3 OA	
PA			18.9/–							1.1
RI			20/–						0 when > 20; 2.2 when <20	
SC			None; unless site-specific stds. apply						0 ON	
SD	[e]		18.3/–						2.2 OA	1.1
TN			20/–						3 relative to upstream control point	2
TX			26.7–33.9/–						2.8	
UT			20/–						2	
VT			None						[c]	
VA			20/–						1 ON for trout waters; otherwise, 3 ON	0.5 trout waters
WA		13/–		16/–		17.5/–	9 spawning; 12 spawning and rearing	Bull trout	[d]	
WV	[e]		18.9 (June); 21.1 (Aug)/–						2.8 ON	
WI	[e]		23.9/						2.8 ON in rearing areas	
WY			20 (or max. natural)/–						1.1 when T > 15.6	

*Max/mean; **Average daily maximum/average daily mean; [a]0.56 when T > 0 and <18.9; no discharge to result in >19.4 when T > 18.9 and <19.2; and 0.28 when T > 19.4; [b]0 when water temperature >21.1; otherwise, 1.1; [c]0.56 when >18.9; 1.1 when >17.2 and <18.9; 1.7 when >15 and <17.2; 2.2 when >12.8 and <15; 2.8 when <12.8; [d]0.3 cumulative increase if T = std. + 0.3; 28(T + 7) when T< std. –2.8; not to exceed 2.8 cumulatively in all cases; [e]No temp. change allowed over spawning beds.

maximum temperatures. Exemptions are written into the rules for various States that are based on extreme low flows. The low flows that are used to draft these exceptions are the $7Q_{10}$ low flows (OR, SC), $7Q_3$ (CO) and the $7Q_2$ (TX). These latter exemptions are particularly lax.

More complex water temperature standards that involve special protection for spawning, rearing and adult migration for salmonids are found only in AK, OR and WA. Temperatures for rearing standards range from 15 °C (daily max., AK), to 16 °C (7DADM, OR, WA). Temperatures for spawning standards for these salmonids range from 13 °C (daily max., AK), to 13 °C (7DADM, OR, WA). OR allows an increase of 0.5 °C during the spawning period when the temperature is between 10 and 12.8 °C (as a 60-day rolling average maximum) and 1.0 °C when the temperature is less than 10 °C (as a 60-day rolling average maximum). Temperatures for adult migration standards are 15 °C (daily max., AK), 17.5 °C (7DADM, WA) and 20 °C (7DADM for the Columbia and Snake rivers, OR). Three States have temperature standards for spawning and rearing for general coldwater species. Of these, the temperature for the spawning standards are 9 °C (daily mean, ID), 9 °C (MWAT, CO), 13 °C (daily max., CO, ID) and 18.3 °C (daily max. IN). For these States, the temperatures for the associated rearing standards are 18.2 °C (MWAT, CO), 19 °C (daily mean, ID), 21 °C (daily max. ID, IN) and 23.8 °C (daily max., CO). States SD and WV note a qualitative need to prevent heated discharge over spawning beds. WI indicates merely a need to prevent significant temperature increases over spawning beds. States that note a need to prevent migration barriers include MD and MS. Although WI does not have a maximum temperature standard for spawning, it does have one for maximum allowable temperature increase over natural of 0 °C in spawning areas.

Special rearing standards for the most sensitive salmonids exist for CO, ID, OR and WA. These temperature standards range from 12 °C (7DADM, OR, WA, bull trout), 13 °C (7DADM, Idaho, bull trout), 17.0 °C (MWAT, CO, cutthroat) and 21.2 °C (daily max., CO, cutthroat). CA, MT and NV do not have special standards for bull trout in their State rules that protect them to a higher level compared with other trout species. This difference does not eliminate the possibility that more protective standards have been developed on a site-specific basis in either basin plans or ESA-related agreements. Special State spawning temperature standards for very coldwater species range from 9 °C (daily mean, ID, bulltrout), 9 °C (7DADM, OR, WA, ID,bull trout), to 9.0 °C (MWAT, CO, cutthroat), to 13.0 °C (daily max., CO, cutthroat).

Conclusions

Native coldwater fish distribution is extensive in the 50 States that make up the USA. Most of the States that historically lacked native coldwater fish have had introductions of non-native coldwater fish. Forty-six of the 50 States have native or non-native self-sustaining populations of coldwater fish. The broad distribution of coldwater fish imposes a CWA responsibility on most States to protect water quality and therefore to protect the future viability of these fish. The CWA delegates to the States the role of development of water temperature standards and other WQS for their respective State's waters in order to protect aquatic resources. The wide variety of temperature standards that are applied to coldwater fish, despite their high level of similarity in thermal tolerance (see McCullough 1999, McCullough et al., 2001), reveals that States apply very different concepts on which they base their full protection of beneficial uses. In addition, the EPA can only judge the suitability of standards after they are modified upon State review and following provisions of the CWA. The EPA has no option to approve a standard or recommend a more adequate standard if temperature standards are never subject to State triennial review. States with no inherent temperature standards and that use surrogates (e.g. biocriteria) may not be subject to the EPA determination that thermal needs of biota are not being met. These shortcomings are merely a few of those that arise in the regulations set by CWA and associated federal and State legislation for the protection of fish.

There is a general lack of clarity in language in the CWA that allows practitioners to invent interpretations that can

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be manifested in various common circumstances. It is not the intent of this review to identify any particular State as being guilty of a litany of abuse, but simply to highlight some arguments made by regulators and scientists who are involved in the setting or application of standards. For example, it is claimed that it is better to aim a standard at the average for an entire fish community from headwaters to river mouth because the optimal conditions of all species cannot be addressed with a single standard. It is claimed that average temperature standards ensure protection of the entire ecosystem. It is also claimed that less sensitive species will be hurt by full protection of the most sensitive coldwater species. These similar claims stem from a failure to treat the river system as an ecosystem in which the NTP varies spatially (Poole et al., 2004). Standards that aim toward a natural potential temperature distribution across all basins would satisfy the thermal requirements of all native species. Of course, many States have introduced and promoted warmwater sport fish that have invaded coldwater and coolwater fish habitats. Given State authority to promote the viability of these fish, temperature standard development can become confused with intention to support multiple fish uses. However, a multiple use cannot be supported by selection of an average temperature requirement that spans the range from coldwater to warmwater species. CWA allowances for considering RIS in Section 316 facilitate a blurring of the needs of coldwater fish with those of warmwater fish. Even if the intent is merely to 'balance' the temperature requirements of the full range of coldwater species by aiming standards to the median sensitivity of the coldwater community, the most sensitive species will be underprotected.

There is the potential for the most stringent level of water temperature regulation when there is an overlap between the CWA and the ESA rules that govern fish protection (EPA, 1994; EPA, 2003c). However, on private land, even this combination has been ineffective in bringing about either significant or rapid correction of thermal problems. The ESA application to list salmon and steelhead species in the Pacific Northwest has sought to recover species to a 'viable' level, which tends to be equated with population abundances that are approximately 10 % of historical values plus increased productivity to ensure sustainability and geographic distribution. This application, however, does not require restoration of all historical habitats and leaves the 'non-critical' habitats at a low priority level. Thermal recovery does not occur on a systemic basis when the States that apply the CWA rules defer to the ESA and adopt a lax enforcement attitude toward these non-critical streams. The history of application of the CWA temperature guidelines has been one long story of development of permits and regulations for thermal discharges (PS) and, in general, a relaxed but slowly improving stance on timber harvest, grazing, agriculture and urban development (NPS). There has been a minimal link drawn for NPS thermal pollution between full protection and the land management activities that would be required to restore a natural thermal regime for the most sensitive species.

Future climate change has been predicted to have significant potential effects on all obligate coldwater fish species. Patterns of projected future air temperature increases will be linked tightly to water temperature distributions (Crozier & Zabel, 2006). This effect will most likely cause a reduction in spatial distribution of coldwater fish (DOW & NRDC, 2002). The average percentage loss in salmonid habitat on a national basis will be between 6 % and 14 % by 2030 due to climate change alone. However, the anticipated effects will be substantially more in certain States (DOW & NRDC, 2002). Land management actions that are needed to moderate this effect include an increased emphasis on protection and restoration of riparian vegetation cover along all streams that provide habitat for, or are tributary to, salmonid fish-bearing waters (ISAB, 2007). In addition, a reduction in riparian and watershed road density would aid to limit the effects of increased air temperature (Rhodes et al., 1994). Coldwater fish populations, subject to climate change and land use effects leading to warming, will also have their abundance, productivity, and spatial distribution within their historic range affected by State-level development of water temperature standards and interpretation of the CWA requirements.

Another future concern that has been predicted to accompany climate change will be increased urbanisation and demand for both water and energy. Increased water withdrawal for all consumptive uses will reduce the thermal buffering capacity of streams. Water withdrawn for irrigation may either evaporate or provide a heated return flow to rivers and will be an unregulated form of pollution under the CWA (Blumm & Warnock, 2003). The future increase in energy production based on conventional thermoelectric power generation will create added thermal stress on the large rivers, where many of these facilities will be sited. Electricity generation, by use of once-through cooling, was responsible for 91 % of water withdrawals for all thermoelectric facilities in the USA in 2000 (USGS, 2000). Currently, water withdrawals for thermoelectric generation are most heavily concentrated in both the eastern and mid-western States, and in Texas and California (Fig. 3). Once-through cooling relies on more heat discharge into rivers compared with closed-loop systems, which utilise cooling towers and have lower water consumption levels. The prospect of large increases in the use of once-through cooling systems powered by nuclear energy, coal, or natural gas has caused great concern for the future ability of the USA to maintain its coldwater species.

Water temperature is the leading cause of CWA 303(d) listings of water quality impairment in Oregon, but water temperature is not even mentioned as a factor for listing in Connecticut (EPA, 2011). Nationally, water temperature is not among the top 10 causes of stream impairment (EPA, 2009). This polarity among States in their approach to dealing with water temperature illustrates that measurement of water temperature-impaired streams in the USA is not comprehensive. For example, EPA's 305(b) reports for each State, which are accessible on the Internet (EPA, 2011), can be used to compile a picture of the effort

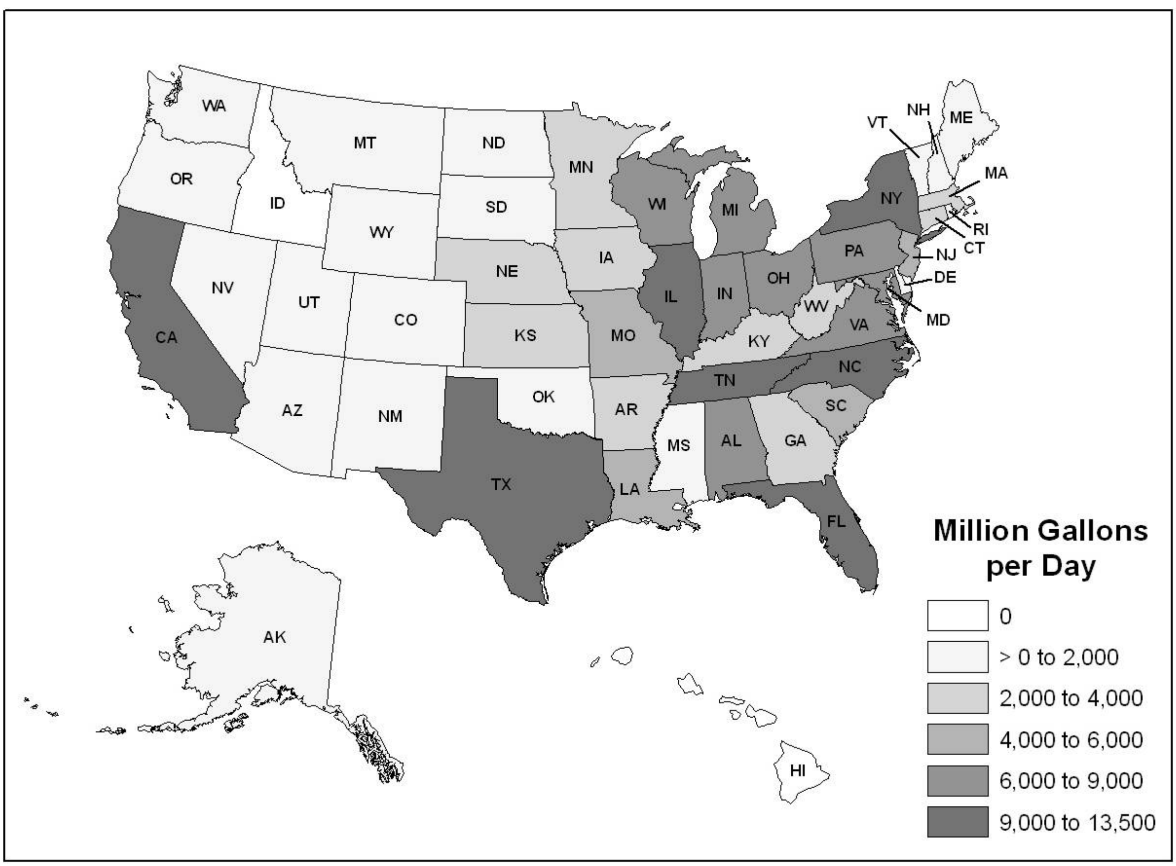

Fig. 3. Thermoelectric power water withdrawals by state for 2000. From USGS (2000).

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Table 5. Summary of each State's 305(b) reports submitted to the EPA, reporting overall water quality impairment and water temperature impairment.

State acronym	Total miles surveyed (%)	Surveyed miles impaired (%)	Surveyed miles with temperature impairment (%)
AL	13.2	25.1	0.0
AK	1.3	9.8	0.3
AZ	3.1	36.8	0.0
AR	11.4	44.5	0.9
CA	15.5	97.2	52.5
CO	66.2	15.5	0.7
CT	36.0	41.6	0.1
DE	99.9	99.6	0.4
FL	0.3	0.0	0.0
GA	18.4	58.7	0.2
HI	0.2	100.0	0.0
ID	52.2	56.8	25.4
IL	21.5	57.7	0.0
IN	54.0	57.6	0.1
IA	13.3	68.8	0.0
KS	20.4	88.4	2.9
KY	21.0	61.1	0.4
LA	14.3	77.5	0.0
ME	68.4	3.9	0.0
MD	72.0	60.0	0.0
MA	28.8	69.1	1.3
MI	100.0	76.1	0.1
MN	14.2	78.9	0.1
MS	9.7	56.4	0.0
MO	31.1	19.9	0.2
MT	10.7	85.2	12.9
NE	9.6	57.4	5.1
NV	28.9	50.9	22.7
NH	100.0	100.0	0.0
NJ	96.3	87.7	8.5
NM	5.6	56.5	18.4
NY	70.8	13.9	0.5
NC	18.8	50.5	0.0
ND	100.0	12.7	0.1
OH	87.9	95.8	3.6
OK	15.8	83.5	0.0
OR	40.1	67.5	37.5

cont. of Table 5.

State acronym	Total miles surveyed (%)	Surveyed miles impaired (%)	Surveyed miles with temperature impairment (%)
PA	100.0	19.0	0.1
RI	49.4	45.2	0.0
SC	18.8	64.1	0.0
SD	8.3	50.6	6.6
TN	50.9	38.0	0.3
TX	10.5	39.5	0.0
UT	12.2	27.8	3.9
VT	78.3	7.1	0.6
VA	31.5	66.4	2.4
WA	5.3	52.8	24.8
WV	56.6	55.7	0.0
WI	17.8	60.8	8.5
WY	6.8	16.0	0.3

applied by States to both water quality monitoring and water temperature monitoring, specifically (Table 5). This survey revealed that, among the 50 States, the percentage of total State stream miles surveyed ranged from <1.3 % (AK, FL, HI) to 100 % (MI, NH, ND, PA). The percentage of miles that were impaired by any of the water quality parameters monitored by the State ranged from <1.1 % (AK, AZ, HI and WY) to 100 % (NH). However, the percentage of miles surveyed that were listed for water temperature threat or impairment were <1.1 % in all States except for CA (8.1 %), ID (13.2 %), MT (1.4 %), NV (6.5 %), NJ (8.2 %), OH (3.1 %), OR (15.0 %), WA (1.3 %) and WI (1.5 %). States that listed absolutely no stream miles that were threatened or impaired by water temperature included AL, AZ, FL, HI, IL, LA, ME, MD, MS, NH, NC, OK, RI, SC and TX.

This review, despite the caveats of the 303(b) data, illustrates that many States with water temperature standards never use them to list any streams for violations. Also, there is a very large disparity in the effort placed in monitoring water temperature. It is not reasonable to just conclude that some States have very few problems with regard to water temperature. This evaluation highlights the caution that should be applied in reviewing national water quality assessments (e.g. EPA, 2009) that show that water temperature is not a significant cause of water quality impairment. Clearly, water temperature is a significant source of impairment, but it has received scant attention from most States, even from those States that have temperature standards.

The ability of a State to provide full protection for its coldwater fish resources depends upon a series of effective elements: clear federal laws and technical guidance documents; fully protective temperature standards with few exemptions; monitoring for and enforcing compliance; and full implementation of effective BMPs (McCullough, 2010). Unfortunately, two recent US Supreme Court decisions, the SWANCC (Solid Waste Agency of Northern Cook County v. United States Army Corps of Engineers) and Rapanos cases, have emerged that involved the extent of federal jurisdiction over 'waters of the United States' (Austin & Meyers, 2007; USACE, 2008) and have added to the many threats to full realisation of the original goals of the CWA. These cases have made protection uncertain for isolated wetlands, and their intermittent and ephemeral streams and are subject to studies on ecological processes. Such headwater components of stream systems are integral to the full support of the water quality

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(Beuchler, 2010) of downstream waters and often provide a habitat for salmonids themselves.

The wide variety of standards that are applied to streams that support coldwater fish species across the 50 States implies that there is great variety in the levels of protection provided (or that would be provided if the individual States were to monitor for violations) and in the conditions that would initiate a listing. The federalist system in the USA permits each State to develop standards that meet or exceed the goals of the US Clean Water Act, but it is the responsibility of the EPA to ensure that State standards, when it approves them, meet the intent of the CWA. Currently, official US guidance for minimum level protection against chronic thermal stress and expected compliance of all States still refers to the use of the MWAT criterion (EPA, 1986). This guidance represented a landmark; it highlighted the multiple types of chronic thermal stress in sensitive species. However, its weaknesses, obvious from its inception, prompted the EPA Region 10 to supplant MWAT with a reliance on optimum salmonid growth temperatures and an estimation of the natural temperature patterns (diel, seasonal and annual) to set standards at a basin scale for control of cumulative temperature increases over time (EPA, 2003c). Future climate change, therefore, makes our task to estimate NTP throughout stream systems, and to recognise the controls on stream water temperature via climatic and anthropogenic effects, to take restoration and protection actions to address causes of stream warming, and to establish standards to protect the most sensitive members of the fish communities based upon the intersection of GO and NTP more critical than ever.

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Glossary

Commonly used acronyms and terms:

303(d)	A section of the Clean Water Act (CWA). It specifies that water bodies that do not meet water quality standards after point sources have had pollution control technology applied, and will be listed in a statutory report (commonly referred to as the '303(d) List'). Listed water bodies require development of a TMDL.
303(d) report/list	A report to EPA required under the CWA that lists all water bodies that do not meet water quality standards set individually by each State to meet all State-designated uses of the waterbodies. When a waterbody is placed on the 303(d) list for water temperature impairment, the State must develop a TMDL that defines how thermal loads will be managed to protect fully the designated beneficial use(s).
305(b)	A section of the CWA that requires the EPA and the States to submit a biennial report to Congress detailing water quality by State.
305(b) report	A report that is required to be submitted to the EPA by each of the United States every two years and stating the water quality condition of all navigable waters and the extent to which they provide protection and propagation of a balanced population of shellfish, fish and wildlife, and allow recreational activities.
316(a)	A section of the CWA that regulates point-source thermal discharges into water bodies. A permittee (e.g. power plant owner) interested in gaining a thermal variance may conduct a 316(a) 'demonstration' to show that a 'balanced indigenous population' (BIP) [interpreted as community] will be maintained. Harm to the BIP was interpreted by the EPA (1977) as impairment to growth, development, reproduction, survival and distribution.
Antidegradation	This is a policy under the CWA to prevent deterioration of good water quality.
BIC	Balanced indigenous community. BIC was interpreted by the EPA (1977a) to be equivalent to BIP.
BIP	Balanced indigenous population. The BIP consists of desirable species of fish, shellfish and wildlife that are essential components of the food web, but may also include desired, introduced species.
BMP	Best Management Practices. BMPs are considered to be best procedures for controlling pollution sources and are employed in TMDL implementation plans to control thermal sources.
CFR	Code of Federal Regulations. This document is the codification of rules published in the Federal Register by executive departments and agencies of the US Government published fewer than 50 titles and representing subjects under Federal regulation.
CWA	Clean Water Act. This is the major US environmental law, passed in 1972, dealing with regulation of surface water pollution.
Designated beneficial use	A purpose or benefit to be derived from a waterbody and which is formally designated for the waterbody. Potential beneficial uses include watering of livestock irrigation, aquatic life, recreation involving contact with the water, municipal or domestic supply, industrial supply, propagation of wildlife, waters of extraordinary ecological or aesthetic value and enhancement of water quality. States may tailor beneficial uses to local conditions, such as subdividing aquatic life uses as coldwater fish or warmwater fish uses. The CWA requires States to designate one or more beneficial uses for each waterbody. Water quality standards must then be devised so that designated beneficial uses are fully protected, especially the most sensitive use.
EPA	US Environmental Protection Agency. The EPA is an agency of the US Government charged with protecting human health and environmental quality. It interprets and enforces laws created by Congress.
ESA	Endangered Species Act. An Act of the US Congress designed to protect threatened and endangered species of wildlife and plants plus their habitats. The ESA is administered by the US Fish and Wildlife Service and the US National Oceanic and Atmospheric Administration (NOAA) Fisheries Service.
FWPCA	Federal Water Pollution Control Administration. The FWPCA, an agency within the US Department of Interior, was authorised by the Water Quality Act of 1965 to require States to issue water quality standards for interstate waters, subject to federal approval. In 1970 this agency was merged with several others assigned to monitor pollution to become the EPA. Water quality legislation and subsequent amendments eventually became known as the CWA.

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IBI	Index of Biotic Integrity. This is a multimetric index of community composition.
Mixing zone	An area where an effluent discharge undergoes initial dilution. In the mixing zone, water quality criteria can be exceeded as long as acutely toxic conditions are not produced. Water quality criteria must be met at the downstream edge of a mixing zone.
NAS	National Academy of Sciences. An honorific society of scientific scholars established by Congress and signed into law by Abraham Lincoln. This society is called upon to review difficult scientific questions for governmental agencies.
NPDES	National Pollutant Discharge Elimination System. Section 402 of the CWA requires that industries obtain an NPDES permit with TBELs and/or WQBELs and monitor and report pollution discharges.
NPS	Non-point source pollution. Common sources of NPS pollution are the diffuse runoff from agricultural, urban and forestry lands.
NRC	National Research Council. Established by the NAS in 1916 to act as the operating arm of the NAS to provide independent scientific advice.
NTP	Natural Thermal Potential. NTP is an estimate of the thermal regime without prior anthropogenic modification and accounting for potential riparian vegetation, stream geomorphology and streamflows.
OT	Optimal temperature. OT for a certain life stage is identified generally as that temperature that maximises growth rate and survival.
PS	Point source. This describes a source of pollution emanating typically from a pipe, ditch, or animal feedlot.
RIS	Representative Important Species. RIS is a set of species that is considered representative of a BIC. It is assumed that if they are protected, the entire community will be protected.
TBEL	Technology-based effluent limitations. TBELs are effluent limitations required by the EPA for the discharge from a particular industrial plant, regardless of the quality of the receiving water.
TMDL	Total Maximum Daily Load. This is a calculation of the maximum pollutant load permissible that will still result in water quality standards being met. This is followed by an implementation plan to meet standards.
USC	US Code. The USC is the codification of the permanent laws of the USA under 50 titles, published by the US House of Representatives.
UUILT	Ultimate Upper Incipient Lethal Temperature. UUILT is the highest UILT possible under conditions where organisms with prior temperature acclimation are then subjected to a test temperature for a period of either 1000 min or 24 h, producing 50 % survival.
WQBEL	Water quality-based effluent limitations. WQBELs are effluent limitations imposed on a point source and are based on the water quality standards for the receiving waterbody designed to support a designated beneficial use.
WQS	Water quality standard. WQSs include designated uses, water quality criteria (narrative or quantitative) and antidegradation provisions.

Acronyms used to describe water temperature statistics:

7DADM	7-day average of the daily maximum. 7DADM is the same as MWMT or maximum weekly maximum temperature.
MWAT (biological)	Maximum weekly average temperature. MWAT (biological) is computed by an equation relying on OT and UUILT EPA (1973). A physical MWAT under field conditions equal to the biological MWAT is assumed to be protective (EPA 1973).
MWAT (physical)	Maximum weekly average temperature. MWAT is the largest 7-day running average of daily average temperatures, generally computed from hourly temperatures.