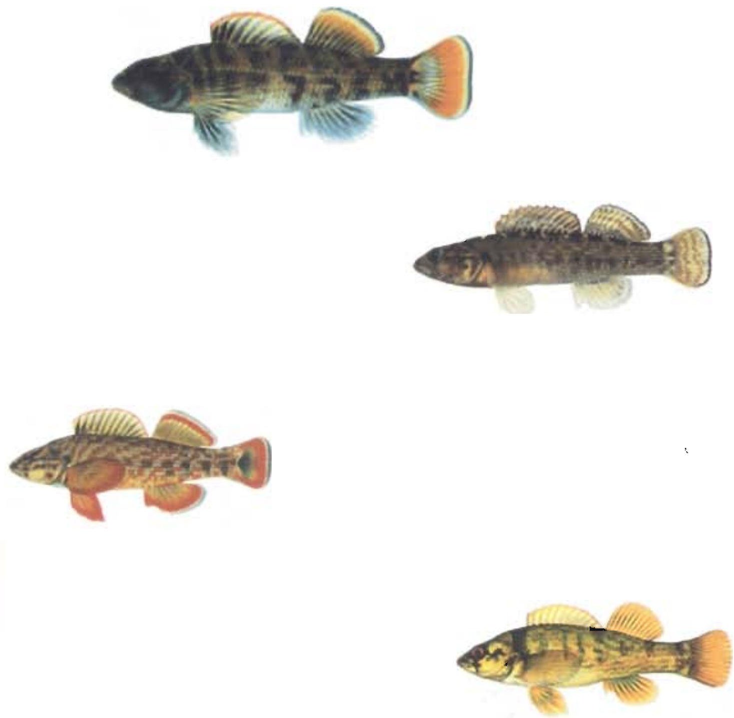
STUDIES OF NORTH AMERICAN DESERT FISHES IN HONOR OF E. P. (PHIL) PISTER, CONSERVATIONIST



MA. DE LOURDES LOZANO-VILANO
AND
ARMANDO J. CONTRERAS-BALDERAS
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CONSERVATION OF MEXICAN NATIVE TROUT AND THE DISCOVERY, STATUS, PROTECTION AND RECOVERY OF THE CONCHOS TROUT, THE FIRST NATIVE

Conservación de truchas natives mexicanas y su descubrimiento, estatus, protección y redescubrimiento de la trucha del Conchos, la primera especie nativa.

DEAN A. HENDRICKSON[1], DAVID A. NEELY[2], RICHARD L. MAYDEN[2], KARL ANDERSON[2], JAMES E. BROOKS[3], FAUSTINO CAMARENA-ROSALES[4], RALPH CUTTER[5], LISA CUTTER[5], ANNA BELLIA DE LOS SANTOS[6], GUY W. ERNSTING[7], HECTOR ESPINOSA-PÉREZ[8], LLOYD T. FINDLEY[9], FRANCISCO J. GARCIA-DE LEÓN[6], ANNA L. GEORGE[10], JOHN HATCH[11], BERNARD R. KUHAJDA[12], KYLE E. MAYDEN[13], KRISTINA MCNYSET[14], JENNIFER L. NIELSEN[15], FRANK W. PFEIFER[16], DAVID L. PROPST[17], GORGONIO RUIZ-CAMPOS[4], ERIC ST. CLAIR[18], JOSEPH R. TOMELLERI[19] AND ALEJANDRO VARELA-ROMERO[20]

[1]. University of Texas, Texas Natural Science Center, Texas Natural History Collections, PRC 176 / R4000, 10100 Burnet Road, Austin, Texas 78758 USA. [2]. Department of Biology, 3507 Laclede Ave., Saint Louis University, St. Louis, Missouri 63103 USA. [3]. U. S. Fish and Wildlife Services, New Mexico Fishery Resources Office, 3800 Commons N.E., Albuquerque, New Mexico 87109 USA. [4]. Facultad de Ciencias, Universidad Autónoma de Baja California, Ensenada, Baja California Norte, México. [5]. California School of Flyfishing, 14140 Sunrock Rd., Nevada City, California 95959 USA[6]. Centro de Investigaciones Biológicas del Noroeste, S.C. Mar Bermejo 195, Col. Playa Palo Santa Rita, C.P. 23090, P.O. Box 128. La Paz, México. [7]. Rt. 2, Box 153, Ellinwood, Kansas 67526 USA [8]. Instituto de Biología, Universidad Nacional Autónoma de México, México, D.F., México. [9]. CIAD-Unidad Guaymas, Lote 18 Manzana 1, Calle Banamichi, Fracc. Lomas de Cortes, Guaymas Sonora 85450 México
[10]. Tennessee Aquarium, One Broad St., P. O. Box 11048, Chattanooga, Tennessee 37401 USA.
[11]. Domicilio conocido, Colonia Juarez Chihuahua, México. [12]. Department of Biological Sciences, Scientific Collections, Box 870345, The University of Alabama, Tuscaloosa, Alabama 35487-0345 USA. [13]. John F. Kennedy Catholic High School, 500 Woods Mill Rd,

Manchester, Missouri 63011 USA [14].U. S. Environmental Protection Agency, 200 SW 35th St., Corvallis, Oregon 97333 USA. [15]. USGS, Alaska Science Center, Biological Science Office, 1011 E. Tudor Rd., MS 701, Anchorage, Alaska 99503 USA. [16]. Pfeiffer USA. [17]. Conservation Services Division, New Mexico Department of Game and Fish, P.O. Box 25112, Santa Fe, New Mexico 87504 USA. [18]. Alabama State Oil and Gas Board, 420 Hackberry Lane, Tuscaloosa, Alabama 35486 USA [19]. Cimarron Trading, 8436 Meadow Lane, Leawood, Kansas 66206 USA. [20]. Universidad de Sonora; DICTUS - Departamento de Investigaciones Científicas y Tecnológicas, Hermosillo, Sonora, México.cypriniformes@gmail.com

ABSTRACT. The Northwestern Sierra Madre Occidental of Mexico is a rugged mountain range covering portions of Sonora, Chihuahua, Durango and Sinaloa, and is drained by multiple Pacific Slope Rivers to the west and the Casas Grandes, Conchos, and Nazas to the east. The overall area is topographically, climatically and biotically diverse, ranging from endorheic basins (Casas Grandes) to mountainous areas elevations up to 3348 m, average mean temperatures from 10-20°C and precipitation from 250-1100 mm/yr. The regions is also geological complex that, combined with these other variables, provides a great diversity of both aquatic and terrestrial habitats conducive to both biotic endemicity and diversity. The over all diversity of the region has contributed to the recent listing of this region by Conservation International as one of six new high-priority biodiversity hotspots. Our understanding of the aquatic and terrestrial biodiversity of this region, however, is poorly understudied and in urgent need of rapid investigation by collaborative communities. The combination of an incredibly rugged landscape, drug and bandit activities and indigenous peoples that have not always been welcoming to visitors has resulted in a general paucity of roads in the region, and the lack of access has limited inventory studies. Recently, however, access to the region has changed dramatically and many of the areas are now accessible enough for logging, mining, and agriculture practices, all exerting extreme pressures in some areas on the biodiversity. In addition to human-induced changes to these diverse ecosystems impacts of invasive aquatic species are becoming more and more apparent, and the potential for severely reducing population sizes of species or their extirpation or extinction is real. While several invasive or exotic species are identified as potentially destructive to these communities, the exotic Rainbow Trout (Oncorhynchus mykiss) that is derived from hatcheries or culture facilities within the region represents one of the most critical threats to the aquatic and semi-aquatic biodiversity. The native trout of mainland México represent the southern-most salmonids, and are at imminent risk of introgression and/or replacement by feral Rainbow Trout, Oncorhynchus mykiss. Our recent survey efforts have expanded the known diversity and ranges of each of several distinct forms, which we feel represent valid species. We discuss our discovery of multiple new species from the Sierra Madre Occidental and focus on a new species of trout restricted to the upper Conchos drainage, the first native species of Oncorhynchus known to occupy the Atlantic Slope in Mexico. Many of these taxa are restricted to small areas of intact habitat in headwater areas of high-elevation streams, and are at risk from a suite of human-associated perturbations, emerging diseases, and introduced species. These fishes occupy unique habitats, and represent a diverse portion of the Méxican montane ichthyofauna. The habitats on which they depend support a wide range of other aquatic organisms, most of which are grossly understudied. The discovery of the Conchos Trout, derived primarily from the use of GARP niche modeling of a subset of localities of previously sampled undescribed native Mexican trout, provides only a snapshot of the biodiversity awaiting to be discovered in this region. The rugged landscape of the Sierra Madre Occidental simply precludes routine sampling at easily accessible locations of streams and most sampling locations require time-intensive access. In an effort to rapidly assess the biodiversity of rivers of this region we employed this method to aid in predicting the most suitable and highly probable Mexican trout niches in the region. This method offered highly efficient and powerful results that not only predicted the occurrence of a previously unknown trout in the upper Rio Conchos but also provided excellent predictions of available habitats in drainages where previously unknown trout have been discovered by the Truchas Mexicanas team in the last nine years. Multiple threats exist to the biodiversity of the northern Sierra Madre Occidental, including uncontrolled introductions of exotic and invasive species, emerging diseases such as whirling disease, Myxobolus cerebralis, infectious pancreatic necrosis (IPN), iridioviruses and pathogenic water mold, Saprolegnia ferax, land-use practices leading to habitat degradation via overgrazing, logging, deforestation and road construction, increasing human population growth, over-fishing or overharvesting of aquatic resources and global climate change reducing surface and ground water in the area and creating environments more conducive to the spread of invasive species, congregated and dense human populations, and emerging diseases. Immediate actions need to be developed to aid in public education as to the threats to these ecosystems, protection of areas, assessment of diversity, and sustainable development throughout the region that incorporates a likely highly successful ecotourism system for the region.

Key words: Sierra Madre Occidental, Trout, *Oncorhynchus*, Aquatic Biodiversity, Invasive Species.

RESUMEN. El Noroeste de la Sierra Madre Occidental de México es una montaña escarpada con grandes pendientes que abarca una porción de Sonora, Chihuahua, Durango y Sinaloa, y drena por múltiples ríos de la vertiente del Pacifico hacia el oeste y el Casas Grandes, Conchos, y Nazas hacia el este. El área total es topográfica, climatológica y biológicamente diverso, desde una cuenca endorreica (Casas Grandes) a áreas montañosas con elevaciones arriba de 3348 m, promediando una temperatura entre 10-20° C y una precipitación que varía de 250-1100 mm/año. La región es además geológicamente compleja, que, combinada con algunas otras variables, provee una gran diversidad de ambos hábitats: acuático y terrestre que conduce a endemismos bióticos y diversidad. El total de la diversidad de la región ha contribuido a la aparición en la reciente lista de esta región por Conservation International como una de seis nuevos puntos importantes de alta prioridad por su diversidad. Nosotros entendemos de la diversidad acuática y terrestre de esta región, generalmente es pobremente estudiada y es necesaria y urgente, una rápida investigación por colaboración de las comunidades. La combinación de un increíble paisaje accidentado, drogas y actividades ilegales, y las poblaciones indígenas que no siempre les dan bienvenida a los visitantes ha causado una falta general de caminos en la región y la carencia de accesos, ha limitado los estudios. Recientemente, sin embargo, el acceso a la región tiene cambios dramáticos y muchas de las áreas son ahora accesibles suficientemente para talar y para trabajos which they depend support a wide range of other aquatic organisms, most of which are grossly understudied. The discovery of the Conchos Trout, derived primarily from the use of GARP niche modeling of a subset of localities of previously sampled undescribed native Mexican trout, provides only a snapshot of the biodiversity awaiting to be discovered in this region. The rugged landscape of the Sierra Madre Occidental simply precludes routine sampling at easily accessible locations of streams and most sampling locations require time-intensive access. In an effort to rapidly assess the biodiversity of rivers of this region we employed this method to aid in predicting the most suitable and highly probable Mexican trout niches in the region. This method offered highly efficient and powerful results that not only predicted the occurrence of a previously unknown trout in the upper Rio Conchos but also provided excellent predictions of available habitats in drainages where previously unknown trout have been discovered by the Truchas Mexicanas team in the last nine years. Multiple threats exist to the biodiversity of the northern Sierra Madre Occidental, including uncontrolled introductions of exotic and invasive species, emerging diseases such as whirling disease, Myxobolus cerebralis, infectious pancreatic necrosis (IPN), iridioviruses and pathogenic water mold, Saprolegnia ferax, land-use practices leading to habitat degradation via overgrazing, logging, deforestation and road construction, increasing human population growth, over-fishing or overharvesting of aquatic resources and global climate change reducing surface and ground water in the area and creating environments more conducive to the spread of invasive species, congregated and dense human populations, and emerging diseases. Immediate actions need to be developed to aid in public education as to the threats to these ecosystems, protection of areas, assessment of diversity, and sustainable development throughout the region that incorporates a likely highly successful ecotourism system for the region.

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de minería, y prácticas agrícolas, todas ellas causando extrema presión en algunas áreas y su diversidad. En suma, los cambios inducidos por el hombre a estos ecosistemas impactan con especies acuáticas invasivas se hacen mas y mas aparentes, y el potencial para reducir severamente el tamaño de las poblaciones de especies o su extirpación o su real extinción. Mientras las especies invasivas o especies exótica son identificadas como potencialmente destructivas a estas comunidades, la exótica Trucha arcoiris (*Oncorhynchus mykiss*) que es derivada de granjas o cultivos, facilitan que para la región represente una de las mas criticas amenazas para la biodiversidad acuática y semi-acuática. La trucha nativa de las tierras principales de México, representa la distribución mas sureña de los salmónidos, y presenta un inminente riesgo de introgresion y/o reemplazo por individuos ferales de la Trucha arcoiris, *Oncorhynchus mykiss*. Nuestros recientes viajes y esfuerzos han expandido el conocimiento de la diversidad y la distribución de cada una de estas distintas formas, que nosotros sentimos, representan especies validas. Nosotros discutimos nuestros descubrimientos de múltiples especies nuevas de la Sierra Madre Occidental y nos enfocamos a una nueva especie de trucha restringida al alto Río Conchos, la primera especie nativa conocida de *Oncorhynchus* conocida, que ocupa la Vertiente del Atlántico en México. Muchas de estas son restringidas a pequeñas áreas de hábitat intactos en áreas de cabecera con arroyos de gran elevación, y están en riesgo, asociadas por las actividades humanas perturbadoras enfermedades emergentes, y especies introducidas. Estos peces ocupan hábitat únicos, y representan una diversa porción de la ictiofauna de montaña de México. El hábitat del que ellos dependen, dan soporte a una amplia gama de otros organismos acuáticos, la mayoría no han sido estudiados. El descubrimiento de la Trucha del Río Conchos, deriva primeramente del uso del modelo de nicho GARP, de un subconjunto de localidades de muestras previas de truchas mexicanas indescritas, proveyendo solo una chasquido de la biodiversidad aguardando para ser descubierta en esta región. El paisaje accidentado de la Sierra Madre Occidental, simplemente excluye la rutina de muestreo en las locaciones fácilmente accesibles de corrientes y las locaciones que requieren un intenso tiempo de acceso. En un esfuerzo de rápido acceso a la biodiversidad de ríos de esta región, nosotros empleamos este método para ayudar a predecir la probabilidad mas alta y conveniente para la trucha mexicana. Este método ofreció resultados sumamente eficientes y poderosos que no sólo predijeron la presencia de una trucha antes desconocida en la parte superior del Río Conchos, pero también las excelentes predicciones proporcionadas de los hábitats disponibles en los drenajes donde la trucha ha sido descubierto por el equipo *Truchas Mexicanas* en los últimos nueve años. Múltiples amenazas existen a la diversidad biológica del norte de la Sierra Madre Occidental, incluyendo las introducciones incontroladas de las especies exóticas e invasoras, surgiendo enfermedades como la enfermedad del remolino, *Myxobolus cerebrales,* infección de necrosis pancreática (INP), iridovirus y moho de agua patógena, *Saprolegnia ferax,* las practicas del uso de suelo llevan a la degradación de los hábitat por medio del sobrepastoreo, tala, deforestación y construcción de carreteras, incrementando en el crecimiento demográfico, sobrepesca o sobre explotación de los recursos acuáticos y cambios climáticos globales, reduciendo las aguas superficiales y de los mantos acuíferos en el área y creando medios ambientes que llevan a la dispersión de las especies invasivas, congregadas y densas poblaciones humana y apariciones de enfermedades. Se necesitan acciones inmediatas en el desarrollo en programas de educación pública en cuanto a las amenazas a estos ecosistemas, protección de áreas, evaluación de diversidad, y desarrollo sustentable a través de la región que incorpora un sistema probable y sumamente acertado de ecoturismo para la región.

Palabras clave: Sierra Madre Occidental, Truchas, *Oncorhynchus*, Biodiversidad acuática, Especies invasivas.

INTRODUCTION

The Northern Sierra Madre Occidental is a mountain range covering portions of four Mexican States (Sonora, Chihuahua, Durango and Sinaloa) (Fig. 1). The range is topographically, climatically and biotically diverse (Brown 1994), with elevations up to 3348 m, average mean temperatures from 10-20°C and precipitation from 250-1100 mm/yr. Its geological complexity (Ferrusquia 1993) further increases habitat diversity that contributed additional justification for its recent listing by Conservation International (Mittermeier et al. 2004) as one of six new high-priority biodiversity hotspots. The combination of an incredibly rugged landscape, drug activities and indigenous peoples that have not always been welcoming to visitors has resulted in a general paucity of roads in the region. As late as 1936, large portions of the Río Yaqui basin had not been substantially modified from a pre-European contact state (Leopold 1949). Despite recent construction of several new roads that facilitate access, travel within most the range is still extremely difficult, sometimes requiring several days and travel by foot or mule to access a single locality. Thus, despite both its proximity to the US, and interest in both the terrestrial (e.g. Escalante-Pliego et al. 1993, Ramamoorty et al. 1993, Navarro and Benítez 1993, Ceballos et al. 1998, Navarro and Peterson 2004) and aquatic biodiversity of México (e.g., Hulbert and Villalobos-Figueroa 1982, Villalobos-Figueroa 1983, Miller et al. 2005), the aquatic fauna of the Sierra Madre Occidental remains poorly known, especially in areas above 1500 m where trout species and many other cool-water adapted aquatic life forms occur.

Through more detailed investigations on the distributions, taxonomy and systematics of the aquatic faunas of this region we predict that the Northern Sierra Madre Occidental will also be recognized by Conservation International as a priority biodiversity hotspot for aquatic species. Unfortunately, these diverse, yet poorly known, aquatic ecosystems are under an imminent threat of extirpation and extinction. Threats include 1) uncontrolled introductions of exotic and invasive species including hatchery-reared Rainbow Trout (*Oncorhynchus mykiss*), the chytrid, *Batrachochytridium dendrobatidis* and New Zeland mudsnail (*Potamopyrgus antipodarum*), 2) emerging diseases such as whirling disease, *Myxobolus cerebralis*, infectious pancreatic necrosis (IPN), iridioviruses and pathogenic water mold, *Saprolegnia ferax,* 3) land-use practices leading to habitat degradation via overgrazing, logging, deforestation and road construction, 4) increasing human population growth, 5) over-fishing or over-harvesting of aquatic resources and 6) global climate change that is not only modifying habitats to be more conducive to the invasion of non-native species but is leading to decreased rainfall and lowering of the water table. All of these activities and their synergistic interactions will ultimately lead to the loss of, or reductions in, the native biodiversity of this unique region.

Our collaborative international alliance of investigators called *Truchas Mexicanas* (*est.* 1997) (Camarena et al. 2001, Hendrickson et al. 2003, Mayden 2002, Mayden 2004) is devoted to understanding the diversity of native aquatic species of the desert southwest, particularly trout species of México. The mission of *Truchas Mexicanas* is: A binational organization, est. 1997, founded by scientists and concerned citizens of México and United States, dedicated to proactive efforts conducive to better understanding the biodiversity and conservation of aquatic species of high-elevation aquatic systems of the Sierra Madre Occidental, especially the genus Oncorhynchus, and the ecosystems upon which they depend, via collaboration with indigenous peoples, local communities, and government and private conservation groups, to preserve these natural habitats, species diversity and ecosystems through partnership, education, sustainable development and acceptable models of ecotourism. The efforts of *Truchas Mexicanas* focus on revealing the distribution of trout and other aquatic diversity and habitat needs, evaluating threats to their continued existence, assessing community structure, modeling niches of vertebrate and invertebrate species and communities and working closely with Mexican citizens (including indigenous Rarámuri) and private groups and citizen education for the lasting conservation of these ecosystems through protection, public appreciation and education and ecotourism. The United States has been a terrible steward of similar high-elevation aquatic communities of its western and southwestern rivers through poor management of once pristine and diverse ecosystems, introductions of exotic hatchery-reared trout into basins with native trout species, a history of relocations of trout into different basins, non-existent or poor water and land management practices and a lack of foresight for sustainable development, agriculture and ranching. Our overarching goal is to prevent this mistake from happening in the Sierra Madre Occidental south of the US-México boarder and to educate the citizens and government for the lasting survival of these ecosystems and the species they contain.

The diverse efforts of *Truchas Mexicanas* have focused on conducting extensive fieldwork in aquatic ecosystems of the Sierra Madre Occidental for samples of native and exotic fishes for taxonomic, systematic, biogeographic, ecological, genetic and conservation studies. Samples of diversity from these expeditions have been deposited in natural history collections in México and US and are available for research and conservation purposes. To date, our efforts have focused primarily on native trout diversity and sampling for morphological and molecular variability in these fishes because of the urgency for knowledge of this diversity that is under siege by the region-wide threat posed by the exotic and invasive hatchery-reared Rainbow Trout (*Oncorhynchus mykiss)*.

STUDY AREA

Sierra Madre Occidental

The specific focal region of *Truchas Mexicanas* centers on high-elevation (>1500 m) aquatic habitats throughout the northern Sierra Madre Occidental (Figs. 1, 2) a north-south trending volcanic formation ranging from Cretaceous to Miocene in age (de Cserna 1989), with an average elevation of 2000 m (max. 3348 m). It is a natural biogeographic and physiographic entity (Brown 1994, Debano et al. 1994) covering about 300,000 km^2. This area is extremely poorly sampled for aquatic organisms; Miller et al. (2005), for example, presented data for 14 Río Conchos localities, only four above 2000 m, and almost all taken at road crossings. This is despite this drainage being an economically extremely important and very large, major tributary of the Río Grande (Rio Bravo), with relatively good access over much of its total area. Our searches of all North American fish collections databases revealed few collections from our study region and very sparse and uneven spatial sampling across it. While the Yaqui River basin was relatively thoroughly surveyed for fishes in 1978 (Hendrickson 1980), few recent collections exist, and collections from more remote areas (deep canyons and highest elevations) remain virtually absent. More southern basins like the ríos Sinaloa, Culiacán, San Lorenzo and Baluarte, prior to our work each had only two to five fish collections above 2000 m.

Taxonomic Groups Included in Surveys

Our taxonomic focus has been on fishes but future efforts will also include amphibians, riparian reptiles and aquatic invertebrates. Our preliminary data from morphological and molecular analyses of trout samples suggest that the Sierra Madre Occidental in México supports roughly one-fifth of the planet's trout species, almost all of which are currently unrecognized as distinct or unique. Our investigations have included analyses of the observations on the impact of hatchery-reared or cultured Rainbow Trout on native trout, amphibian and invertebrate communities and our surveys of other fishes provided unpublished morphological and molecular sequence data that support the existence of significant undescribed diversity in those groups as well. Given the patterns of diversity in the historically poorly studied fishes, we predict that collections of aquatic invertebrates and amphibians will similarly include high numbers of undescribed taxa in these even more poorly sampled groups.

Trout

Although existence of native trout in the Sierra Madre Occidental was first reported in the 1880s, inaccessibility of the region has hindered further detailed studies. The historic focus of *Truchas Mexicanas* on trout is largely a product of the general expertise of most participants and the need to rectify a striking lack of knowledge on this extremely important clade before it faces demise due to heightened levels of stocking and culture facilities for Rainbow Trout and other activities. In light of the rich interdisciplinary knowledge-base on species and subspecies of this trout clade residing north of the US-México border, the near total lack of knowledge of Mexican taxa is remarkable and unfortunate. The collective knowledge on non-Mexican taxa, however, provides an exceptionally rare scientific opportunity to reap disproportionate rewards from detailed inventory and analyses of the new, or at least nearly unstudied, Mexican taxa. While morphology-based taxonomic and systematic research can be difficult with trout due to phenotypic plasticity, our incorporation of a strong molecular component benefited immediately and immensely from the extensive genetic databases existing on the rest of the clade including *Oncorhynchus mykiss, O. chrysogaster* and their US and Canadian relatives. Furthermore, much of the notion of plasticity of morphology that is argued for non-Mexican trout has not been observed to the same degree in our Mexican samples. Our observations indicate that the argument that morphology is of limited value in taxon delimitation is intrinsically related to a "polytypic" species concept or Biological Species Concept superimposed on many years of trout species being considered composites of many subspecies or races. Our investigations of Sierra Madre trout employ the Evolutionary Species Concept with the Phylogenetic Species Concept as an operational surrogate (see Mayden 1997, 1999). When non-Mexican trout taxa are evaluated within this context and characters are evaluated in a phylogenetic context, arguments for polytypic species supported by a confusing mosaic of morphological variation are found to be largely unfounded and support recognition of *O. mykiss* ssp. north of México as multiple species or lineages (Mayden 2004, Mayden and Wood 1995, Mayden 1997, 1999). The polytypic concept for *O. mykiss* is unquestionably falsified by the historic occurrence of subspecies in sympatry. We find it more profitable to discover and describe diversity in Sierra Madre Occidental trout before it is lost or contaminated by introductions because of misguided transplants and stockings of "subspecies."

Our combined morphological and molecular investigations indicate that in addition to two species masquerading within the Mexican Golden Trout (*O. chrysogaster*) (Ruiz-Campos et al. 2003), the trout of the Sierra Madre Occidental may consist of as many as 10 new species within what was once thought to be a single subspecies of the Rainbow Trout lineage, the Coastal Rainbow Trout (*O. mykiss irideus*). These new taxa inhabit Pacific Slope rivers from the Río Yaqui south to the ríos Acaponeta and Baluarte, and the upper Río Conchos, the latter being the first record of a native trout of the Rainbow Trout clade from the Atlantic Slope. Historically, researchers have thought that the most southern populations of Rainbow-like trout of México were the products of introductions and not native elements of the fauna (Needham and Gard 1959, Behnke 1992, Miller et al. 2005). However, our analyses of varied character suites indicate that these trout are not only native but represent highly distinctive lineages worthy of taxonomic recognition and protection. Only in areas near culture facilities for hatchery Rainbow Trout have we found coloration differences and microsatellite and DNA sequence-based evidence of feral hatchery trout.

The native trout of the Sierra Madre Occidental are the southern-most living native salmonids and are adapted to the unique thermal and hydrological regimes of these ecosystems. We have only recently started to discover some of the unique qualities of these species, members of a clade typified as cold-water adapted to streams in low north latitudes. As an example, Nielsen et al. (2001), and confirmed by our studies, note the loss and/or modification of regions of the mtDNA control region (CR) in the restricted Mexican trout examined relative to *Oncorhynchus* in more northern latitudes. While at present the functional significance of this difference is unknown, the CR is known to contain regulatory elements and Coskun et al. (2003) hypothesize variants of CR are related to longevity, climatic adaptation, or enhancing the immune system via slowing the turnover of memory T-cells, and may function in this manner, as well as others visa-via binding to nDNA-encoded regulatory factors. Introductions of *Oncorhynchus* are documented over and over to lead to introgressive hybridization with native species a process that will compromise adaptations of these native trout to their more southern latitude environments and jeopardize these populations. Such loss of this diversity (species, genes, proteins) or their contamination via introgressive hybridization with cultured Rainbow Trout is tragic and irresponsible.

Native trout are important sources of protein for human populations, constituting a major dietary component for indigenous peoples especially in some regions of the Sierra Madre Occidental. Historical accounts (e.g., Needham and Gard 1959) discuss use of dynamite to gather trout, several guides demonstrated remarkable prowess with handlines, and ranchers told us how they collect trout by hand, with rocks, levers, knives, or using powdered gypsum to stun fishes. Others showed us several varieties of native plants that contain natural fish toxins used to collect trout. Native trout fisheries clearly represent an undeveloped economic resource to these regions. The rugged landscape and spectacular scenery already is driving a burgeoning tourism industry in portions of the Sierra Madre Occidental, most notably in the famous Barranca del Cobre, or Copper Canyon. Understanding and promoting native trout species diversity in México provides an incentive to retain native salmonids, and trout represent an un-tapped incentive for additional tourism based on sport fishing and ecotourism. Trout anglers make a substantial contribution to the economy of the neighboring American Southwest; in Arizona and New Mexico during 2001, 733,000 anglers spent 512 million US dollars on trips and equipment (USFWS 2002). With publicity, similar expenditures by anglers visiting the Sierra Madre Occidental are a reasonable expectation, thus providing a tremendously large new infusion of capital into this economically depressed region. Efforts by groups such as *Trout Unlimited, Conservation International* and *World Wildlife Fund,* in collaboration with developing governmental and private ecotourism initiatives could make this and sustainable development a reality.

Other Fishes

In addition to trout most of the high elevation Sierra Madre Occidental diversity in other fish groups is in four Cypriniform genera: *Campostoma*, *Codoma* and *Gila* (Cyprinidae), and *Catostomus* (Catostomidae). The first two genera have only two described species in our study area (*Codoma ornata* and *Campostoma ornatum*), but our examination of live and preserved specimens over the past nine years indicates that each represents polytypic complexes (some also noted in Contreras-Balderas 1975, Burr 1976, Miller et al. 2005), and preliminary molecular data reinforces those diagnoses. A few new species have recently been described from the area in the other two genera (*Catostomus leopoldi* and *C. cahita* by Siebert and Minckley 1986; *Gila brevicauda* by Norris et al. 2003), but within *Catostomus*, species relationships in the region are not well-resolved and several undescribed species are known (Miller et al. 2005; pers. obs.). The most widely-distributed species in the region, *Catostomus plebeius*, is clearly a complex of several undescribed species (Ferris et al. 1982, Crabtree and Buth 1987, pers. obs.), however, none of these groups have been rigorously analyzed in a phylogenetic framework . Efforts toward describing the additional fish diversity within the Sierra Madre Occidental have barely scratched the surface of the diversity remaining within *Catostomus*, *Gila, Codoma and Campostoma.*

Amphibians

Our biotic surveys have also included observations of a variety of amphibians, another group that is poorly inventoried and studied in this region (J. Campbell, D. Frost, pers. com.) and that will very likely be heavily impacted by introduced Rainbow Trout as well as possible chytrid and iridovirus (*Ranavirus*; Iridoviridae) infections. The Sierra Madre Occidental hosts a suite of endemic stream-associated amphibians that are likely to be complexes of species, including *Ambystoma mexicanum, A. rosaceum, Pseudeurycea belli sierraoccidentalis, Lithobates tarahumara and L. pustulosa.* Inventories and taxonomic revisions of these and other amphibians in the regions are critically important at this early stage before the exotic Rainbow Trout becomes more widely established.

Invertebrates

To date, our inventories of invertebrate faunas of high-elevation streams of the Sierra Madre Occidental have been highly cursory, but have included species of Odonata, Trichoptera, Ephemeroptera, Plecoptera, Diptera (Chironomidae, Simuliidae, Tabanidae), Coleoptera (Elmidae, Gyrinidae, Psephenidae). A dietary study by A. Reyes Valdez (2005), however, of gut contents of the different trout from drainages across the Sierra Madre Occidental (summarized for all taxa in Table 1) revealed a tremendous diversity of both aquatic and terrestrial invertebrates. It is highly likely that a thorough inventory of the region will reveal unknown biodiversity from these poorly inventoried streams. Such inventories are needed as soon as possible because as exotic Rainbow Trout expand predation pressure will be heightened and biodiversity could be lost.

Diversity, Sustainability and Socioeconomics

Based on our preliminary data from morphology, nDNA and mtDNA, Mexican trout populations and other fish species of these poorly inventoried streams are morphologically and genetically distinctive and offer important insights into the zoogeography of the region. These species and the amphibians and invertebrates are also important indicator species of habitat quality and environmental integrity in the region. Our discovery of several new species of cyprinid and catostomid fishes suggests additional still-undocumented diversity in fishes, aquatic invertebrates and amphibians in the region's poorly sampled and studied stream systems.

While the future of native trout and other aquatic biodiversity of the Sierra Madre Occidental appears bleak and heading down the same path that led to the high level of imperilment of diversity of numerous western US taxa, there remains room for cautious optimism. On visiting the town of Las Truchas, Durango, we observed that the municipal basketball court had a leaping trout painted on the backboard. Indigenous peoples in the region are very aware of their native trout, and in some cases fiercely proud. These people are also aware of the introduced trout. Most living in the countryside where trout occur can easily distinguish between the native and non-native trout when tested with unlabeled color identification sheets of the different trout and *Gila* (sometimes also called trout or truchus in some areas) known from within and outside of the area. Indigenous villagers refer to two types of trout, the native "aparí" or "*aparique*" and an introduced "*arco iris*" (Rainbow Trout), and tell us that the "*arco iris* drives out the *aparí*." Throughout much of the Sierra Madre Occidental, federal, state and municipal governments promote Rainbow Trout culture or grow-out facilities, much like the US government in western drainages. Eggs and/or larvae are readily available for transport to sometimes extremely remote and minimal facilities where they are reared for sale. Though promoted as a new source of food and income for local people, the short-term monetary gain to be made by promoting Rainbow Trout-based aquaculture in the mountains of the Sierra Madre Occidental is not justifiable when compared to the long-term worth and value of intact native faunas. Without concerted action and development of regional socioeconomic cures for largely non-sustainable resource management practices, not only will native Mexican trout soon be in grave danger of extinction, but the ecosystems of the region and associated biodiversity stand to be severely negatively impacted by invasive species and land management issues. Our work with *Trout Unlimited, World Wildlife Fund, Conservation International, México-Norte* and others is critical for advancing alternative means of subsistence and economic alternatives that focus on carefully managed use of native trout to replace Rainbow Trout. Tourism based on native trout, and perhaps one day even limited culture of them, is much more likely to produce sustainable income in this beautiful rugged country with multiple other tourist attractions.

Maintenance of this rich biodiversity and the outstanding array of ecosystems in the Sierra Madre Occidental calls for development of an organized effort by indigenous peoples of the region, supported through Mexican governmental agencies, to enact legislation for the sustainable development of the region before it is severely impacted. Strong economic incentives exist for maintaining this biodiversity if a holistic plan can be developed in concert with partners sharing a common goal to maintain the native diversity and its habitat that will serve as underpinnings for the plan. Scientists and managers of *Truchas Mexicanas* as well as representatives from *Trout Unlimited, World Wildlife Fund, Conservation International, México-Norte* and our other collaborators are willing participants to provide any form of assistance in developing long-term plans in collaboration with the indigenous peoples of this important biotic region.

Imminent Threats to the Aquatic Biodiversity of Sierra Madre Occidental

The aquatic biodiversity of the Sierra Madre Occidental, known and to be discovered, is at imminent risk of loss, either by extirpation or extinction, from a whole suite of adverse impacts from habitat degradation via logging, road building, overgrazing, infectious disease introduced via exotic Rainbow Trout, human population growth and land-use practices without education towards sustainable development. Furthermore, as is now well documented throughout North America, Europe and elsewhere for many taxa (Parmesan et al. 1999; Parmesan and Yohe 2003; Parmesan and Galbraith 2004), distributions of organisms are being forced to shift upward in both elevation and latitude as a result of global climate change. Native Mexican trout, occurring as they do at the most extreme altitudes on mountaintops, and constrained to their headwater streams, are severely threatened by and exceedingly susceptible to climate change. It is only through greater understanding of their distributions, ecology and evolutionary history that humans might be able to help preserve the biodiversity of such areas (e.g. Parmesan and Galbraith 2004, O'Neal 2002). Climate change altering the amount of rainfall in the region may also provide environmental conditions more conducive to spread of invasive and/or infectious exotic pathogenic species. The native trout are additionally imminently threatened by introgressive hybridization and competition with introduced Rainbow Trout. Protection of the region's native biodiversity and educational efforts with indigenous people are critical and integral efforts that must accompany the inventory and discovery process. Such efforts must be developed with the aid of NGOs, public and private agencies and governmental bodies through input and direction provided by scientists and sociologists and with a sensitivity for indigenous cultures. Only with the efforts and cooperation of the indigenous peoples can these sensitive ecosystems continue to flourish.

Habitat Degradation

Logging is currently the principal form of legal resource extraction in the region, and even the most remote areas visited in expeditions exhibited signs of overgrazing and logging. Many stream channels display evidence of abnormally high maximum flows and extreme low flow periods, characteristic of streams with disturbed watersheds. Loss of riparian ground cover through overgrazing and/or logging can dramatically increase both the amplitude of stormwater runoff and maximum temperature at baseflow conditions, and result in reduced survival of adapted biodiversity (Propst et al. 1992, Li et al. 1994, Knapp and Matthews 1996). Both overgrazing and logging also lead to increased erosion and accumulation of siltation in aquatic habitats. This, in itself, is perhaps one of the most significant threats to freshwater ecosystems worldwide. The negative impacts of siltation on locally adapted aquatic communities is well documented to clog the gills of fishes, smothers eggs of fishes, amphibians and invertebrates, lead to a generally silent elimination of microhabitats for all species and significantly diminishes the filtration capacity of the hyporheic zone (Williams et al. 1993, Lydeard and Mayden 1995, Carpenter et al. 1998, Wilcove et al. 1998, Boulton et al. 2003). Trout are especially susceptible to siltation because successful egg incubation can only occur in clean gravels with large amounts of interstitial spaces that provide water flow sufficient to keep eggs and larvae well oxygenated. We have visited many Sierra Madre streams that might support trout were it not for severe siltation. Furthermore, soil particles washed into streams serve as vehicles for the transport of toxins like pesticides, herbicides and fertilizers that can become attached and leach out into aquatic systems (Goldman et al. 1986, Carpenter et al. 1998, Osterkamp et al. 1998). Construction of roads to support logging increases access for settlers and impacts associated with higher human density. Sawmill-related contaminants such as sawdust, oils, diesel fuel and tannin leachate have local point-source effects on aquatic systems.

Few of the many villages of the Sierra Madre Occidental have any form of sewage treatment and contamination of streams by human waste is nearly pandemic. Nutrient enrichment from livestock and human wastes can drive increased microbial production, depleting dissolved oxygen and causing catastrophic mortality of native aquatic organisms (Fleischner 1994, Strand and Merritt 1999). Likewise, increased human populations with limited availability of food resources has exerted "unnatural" pressure on the native fish populations. Intense fishing pressure on some streams has driven some of the diversity to extirpation within the period of time that we have worked in the Sierra Madre Occidental.

To date, while reservoir construction has mostly been at lower elevations, there is increasing interest in hydropower development of rivers of the Sierra Madre Occidental, and many smaller reservoirs are being constructed or proposed in higher elevation locations. Such reservoirs will lead to an unequivocal loss of valuable habitat for the native aquatic biodiversity, and along with them will come additional settlers, as well as introductions of exotic fishes, amphibians, invertebrates and likely new diseases that will negatively impact the native biodiversity.

Invasive Rainbow Trout

Rainbow Trout have been reared in hatcheries across North America since the U.S. Fish Commission established a hatchery on the McCloud River, California in 1872. Over the subsequent ~130 years, Rainbow Trout have been broadly introduced around the globe (Fuller et al. 1999), with considerable impacts on local faunas. The first hatcheries in México were founded in 1888 with a shipment of ~25,000 McCloud River Rainbow Trout eggs to a hatchery in México City, but the extent to which progeny from these fish were distributed across the Sierra Madre Occidental is unknown. However, Rainbow Trout production is now a significant business in México, with the greatest production (5,000 tons/year) in the state of México. Production in Chihuahua and Durango is exceeded by 5 or 6 central and southern states (far from currently known native trout ranges), but the number of new facilities is increasing very quickly throughout the country (Gómez Lepe and Sarmiento Frader 1999).

Though Chihuahua and Durango are far from the biggest Rainbow Trout producers in the country (or were in 1999 - Gómez Lepe and Sarmiento Frader 1999), one of the most striking field observation from our expeditions was that Rainbow Trout culture operations are abundant, and we have witnessed an apparent rapid increase in them throughout the range of Mexican native trout. We have collected Rainbow Trout at numerous sites in the Sierra Madre Occidental, both at areas in close proximity to hatcheries or culture facilities as well as in relatively remote headwater streams. Some local entrepreneurs have also developed basic grow-out facilities by diverting portions of stream channels into side areas dammed by cement block, cobble and cement or even galvanized sheet metal roofing; these makeshift facilities are frequently destroyed by floods releasing their captive non-native trout. Introduction of Rainbow Trout in Sierra Madre Occidental streams will result in a situation closely paralleling that of cutthroat trout in the U.S., where pure native populations are largely restricted to headwater streams. Populations in such habitats are more susceptible to both demographic effects of low population size, as well as external threats as climate change, droughts, fire, human utilization, etc. This suite of threats has led to a recent reassessment of the long-term viability of conservation strategies based on isolation (Kruse et al. 2001, Hilderbrand and Kirschner 2000, Novinger and Rahel 2003). Our genetic assessments of some populations of native trout reveal similar evidence for genetic bottlenecks.

Abundant literature clearly demonstrates that hybridization between *Oncorhynchus* spp. is a major obstacle to effective management of native stocks throughout the range of the genus in North America. Recent studies in Montana (Hitt et al. 2003) suggest that even areas previously thought safe from introgression are at risk. While hatchery-reared Rainbow Trout, whether intentionally stocked or accidental escapees, may not be very successful due to lack of adaptation to local environmental conditions (Leider et al. 1990, Fleming and Petersson 2001, McLean et al. 2004) they may still competitively interact with native trout (Griffith 1988, Einum and Fleming 2001) and displace them from the best habitat. We have documented feral Rainbow Trout in Mexican rivers and have evidence from microsatellite markers for gene exchange in some areas; thus demonstrating that they are surviving in these drainages and non-native genes are introgressing into native trout populations. This may be the most disastrous long-term impact, as even low levels of hybridization with introduced individuals of low fitness can lead to breakdown of locally-adapted gene complexes and reductions in fitness of the introgressed population (McGinnity et al. 2003). Introgression with introduced Rainbow Trout is one of the most severe threats to cutthroat (Weigel et al. 2003), Gila (Rinne 1990), Apache (Rinne 1990) and California golden trout (in Rainbow Trout lineage) (Cordes et al. 2006), and likely represents the greatest threat to native Mexican trout as well.

The potential for introgression is exacerbated by behavioral and life-history attributes of salmonids; as hatchery fish are usually larger at the same age as native fish, and body size plays a large role in reproductive success in salmonid populations (Foote and Larkin 1988, Dowling and Childs 1992, Rosenfield et al. 2000, Ostberg et al. 2004). Larger males are preferred by females (Foote 1989) and may exclude smaller males from access to females (Quinn and Foote 1994). Larger females occupy higher quality nest sites (van den Berghe and Gross 1989, Foote 1990) and dig deeper nests (Steen and Quinn 1999) resulting in lower mortality of eggs and higher larval survivorship.

The negative impacts of Rainbow Trout are not limited to native Mexican trout. Introduced Rainbow Trout have been strongly implicated in declines of both macroinvertebrate and amphibian communities in western North America (Taylor et al. 1984, Dunham et al. 2004). Trout impact composition and function of benthic communities by either altering behavior of invertebrates (Peckarsky et al. 2002), or through direct predation (Simon and Townsend 2003). Trout tend to select larger food items, especially grazing caddisflies (Flecker and Townsend 1994, McIntosh et al. 1996) and predatory stoneflies (Herbst et al. 2003), and the effects of predation can include increases in both algal biomass and abundance of chironomid midges (Herbst et al. 2003). With the increased algal biomass there can be toxic algal blooms (Carpenter et al. 1998) and streams exposed to increased sunlight through clear-cutting of forests will increase in temperature and lead to anoxic conditions that will be intolerable to native species.

Populations of several amphibians, particularly ranid frogs of the genus *Lithobates* (formerly *Rana*) and ambystomatid salamanders appear particularly susceptible to impacts from introduced trout (Drost 1996, Tyler et al. 1998, Matthews et al. 2001, Vredenburg 2004, Knapp 2005, Welsh 2006), as both groups lack chemical defenses to fish (Kats et al. 1988) and use permanent bodies of water for reproduction. Introduced salmonids prey on larvae of both taxa, and can have major impacts on local population size (Welsh et al. 2006). Interestingly, in the past several years of our expeditions, only sites without fishes or with native salmonids have been observed to maintain populations of *Ambystoma* or *Lithobates*. As this portion of the Sierra Madre Occidental hosts a suite of endemic stream-associated amphibians, including *Ambystoma mexicanum, A. rosaceum, Pseudeurycea belli sierraoccidentalis, Lithobates tarahumara and L. pustulosa*, the impacts of Rainbow Trout introductions could be devastating.

Fish Diseases and Hatchery Rainbow Trout

Aquaculture of Rainbow Trout poses a high risk of infecting native trout with exotic diseases, either through escape or exchange of water in culture facilities (Bartholomew and Wilson 2002). The rapid spread of *Myxobolus cerebralis*, the causal agent of whirling disease, is implicated in catastrophic declines in trout populations in the western US (Bergersen and Anderson 1997). Similarly, recent discovery of infectious pancreatic necrosis (IPN) in trout-based aquaculture facilities in México (Ortega et al. 2002) is of grave concern. IPN is a highly virulent virus causing substantial mortality in salmonids (Reno 1999). If wild populations are exposed they are potentially compromised, and our research indicates that IPN-exposed hatchery stocks were shipped to culture facilities in Chihuahua within the range of native trout (Gerardo Zamora, pers. comm.).

We have no insights as to how native trout will respond to these new pathogens that have now almost surely been carried into streams in some areas of the Sierra Madre Occidental. Clearly the longer we wait for preventive measures, the more pervasive the impacts of these complex issues will become, further confounding their resolution and exacerbating biodiversity loss. The huge part of the diversity of *Oncorhynchus* residing in México remains more vulnerable than ever to extirpation/extinction via hybridization, competition, predation, diseases and habitat alteration. The same factors will, of course, have repercussions throughout the aquatic ecosystems, extending obviously far beyond fishes.

Other Emerging Diseases

The decline of amphibian populations, both in the Sierra Madre Occidental (e.g. Clarkson and Rorabaugh 1989, Hale et al. 2005) and at a worldwide scale (Blaustein and Wake 1990, Wake 1991, Wake and Morowitz 1991, Houlahan 2000), is a source of considerable concern. While causal factors ranging from climate change (Carey and Alexander 2003, Pounds et al. 2006), UV radiation (Kiesecker and

Blaustein 1995, Blaustein and Kiesecker 1997), air pollution (Clarkson and Rorabaugh 1989, Beebee et al. 1990), pesticides (Davidson et al. 2002, Relyea 2004), endocrine disruptors (Reeder et al. 2004), diseases from fish culture (Kiesecker et al. 2001), emerging diseases (Laurance et al. 1996, Berger et al. 1998), introduced bullfrogs (Hayes and Jennings 1986, Kiesecker and Blaustein 1998) and fishes (Bradford 1989, Kiesecker and Blaustein 1998, Tyler et al. 1998, Matthews et al. 2001) have all been implicated at local scales, considerable disagreement over the relative role of each of these factors exists (Collins and Storfer 2003).

However, emergent diseases appear to play a large role (Berger et al. 1998, Daszak et al. 2003, Ron et al. 2003, Retallick et al. 2004). Populations of Chiricahua and Tarahumara leopard frogs (*Lithobates chiricahuensis* and *L. tarahumara,* respectively) in Arizona crashed during the late 1970s and early 1980s (Clarkson and Rorabaugh 1989). One is now extirpated from the US. Their decline has been tied to a chytrid, *Batrachochytridium dendrobatidis* (Hale et al. 2005). Other evidence suggests that an iridovirus may be spreading across much of North America (Jancovitch et al. 2005), with similar effects on amphibian populations. Several studies have documented transmission of iridoviruses (Mao et al. 1999) and the pathogenic water mold *Saprolegnia ferax* (Kiesecker et al. 2001) from introduced fishes to native amphibians. All of these were recently reviewed in a scientific symposium involving experts (2006 American Society of Ichthyologists and Herpetologists Annual Meeting, New Orleans, LA, Symposium). Amphibian populations in high-elevation habitats of the Sierra Madre Occidental have not been thoroughly surveyed, and the incidence of *Batrachochytridium dendrobatidis* and iridoviruses in the region will provide valuable data for focused management efforts. Despite laboratory studies that suggest complete mortality of some species of infected postmetamorphic frogs (Briggs et al. 2005), the presence of *B. dendrobatidis* in wild populations is not automatically a death knell for a population (Berger et al. 1998, Davidson et al. 2003, Daszak et al. 2005), and some species (*Xenopus laevis, Lithobates catesbiana*) may serve as vectors of the fungus into new areas (Briggs et al. 2005, Blaustein and Dobson 2006). However, enough studies have implicated chytrids as a principal cause of amphibian declines that identification of the current range of the chytrid would allow additional attention to be placed on infected populations. Climate change may also exacerbate effects of these pathogens (Alford and Richards 1999, Berger et al. 2004, Piotrowski et al. 2004, Ron 2005) and changes in the climatic characteristics of the Sierra Madre Occidental with global warming can provide habitats and conditions more conducive to their invasion or spread throughout the aquatic systems.

Other Exotics

The New Zealand mudsnail (*Potamopyrgus antipodarum*) is a small (<5mm), invasive hydrobiid snail that is rapidly spreading across coldwater streams in western North America. It is currently known to occur in 10 U.S. states, including Arizona, but has not to date been reported from México. It reaches densities of up to 800,000/m^2 (Dorgelo 1987), carpeting substrates and causing dramatic reductions in other benthic invertebrates. It is not generally used as food by fishes (M. Vinson, unpubl. studies suggest ~45% of mudsnails ingested by trout pass through the digestive tract alive), and has the potential to seriously impact streams of the area.

Climate Change and Sierra Madre Occidental Biodiversity

Global warming under a predicted 2xCO_2 model is expected to negatively affect coldwater fishes and other biotas of these communities overall, although the individual effects of climate change may be difficult or impossible to predict (Hauer et al. 1997). Longitudinal displacement of trout upstream as a response to warming (Meisner 1990, Rahel et al. 1996, Eaton and Scheller 1996, Jager et al. 1999) is unlikely in the Sierra Madre Occidental since they are already found only in the uppermost headwater streams, generally with dry reaches for some distance above, and sometimes below, especially during droughts. Results obtained by Jager et al. (1999), who documented an improvement of headwater habitat for coldwater fish in high-elevation streams in Colorado under global warming scenarios, are not applicable to our study area. In that study, persistence and population dynamics are controlled by cold winter temperatures and formation of anchor and frazil ice, both of which are unknown in the Sierra Madre Occidental. Persistence of trout and other fishes under typical conditions in the Sierra Madre is often dependent on availability and spatial distribution of deep pool habitats, which serve as refugia during droughts. Thus, the aquatic faunas of the Sierra Madre Occidental will likely be highly negatively impacted by global warming, especially if logging in riparian areas continues and exposes stream areas to more sunlight, and human population growth and agriculture activities continue to increase demands on surface and ground waters.

METHODS

Field Collections

Our collections have been done primarily in winter and spring months, and the localities sampled have been preferentially those that we judged most likely to harbor trout, based on elevation (generally > 1500 m) and general habitat conditions, advice of local residents, and GARP modeling. Occasionally we have collected lower elevation streams as we pass by them enroute to higher elevations. Though many of our collections have been made at locations accessible via 4-wheel drive vehicles, many more have required sometimes long hikes. Though many of our collections have been made well within areas determined by the U.S. Drug Enforcement Agency to have the highest densities of Cannabis and Opium cultivation in the region (U.S Drug Enforcement Agency 2001 a, b), occasionally local guides have advised against collecting in certain areas that are known to have high levels of drug-related crime, thus further affecting distribution of our sampling.

Fishes have been collected using a variety of gears, primarily D.C. electrofishing using Smith-Root battery and gasoline-powered backpack units from Coffelt adjusted to function efficiently at each location without causing undue harm to individuals and populations (Snyder 2003). We have also used a diversity of nets, mostly small seines of various meshes, gill nets, and dip nets, and have deployed sport fishing equipment (rod and reel). Occasionally we purchased specimens, especially Rainbow Trout from culture facilities, from local residents. Our observations on amphibians, reptiles and invertebrates have been made coincident with fish collection activities, though we routinely dedicate some time at each field sites for targeted observations of these groups, including surveying invertebrates by turning rocks and using dip nets.

All of our collections have been located using GPS receivers while in the field. Though details habitat conditions have not generally been rigorously quantified, general descriptions of all habitats have been recorded in standard ichthyological fieldnotes.

Specimens for morphology have been preserved in 10% formalin after fin clips are taken and preserved in absolute ethanol. After transport to the lab, specimens are moved to

70% ethanol for long-term storage. Occasionally entire smaller specimens have been preserved in the field directly in absolute ethanol.

Genetic and Phylogenetic Analyses

Tissues from 246 specimens representing 20 wild populations of Mexican *Oncorhynchus* collected between 1997 and 2002 were air-dried or preserved in 95% ethanol. An additional 31 specimens were obtained from three hatcheries in México. Total genomic DNA was extracted with QIAGEN DNEasy kits following QIAGEN protocols. Twelve microsatellite loci (Omy2, Omy27, Omy77, Omy207, Omy325, Onem8, Onem11, Ots1, Sfo8, Ssa14, Ssa85 and Ssa289) were amplified for the preliminary study using standard PCR protocols described in Nielsen and Sage (2001); all microsatellite data generation for these samples was conducted in Dr. Jennifer Nielsen's laboratory, Anchorage, Alaska. Microsatellites were visualized on a LI-COR Long Reader 4200 automatic sequencer with Gene ImagIR (v3.0) software. Mitochondrial D-loop sequence data was generated from a subset of 45 individuals and amplified using primers DL1F and DL4R (Bagley and Gall 1998). ATPase 6 and 8, and GH1C and GH2C were amplified from a further subset of 20 individuals using primers from Kontula et al. (2003) and Phillips et al. (2004). QIAGEN gel purification kits were used to purify PCR products prior to sequencing on an ABI3100 Genetic Analyzer. Complete sequences were assembled from individual electropherograms, edited and aligned with BioEdit v6.0.7 (Hall 2001).

Additionally, two microsatellite loci (Ssa289, One11) have been analyzed for a total of 545 individual trout from expeditions up to 2004. This included 257 wild individuals and 48 hatchery individuals (18 Yaqui trout from G. Zamora and 30 *O. mykiss* from Granja Truticola on A. la Sidra, San Lorenzo). These analyses were conducted by Anna Bellia De Los Santos Camarillo and Dr. F. J. Garcia de Leon at Centro de Investigaciones Biologicas del Noroeste (CIBNOR), La Paz, Baja California Sur, México.

Tests of linkage disequilibrium, HWE and genotypic differentiation were performed using GENEPOP (Raymond and Russet 1997). Genetix was used for Factorial Correspondence Analysis. Analysis of molecular variation (AMOVA) was performed using Arlequin v2.0 (Schneider et al. 2000).

DNA sequences (mtDNA & nDNA) were derived for 271 native Mexican trout and hatchery or cultured Rainbow Trout individuals for Control Region, ATPase 6/8, GH1C and GH2C. Sequences for outgroup taxa and the data set of Bagley and Gall (1998) were downloaded from GenBank and included in all analyses. Outgroup taxa included *Oncorhynchus clarkii, O. masou* and *O. keta*. Phylogenetic analyses were examined under the maximum parsimony (MP) criterion using PAUP* (Swofford 2000) and with Bayesian analysis (Huelsenbeck and Ronquist 2001). Heuristic searches were conducted with characters weighted equally and unordered. Gaps were treated as missing data. Starting trees were obtained by stepwise addition, with 1000 random addition sequence replicates and TBR branch swapping. Support for nodes was assessed using nonparametric jackknife resampling (37% deletion, 1000 pseudoreplicates; Farris et al. 1996). Jackknife scores above 85 were considered well supported (Zander 2004). Bayesian analyses utilized MrBayes v3.0.4 (Huelsenbeck and Ronquist 2001). A four-chain heated MCMC analysis was run for 2,000,000 generations, with sampling every 1000 generations. Stationarity was reached by 100,000 generations; to be conservative, the first million generations were discarded as burn-in. Posterior probabilities above 90 were considered to be well supported (Zander 2004).

Morphological Variation

Native Mexican trout are being evaluated for variation in standard characters used routinely in studies of other species of the genus, including coloration patterns of breeding and non-breeding adults and juveniles, disposition and color of the lateral stripe, arrangement, size and shape of the small melanophore spotting, number of parr marks, number, shape and size of auxiliary parr marks. vertebral counts, fin-ray counts and scale counts.

GIS and GARP modeling

We used the Genetic Algorithm for Rule-set Prediction (GARP; Stockwell and Peters, 1999; Anderson et al., 2003; Peterson and Robins 2003) to estimate species' ecological niches and predict their distributions throughout our study area. GARP is a machine-learning approach for detecting associations between known occurrences of species and landscape characteristics, particularly when the ecological landscape is complex and relationships are not straightforward (Stockwell and Noble, 1992; Stockwell and Peters, 1999). Inspired by models of genetic evolution, GARP models are composed of sets of rules that "evolve" through an iterative process of rule selection, evaluation, testing and incorporation or rejection (Holland, 1975; Anderson et al., 2002). GARP searches for non-random associations between occurrences of species (georeferenced localities in geographic coordinates) and environmental variables (i.e., digital maps of relevant ecological parameters). GARP divides occurrence data randomly into data input into the genetic algorithm for model development ("training") and an independent data set ("extrinsic testing data") for evaluation of model quality at user-determined proportions (80% and 20%, respectively). The training data are resampled to 1250 training data points, and 1250 points are randomly sampled from all cells where training data do not occur (as a pseudo-absence data set). These 2500 points are used to develop the rules and as intrinsic testing data (for evaluation of rule predictivity). Spatial predictions of presence and absence can hold two types of error: omission (areas of known presence predicted absent) and commission (areas of known absence predicted present), which can be summarized in a measure of predictive accuracy as the percentage of points correctly predicted as present or absent (the correct classification rate of Fielding and Bell (1997)). Changes in predictive accuracy from one iteration to the next are used to evaluate whether particular rules should be incorporated into the model or not, and the algorithm runs either 1000 iterations or until convergence (Stockwell and Peters, 1999). The final ecological niche model rule-set is then projected onto the digital maps that are the environmental data sets input into the algorithm to identify areas fitting the model parameters, a hypothesis of the potential geographic distribution of the species. Predictive accuracy of the resulting model is evaluated based on the extrinsic testing data. Accuracy metrics based on these data are used to select the 10 best-subset models from all models generated.

We georeferenced Mexican trout collections extracted from museum specimen records and personal collections, scientific literature and our own field surveys (Hendrickson et al. 2003 and additional unpublished data from *Truchas Mexicanas* team surveys). Environmental data sets used in our GARP analyses included 13 digital maps ("coverages") summarizing aspects of topography (elevation, topographic index, slope, aspect and flow accumulation, from the US Geological Survey's Hydro-1K data set, native resolution 1x 1 km), climate (as absolute and average minimum and maximum temperature (1:1,000,000)), precipitation (1:1,000,000), evapotranspiration (1:4,000,000) and soils (1:250,000 polygon coverage). Climate and soil coverages are from the CONABIO digital map library, available at: http://conabioweb.conabio.gob.mx/metacarto/metadatos.pl. All coverage data were resampled at 0.01 x 0.01 decimal degree resolution and clipped into 2 datasets; one consisting of all of México and one to a buffered distance of 100 km of the locality data. Models are built on the buffered set and then projected onto all of México to facilitate analysis.

Once the model was developed for Pacific Slope Mexican trout species, using the same topographic and remotely sensed physical data sets for the Río Conchos drainage, we asked Desktop GARP to predict the distribution in that drainage of any species with similar ecological parameters. Assuming that the Conchos Trout would have habitat requirements similar to those of trout native to the Pacific drainages, and most likely most similar to the geographically closest other native trout, those from the the Yaqui basin, the GARP model based on input Yaqui trout data, indicated considerable potential trout habitat in the Río Conchos and elsewhere throughout the Sierra Madre Occidental region (Figure 3).

RESULTS

Distribution and Diversity of Trout in México

As reviewed in Hendrickson et al. (2003) relatively few samples of trout from México predated the formation of the binational research and educational team of *Truchas Mexicanas*. Through our concerted efforts of intensive review of the literature and private historic correspondence, reconnaissance of maps and areas throughout the northern Sierra Madre Occidental, interviews with indigenous people and nine years of surveys we have documented the occurrence of native trout from the Río Yaqui system south to the rios Acaponeta and Baluarte. Prior to these efforts sporadic samples of Mexican Golden Trout were known from the rios Fuerte, Sinaloa and Culiacán systems and reports of a Rainbow Trout-like trout were known from the upper Río Yaqui and the endorheic Casas Grandes basin. Our collections made since the publication of the Hendrickson et al. (2003) review have added 20 additional localities from throughout our study area, expanding the known distribution of native trout in México.

Genetics

Microsatellite Variation

No significant linkage disequilibrium was found among any of the 12 loci examined. All but two populations were in Hardy-Weinberg equilibrium; the two populations deviating from Hardy-Weinberg equilibrium were those from the Granja Truticola hatchery and the wild population immediately below the hatchery on Arroyo la Sidra. Factorial correspondence analysis recovered three groups among the trout populations examined, one from the northern drainages, ríos Yaqui and Casas Grandes, one containing the Mexican golden trout, and one from the southern drainages (ríos Presidio and San Lorenzo) and all hatchery individuals. Variation explained by these groups was low (16.74%), but this was possibly due to smaller sample sizes in the southern drainages adding "noise" to the analysis. AMOVA conducted for these three groups revealed a higher variance between groups than between populations in each group (29% versus 19%). Within population variance comprised 52% of the total variance in the dataset. The high F_{st} value of 0.4722 indicates significant population substructure. Additional AMOVAs conducted for each of the groups yielded two groups within the Mexican Golden Trout (*O. chrysogaster*), one composed of trout from the Río Fuerte and the other contained trout from the ríos Culiacan and Sinaloa. Ten individuals of Mexican Golden Trout from the Río Fuerte exhibited no allelic variation across nine of the twelve loci surveyed. This suggests a recent bottleneck event within this population, with concomitant reductions in genetic variability and potentially lowered levels of fitness. This could also be driving the genetic differentiation within the Río Fuerte and other populations of this species. All pairwise population comparisons using microsatellite markers indicated that hatchery trout were significantly distinct from trout in the adjacent streams. This is an indication that introgression has not completely erased the genetic signature of native trout species. The high F_{st} identified in the Presidio sample may suggest co-occurrence of native and hatchery fish without introgression or hybridization. Additional specimens from this area are needed to address this question further.

More detailed examination of 545 semi-rare wild trout and cultured Rainbow Trout for two microsatellite loci (Ssa289, One11) again indicated that neither of these loci exhibited linkage disequilibrium, and populations did not deviate from Hardy-Weinberg equilibrium, except hatchery samples and natives found near hatcheries. As with the more complete survey of loci, three genetically homogeneous and distinct groups were found, a northern group (ríos Yaqui-Mayo-Guzmán), Mexican Golden Trout group (Fuerte-Sinaloa-Culiacán) and southern group (ríos Piaxtla-Acaponeta-Baluarte-San Lorenzo). These two loci provided evidence of 1) different degrees of genetic introgression in the genome of the native populations with introduced Rainbow Trout and 2) the persistence of pure stocks of native forms, confirming that native trout are threatened by introgression. We documented hatchery trout in several additional drainages and that introgression is occurring in several locations. The more detailed analysis of the loci Ssa289 and One11 indicated that almost all major drainages were significantly different from each other; the only exceptions being the ríos Acaponeta-Presidio and the Río San Lorenzo Hatchery–Acaponeta. While this provides weak support for a transfer of fishes between the San Lorenzo hatchery and the Acaponeta, and to a lesser degree into the Presidio, additional loci are required for verification. Notably, F_{st} and genetic distance between native and hatchery samples from the San Lorenzo (F_{st}=0.569, D_s=0.499) suggest that native haplotypes in the San Lorenzo have not been completely lost to introgression with hatchery individuals. No evidence of *O. mykiss* alleles were observed in the Baluarte or Piaxtla drainages; both being rather divergent from all other populations examined, suggesting a long history of isolation.

Genotypic differentiation tests for all pairs of populations revealed that most were significantly different. Populations not included were two within the Río Bavispe drainage (northern Río Yaqui), two localities on the Río la Cueva (Río Yaqui) and two different hatchery populations. All pairs of hatchery trout and wild populations immediately adjacent to the hatcheries were significantly different. For these pairs, F_{st} values were highest for Río Presidio/El Salto hatchery pair (0.45), and lowest for the Río Fuerte/El Aparique hatchery pair (0.05). The Arroyo de la Sidra/Granja Truticola hatchery pair was intermediate with F_{st}=0.06. One allele of the locus Ssa289 was recovered in Río Yaqui trout but was out of the size class of any of the hatchery fish, indicating a wild origin. Based on the microsatellite data, though genetic introgression of hatchery trout has not obscured the genetic signature of stream trout, the possibility of hybridization cannot be discounted.

While genetic data to date suggest introgression near the ríos Fuerte/El Aparique and Arroyo la Sidra/Granja Truticola hatcheries, they are largely uninformative as to the question of more widespread introgression in these systems. We have collected fish that were morphologically "good" Rainbow Trout in streams in close proximity to both hatcheries, and in sympatry with native trout. We have also observed early spawning among native populations of trout. Specimens collected from the rios Acaponeta, Baluarte, Yaqui and Casas Grandes in early March were in spawning condition; males released milt freely upon removal from the water and females expelled eggs on light pressure. Size structure of these populations indicates that reproductive maturity is reached earlier and at a smaller size than is typical of most populations of native fluvial *Oncorhynchus mykiss* in the United States. These factors may reduce the impact of hybridization or introgression by reducing temporal overlap in reproductive seasonality between Mexican *Oncorhynchus* spp. and exotic *O. mykiss*. This may also produce a skewed directionality of hybridization, resulting from size-assortative pairing, as has been observed in both Rainbow Trout and other species of *Oncorhynchus* (Foote and Larkin 1988, Dowling and Childs 1992, Rosenfield et al. 2000, Ostberg et al. 2004). While our preliminary data suggest both local hybridization and reductions of variation from bottlenecks, with our sample sizes, additional data are clearly required to accurately identify the long-term impact of *O. mykiss*-based hatcheries in México.

DNA Sequence Variation

While our analysis did yield limited variation in control region sequences from across much of the natural range of *Oncorhynchus mykiss*, this marker is very useful for phylogenetic inferences and evaluation of species boundaries. In our preliminary molecular analysis involving only the control region, 91 out of 1008 characters were parsimony-informative. Mexican Golden Trout (*O. chrysogaster*) were always embedded within a larger, well-supported clade of samples of the undescribed Mexican trout species. Analysis of partial sequences from *O. apache* and *O. gilae* also resulted in those taxa being embedded within these undescribed taxa. Relationships among all forms within the clade inclusive of the Rainbow Trout (*O. mykiss*) were not resolved in either MP or Bayesian analyses, however, some redband, steelhead and rainbow samples from Bagley and Gall (1999) were consistently resolved with undescribed taxa from the Sierra Madre Occidental in all analyses. Some differentiation among Mexican populations is evident, especially among populations in the ríos Acaponeta/Baluarte/Piaxtla and San Lorenzo/Presidio drainages. This suggests that these populations are native, and have been isolated from northern populations of native (not hatchery) *O. mykiss* for a considerable time. The ATPase 6/8 sequences also revealed relatively low variation; with only 59 parsimony informative characters out of 858 bp. Gila Trout and Apache Trout were recovered as sister to the clade containing native (not hatchery) Rainbow Trout. We did recover similar groupings of the southern drainages as found in the control region phylogeny. The nuclear genes GH1C and GH2C were not informative for variation within clade including Rainbow Trout. However, relationships between Gila, Apache, Cutthroat and Rainbow trout were different from those recovered with mitochondrial genes, especially in the tree recovered using GH1C sequence variation. The genetic variation of these genes across the native trout of the clade inclusive of native Rainbow Trout and Gila, Apache, Cutthroat trout is very promising for ultimately resolving relationships and species boundaries within these clades. Additional genes (ND2, COI, COII, Cyt-*b*) and microsatellite markers for these and other samples will provide further resolution of the genetic diversity in these river systems.

Morphological Variation

Among the samples examined thus far differences between thc different proposed undescribed species exist in all of the standard morphological features (see methods) that are diagnostic for up to 10 different species. Results of these analyses will be presented in a separate publication.

Taxonomy

Descriptions of what we believe to be distinct native trout from the Sierra Madre Occidental of mainland México will be presented elsewhere. However, historically some of these have formerly (and currently) been grouped under the catch-all term of coastal rainbow trout (*O. mykiss irideus*). Based on molecular analyses, however, they are distinct from what has been traditionally referred to as "Rainbow Trout," *Oncorhynchus mykiss*, and are more closely related to other trout species. These taxa are diagnosable on the basis of morphology and molecular traits and such conflation of them with the "Rainbow Trout" is an inaccurate depiction of both the morphological and genetic diversity in México and does not accurately depict either their origins or their ongoing evolutionary divergence. Further, we believe that "lumping" these trout with *O. mykiss* will promote the spread of hatchery or cultured Rainbow Trout throughout the Sierra Madre Occidental, as was historically done the in US under the polytypic species concept, and consequently endanger the gene pools of these native trout.

Therefore, we anticipate describing multiple new taxa (of trout as well as minnows and suckers) in the near future and providing a revised taxonomy that recognizes and accurately reflects the diversity discovered, and the phyolgenetic relationships among natural groups of Mexican trout. Obviously, putting names on these species is of critical importance for their conservation given the largely species-oriented legal protection mechanisms currently in place in Mexico and elsewhere.

GIS and GARP Modeling

Because we had evidence from historic correspondence (reviewed in Hendrickson et al. 2003) of native trout in the Río Conchos basin, and our review of drainage patterns, faunal distributions and habitats in the upper Río Conchos indicated that trout could very well exist in these headwaters, we used GARP analysis to predict what streams were most likely to harbor trout in this system.

We input environmental data derived from remotely sensed imagery coverage of the Sierra Madre Occidental, and our known trout localities from the Río Yaqui basin. As there is a stochastic element to the GARP process, there is no unique solution. Consequently, a number of models are generated (300 in this case) and a best-subset is chosen. By intersecting the 10 best-subset model convergence map with a stream coverage, streams could be assigned respective model convergence values. These values can then be ranked to reflect likelihood of native trout populations — based upon information about the known localities of native trout in the Río Yaqui. Using this algorithm we generated a map of likely locations for trout throughout the Sierra Madre Occidental, including the Río Conchos (Figure 3). The model correctly identified areas known to contain trout in the remaining parts of Pacific-slope drainages, and predicted trout occurrences in tributaries of the upper Río Conchos.

Because the terrain of the Sierra Madre Occidental is very rugged and travel to collection localities is very time consuming in most areas, we found the GARP predictions to be a useful new tool that helped us more quickly sample habitats throughout our study area that were likely to harbor native trout. Discovery of the Conchos Trout at a locality predicted by GARP to have a high likelihood of harboring trout (below), together with the high success of the method reciprocally predicting previously sampled localities harboring either undescribed trout or Mexican Golden Trout based on only a subsample of our known localities (Fig. xx), exemplifies the power and utility of GARP.

Discovery of the Conchos Trout

Although native Mexican trout have been known to biologists for well over a century, scientists, as well as the general public, have remained surprisingly ignorant of them. The first Mexican trout collection was made in the 1880's by Nathaniel T. Lupton, Professor of Chemistry at Vanderbilt University. Lupton gave the specimens to Edward Drinker Cope, who wrote a brief paragraph about them in the American Naturalist (Cope 1886). Unfortunately, Cope did not know the exact collection locality and never formally described the species, and the specimens, believed deposited at the American Museum of Natural History, were ultimately lost. With discovery of other trout populations in Pacific drainages of México, subsequent researchers decided that Lupton's specimens were Mexican Golden Trout (*O. chrysogaster* – from headwaters of the Pacific rivers, ríos Fuerte, Culiacán and Sinaloa) Archival research by *Truchas Mexicanas* team members, however, uncovered not only letters that supported a Río Conchos basin locality for Lupton's specimens (Hendrickson et al. 2003), but also found other strong independent circumstantial evidence (i.e., without collection of voucher specimens) that trout existed in the Río Conchos basin. *Truchas Mexicanas* therefore increased sampling efforts in the Río Conchos basin in an effort to re-discover populations and describe and conserve the diversity first seen by Lupton.

Our first expedition to the Río Conchos in 2002 (funded by a grant from the National Science Foundation) focused primarily on southern and eastern tributaries but failed to produce any native trout populations, despite some appropriate trout habitat. Despite these results and still suspecting the existence of an undescribed Conchos Trout, we input our recent native trout collection localities from other basins into Desktop GARP.

Using the GARP model predictions *Truchas Mexicanas* rapidly focused surveys in 2005 in the streams of the Río Conchos basin with the highest probabilities of trout occurrence. Our extensive efforts thus far have only revealed two populations of a trout in the Río Conchos. When the first population was discovered in 2005 it appeared small (< 100 individuals) and restricted to a short stream segment (<0.5 km) with, at best, marginal habitat and limited evidence of recruitment. Returning to the same stream in 2006 a complete inventory of the stream from its headwaters to its mouth failed to yield any trout specimens, native or cultured. However, throughout the stream reach there was evidence of extensive fishing pressure by indigenous peoples. Laboratory analyses of DNA sequences of the specimens collected in 2005, however, clearly revealed this trout to be a new species endemic to the Río Conchos basin, and a relative of the undescribed trout endemic to the Mayo and southern Yaqui basins. Anxious to expand our data set beyond this small population and to more accurately determine the distribution and conservation status of the new species, our March 2006 expedition involved thorough and more widespread sampling of stream reaches believed to have a high probability of supporting trout from in the Río Conchos.

We had long been aware that native trout are known to the Rarámuri (Tarahumara) by the name "aparí" or "aparique," and that most locals, especially Rarámuri living in the Conchos basin, clearly distinguish them from similar-looking introduced, non-native Rainbow Trout (locally "trucha arco iris"). We have spoken with many local, older residents who quickly and correctly identified Conchos Trout from a large set of illustrations displayed as an array of similar trout and indicated that the species occurred in nearby streams (ones we had identified in GARP analyses as high probability trout habitats). Unfortunately, after confirming that they had seen and captured this species locally, residents almost invariably proceeded to explain that they had not seen "apariques" for 3 to 10 years, and our sampling of those streams substantiated their observations. Thorough reconnaissance and sampling of a wide area of the upper Río Conchos by multiple teams of *Truchas Mexicanas*, and discussions with local Mexican and Rarámuri revealed multiple stream reaches where the "aparí" or "aparique" had once existed, habitats that were evaluated by our team as excellent for trout, or stream reaches that were dry and had been dry according to local residents for many years due to reduced rainfall and increased pressure for water use. Where streams were intact, sampling yielded native species of *Catostomus*, *Gila* and *Codoma*, but no trout. The extirpation of the Conchos Trout from streams in these areas is most likely due to depletion of water in the streams, climatic changes in northwestern Mexico with reduced rainfall, overexploitation of these populations as a food source, or a combination of these factors.

During the March 2006 expedition *Truchas Mexicanas* team members did, however, discover another previously unknown locality for the undescribed Conchos Trout, in a stream reach predicted by GARP analysis to have a high probability of habitat appropriate for Sierra Madre Occidental trout. This stream was also surveyed from mouth to headwaters and a small set of voucher specimens were retained for scientific study. Adjacent tributaries also draining into the same mainstem stream did not maintain any populations of trout. Using standard sampling methods for rapid population evaluation we estimated the population size in this stream as < 300 adults. While sampling fishes and invertebrates from this stream team members identified three new small dwellings being constructed by Rarámuri, small-scale timber removal activities in the watershed and evidence of some pollution in the stream basin. However, during the sampling period no evidence of local peoples harvesting trout from the stream was encountered throughout the basin. The combination of our own collection efforts and observations by locals has convinced us that not only is this undescribed endemic Mexican trout fading from local memory, but is also critically endangered and rapidly disappearing throughout its small remaining range. As can be seen from discussions below, our data regarding this dismal conservation situation is not just anecdotal.

Thus, GARP modeling of niches of species in our efforts to sample remote and difficult terrain has been extremely successful and highly valuable for effective and efficient inventory work. The validity of GARP modeling for Mexican trout is bolstered by the fact that modeling based on subsets of our data from Pacific drainages accurately predicted stream reaches containing known samples that included the omitted subsets of known trout localities. Validity of extending our model to the Río Conchos basin is also bolstered by the fact that the GARP model predicted that both streams where we have found the Conchos Trout to have high probabilites of harboring trout. Furthermore, through blind testing by picking from multiple possible native and cultured trout drawings by Joseph R. Tomelleri ,indigenous peoples confirmed existence of the Conchos Trout in years past in other streams that GARP suggested were likely to harbor them.. We thus consider the GARP model predictions to be a reasonable representation of the maximal, theoretical distribution of trout in the Río Conchos basin. However, various lines of evidence make it clear to us that human impacts, variables that are near impossible to model in GARP, have dramatically restricted the area native trout now occupy and that protective measures, as well as educational efforts are now essential to the continued existence of this and other native trout in the Sierra Madre Occidental.

Conservation Status of the Conchos Trout

This trout is clearly one of the most imperiled in North America with its current known existence being from only a single stream less than 3 km in length and a population size estimated to be less than 300 individuals. Given the inferences from sampling multiple locations for trout through the Sierras and the state of other natural trout populations, it was not surprising that the recently discovered population of the Río Conchos Trout, in a very small stream, was found in the least impacted arroyo sampled. This population is constrained to an area near the headwaters in a narrow, high-gradient canyon with almost no available tillable land. The stream's discharge is exceptionally small (on March 22, 2006 from 0.20 - 0.27 liters per second (L/s) near top of trout population to 28 L/s below it), thus limiting irrigation possibilities. Human population density in the canyon is low; only last year was the first house built, immediately below the trout population in this arroyo. The new residents of the canyon are grazing goats and cutting trees to make bowls and other saleable items. While we found no evidence that they are currently capturing trout, it would be extremely easy for them to do so in this very small stream, with potentially disastrous impacts on the population. They did indicate that they are aware of the presence of apariques and many other regional residents explained to us that locals traditionally fish apariques at Easter.

Following discovery of this population we focused on better documenting local habitat conditions via quick preliminary studies where the trout lived and in adjacent arroyos that locals and GARP analyses also indicated high probabilities of containing trout. We determined that the newly discovered population consists of perhaps 300 individual native trout >100 mm total length distributed over approximately 2.5 km of high-gradient stream. Based on the release of eggs by at least one female handled, spawning was occurring at the time of our visit, and our collection included at least 4 size classes, indicating reasonable and recent recruitment for at least several years. All evidence, ranging from reports by local residents and our own evaluation, indicates that a somewhat larger stream nearby recently supported the native aparique. Extensive fish surveys there during 2005 and 2006, however, failed to produce specimens. We attribute the near absence of apariques in the other stream to heavy fishing pressure, as evidenced by levers wedged under many boulders in the stream. This technique appears to be in widespread use by local residents throughout the region, is highly effective and capable of rapidly decimating small populations already impacted by myriad other factors. Cursory examination of invertebrate samples from both arroyos with and without apariques suggest that toxins might be responsible for paucity of apariques in the tributary lacking them, an observation that merits further study. Despite having flows that we believed sufficient for supporting trout, no apariques were found in a small tributary immediately below the new house. Seepage of toxins from an abandoned upstream mine or from soils contaminated by mining might explain their absence from the tributary, as well as their absence below the mouth of this tributary.

We were told that another small tributary between the two streams mentioned above never did harbor apariques, and we did not sample it for fishes, but we did visit a small impoundment ("presita") on it about 200 m above its mouth. This impoundment, apparently built recently with support obtained by the local municipality, had been stocked in January 2006 with 500 fingerling cultured Rainbow Trout. We have documented many areas in other drainages where Rainbow Trout are interacting with natives (via competition and hybridization) to the detriment of the natives, and these introduced trout could easily leave this presita and invade native trout habitats. We therefore recommend removal of rainbows from this presa as well as the removal of the dam so it cannot be re-stocked, and erection of a barrier on the lower reaches of the stream harboring apariques to prevent upstream movement of any non-native fishes. Some habitat modifications to this stream to aid the Conchos Trout in reproduction success, larval development and evade human and non-human predators are also highly recommended for the continued survival of the species.

DISCUSSION

How to Conserve and Protect the Río Conchos Trout

Members of *Truchas Mexicanas* are fully committed to conservation of Conchos Trout. We not only conclude that it is endangered throughout the basin and one known population was driven to extinction by local fishing pressure and habitat modifications, but the only viable extant population we know is critically endangered.

The most obvious solution for preservation of the only known potentially viable population of the new Conchos Trout is intensive management. We propose declaration of a small reserve that includes the entire drainage of the stream described above. The total area is approximately 100 km^2. The only humans directly affected by such a reserve would be those occupying the new homestead on the stream that harbors the population, immediately below the lowermost collection of apariques. At a minimum, this family should be made fully aware of all ways in which they currently (grazing, tree-cutting), or potentially might (fishing, plowing/planting fields, washing clothes or other discharges of contaminants) impact the species and should be compensated for protecting it by changing the ways in which they use resources. The best solution would probably be to compensate this family to move elsewhere, but we realize this might not be possible. All land that we propose to be declared a reserve is (as far as we can determine) property of an ejido, and presumably, the family living on the stream harboring the aparique population is a member of that ejido. Following our sampling efforts in this area in March, we revisited the area in April only to find additional impacts on the native habitat of the trout and new fishing pressures of this small population. Empty chlorine bottles were found along the stream bank and multiple large levers were discovered beneath large boulders used by trout for habitat and concealment from predators. Where these levers were present no trout were found in the pools. It is likely that the chlorine was used to kill the trout prior to their removal from pools using the levers to displace boulders.

To further justify its protection and management, it appears to us that the intrinsic value of this newly discovered Conchos Trout stream and the nearby streams we propose protecting goes well beyond having the only known, manageable population of Conchos Trout. During our inventory efforts we also collected specimens of a unique, and previously unknown and undescribed species of sucker (apparently a relative of *Catostomus plebeius*) from the stream that also harbors the apariques and are in the process of describing this taxon. In addition to these undescribed species, the same stream also supports Mexican Stoneroller, *Campostoma ornatum*, Ornate Shiner, *Codoma ornata* and Conchos Chub, *Gila pulchra*. Our study of other invertebrates and other organisms was cursory, but all of the arroyos described above are unusual in the upper Río Conchos because they flow to the north, are mostly uninhabited, and consequently likely harbor a unique assemblage of trees, forbs and other organisms otherwise uncommon in the Río Conchos basin. The adjacent stream that apparently once harbored apariques has caves with petroglyphs from prehistoric inhabitants along its banks.

We view a nearby ecotourism facility as a serendipitously fortunate occurrence for protection and recovery of Conchos Trout. The manager, a Spanish-speaking Rarámuri who grew up in the area and is a member of the ejido that owns the streams mentioned above, guided us throughout the area. He is exceptionally knowledgeable regarding local natural history, and interested in the apariques. He introduced us to the owner of a ranch on the lowermost reaches of the stream that harbors apariques (well below the aparique population), who explained he has never eaten aparique and is not interested in them for food. He would thus seem likely to be unaffected by any recovery actions for the trout, but potentially a beneficiary, together with the owners of an ecotourism business and the ejido (which we understand receives part of its income from the tourism business). Ecotourism could be easily extended to include the aparique and other aspects of the area's natural history as an additional attraction. Though the aparique population is currently too small to allow catch and release fly fishing, it potentially could still attract economically significant tourism and such a business might one day be possible in the other stream where apariques apparently were once more abundant, and likely elsewhere, provided that the small surviving aparique population is properly managed and conserved. In the meantime, an ecotourism facility provides convenient housing for researchers and conservation workers.

A barrier on the lower reaches of the stream that harbors the aparique population to protect them from invasions of Rainbow Trout and the highly likely deleterious impacts on the new species through introgressive hybridization, competition and food depletion is crucial. *Truchas Mexicanas* members committed not only personal contributions of funds to establish a base for such an effort, but also committed provision of our experience and expertise toward accomplishing construction of such a barrier. Although other, larger efforts are required, especially outreach and education of the local community, we believe construction of a barrier, local drainage management efforts with residents, and some habitat rehabilitations provide not only tangible protection that can be quickly accomplished, and which are both symbolic and educationally useful. These modifications would utilize local labor, thus demonstrating that conservation of resources, such as aparique, can have tangible and immediate benefits to the local community.

The *Truchas Mexicanas* team is sincerely interested in conservation of the Conchos Trout and other trout species in Mexico. We also believe immediate action to conserve the small population of the Conchos Trout we discovered is a critical first step toward this end. However, we realize that as biologists, all foreign to the local area (and in many cases the country) we are highly ignorant of, and mostly unprepared to deal with the complexities of the local political and cultural systems through which any actions would have to be taken. We therefore offer whatever assistance we can provide with our diverse and highly relevant backgrounds, but depend on the participation of others more qualified to interact with the appropriate local authorities and who can help us generate and administer the required funds.

We cannot emphasize enough the urgency of taking immediate steps to save this exceedingly rare and threatened trout, as well as to forge ahead as quickly as possible to locate other, similarly imperiled taxa in the Sierra Madre Occidental. The impending extinction of this species and the decline of the other native trout of the region will affect Rarámuri tradition as well as other biodiversity. We were fortunate to havc located the population we describe, but the situation requires immediate implementation of recovery actions and proactive planning for sustainable development efforts and education throughout the region, with a vision towards ecotourism capturing a replacement for economic growth in the area without the eventual destruction of habitats that serve as the primary revenue of the region. Members of the *Truchas Mexicanas* organization are prepared to do whatever we personally can to help conserve this new species, but we clearly need international assistance from citizens, conservation organizations, groups interested in fishing and fishes and their conservation, and government agencies.

The Future of all Native Mexican Trout

The Conchos Trout story provides many lessons. It not only exemplifies the extreme habitat degradation that is pervasive and expanding throughout much of our study area, but also exemplifies the possible future of many other populations of Mexican trout. As many have told us, the Conchos Trout was once much more widely distributed by now finds refuge only in the uppermost and tiniest headwaters. Rainbow Trout have been introduced into habitats it likely once occupied, but at least in this case they appear not to have established. An incredible diversity of impacts now threaten the tiny remaining population, which, as far as we know may be the last of the species. If not the last population, our extensive fieldwork leave us confident that not many more will be found.

It is clear to us that much remains to be done to assure persistence of native Mexican trout and their habitats for future generations. Not only are broad-scale management actions urgently needed, ranging from changing land use practices to reconsidering promotion of Rainbow Trout culture to implementing sweeping socio-economic changes, but we also need additional basic scientific research. Systematic studies are required to understand the evolutionary relationships of populations and to allow them to be named with appropriate taxonomy. Naming these species is essential for integration of this unique fauna into socio-political conservation frameworks. Additional genetic research is required not only for evolutionary studies, but to provide insights into population biology of the species, and basic biological and ecological studies are required so we might understand the complexities of the ecosystems in which this biota resides so as to become better informed managers.

A Call for International Proactive Efforts

Most native Mexican trout populations are not yet in the dire condition in which we find the Conchos Trout, but they are clearly headed that way. We thus invite all those interested to join the *Truchas Mexicanas* team in our efforts to learn more about these valuable and fascinating fishes, and to join us in helping to assure that the remaining populations of all Mexican trout species persist in their natural habitats in perpetuity for the benefit of future generations.

Interested parties and financial contributors wishing to promote the protection and sustainable conservation of the Conchos Trout and other new trout species of the Sierra Madre Occidental, as well as educational sociological efforts with the indigenous Rarámuri (Tarahumara) and Mexican peoples for existence of their societies in a more environmentally sustainable manner with the local biodiversity are encouraged to contact members of the *Truchas Mexicanas* group and/or authors of this publication, or email Aparique.Conchos@gmail.com. More information about the *Truchas Mexicanas* project and regarding how others can assist in its efforts and contribute financially to the survival of these unique ecosystems can also be found at http://www.truchasmexicanas.org.

Dedication

This paper is dedicated to Edwin "Phil" Pister, long-time leader of the Desert Fishes Council and supporter of conservation efforts for native fishes throughout the arid west of North America. Phil was not only a leader in the famous battle for protection of the Devils Hole pupfish (*Cyprinodon diabolis*), the population size of which was once similar to that of the Conchos Trout that this paper highlights, but he also has extensive experience with trout conservation. His career-long involvement in management of California's golden trout (*Oncorhynchus aguabonita sspp.*) has achieved significant legal protection for both them and their habitat, while recovering most of populations from hybridization with introduced non-native rainbows and the impacts of habitat degradation. These same issues confront conservation of all native Mexican trout, and it is therefore perhaps not surprising that Phil's work extended into that country long before the *Truchas Mexicanas* team that authored this paper was born. Phil's work with one of the co-authors of this paper (GRC) on the native trout of Baja California (*Oncorhynchus mykiss nelsoni*) helped call attention to its plight and confer it appropriate legal protection. As a result, it is today one of the least endangered native Mexican trout. Finally, Phil's work with the Desert Fishes Council and long-standing support of its work in México is testimony to his commitment to conservation without borders. While we have long been inviting Phil to accompany us on our fieldwork, unfortunately it has not yet been possible for him to join us, but his spirit has always clearly been with us as we wander through the Sierra Madre Occidental searching for Mexican trout.

It is therefore not only highly appropriate, but also a distinct pleasure, to dedicate this paper to Phil. Hopefully, by following his model, one day the Conchos Trout and all other native Mexican trout will enjoy levels of protection and conservation security equal to what he has helped attain for the species mentioned above.

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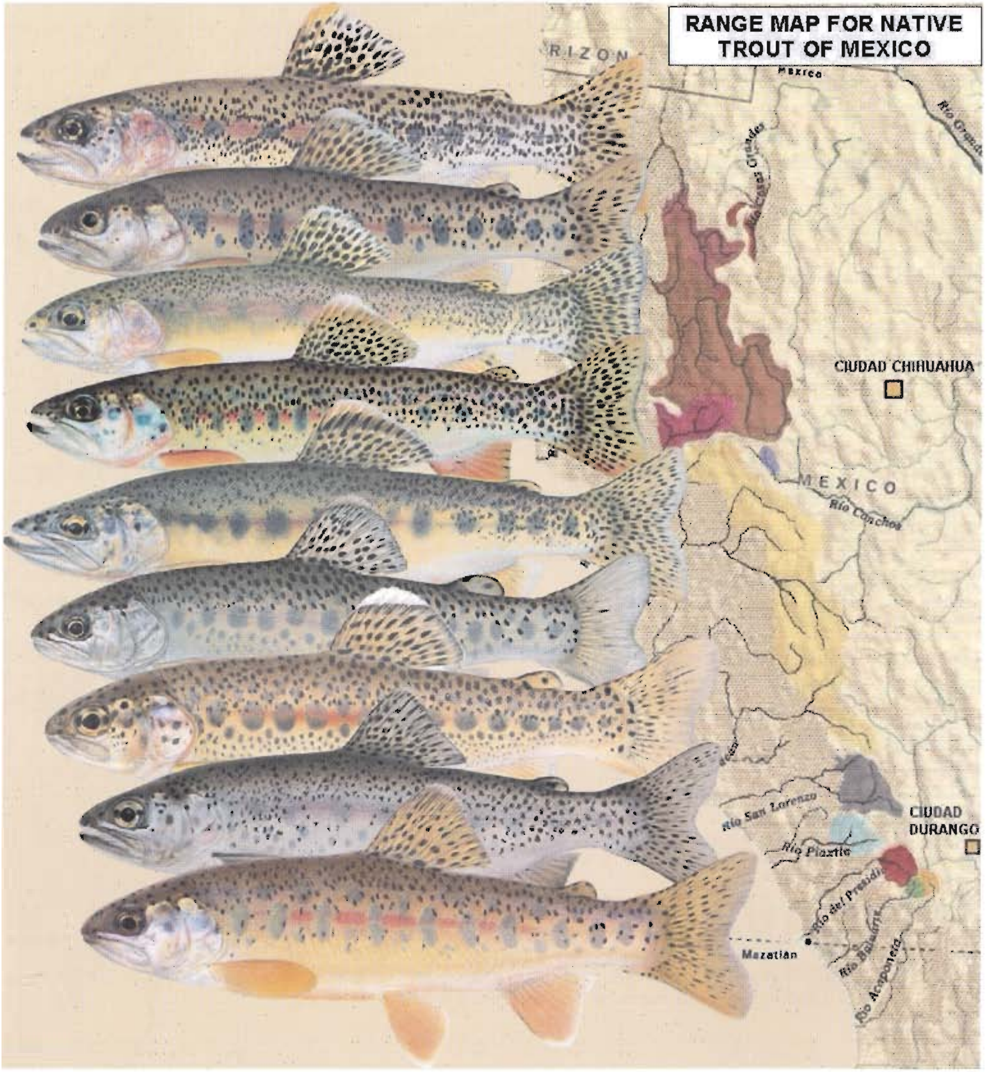

Figure 1. General distributions of native Mexican trout (*Oncorhynchus* spp.) with images of different distinct forms. Trout from top to bottom include forms from the rios Casas Grandes, Yaqui, Mayo, Conchos, *O. chrysogaster*, San Lorenzo, Piaxla, Baluarte and Acaponeta. Fish images copyrighted by Joseph R. Tomelleri; base map adapted from Behnke and Tomelleri (2002).

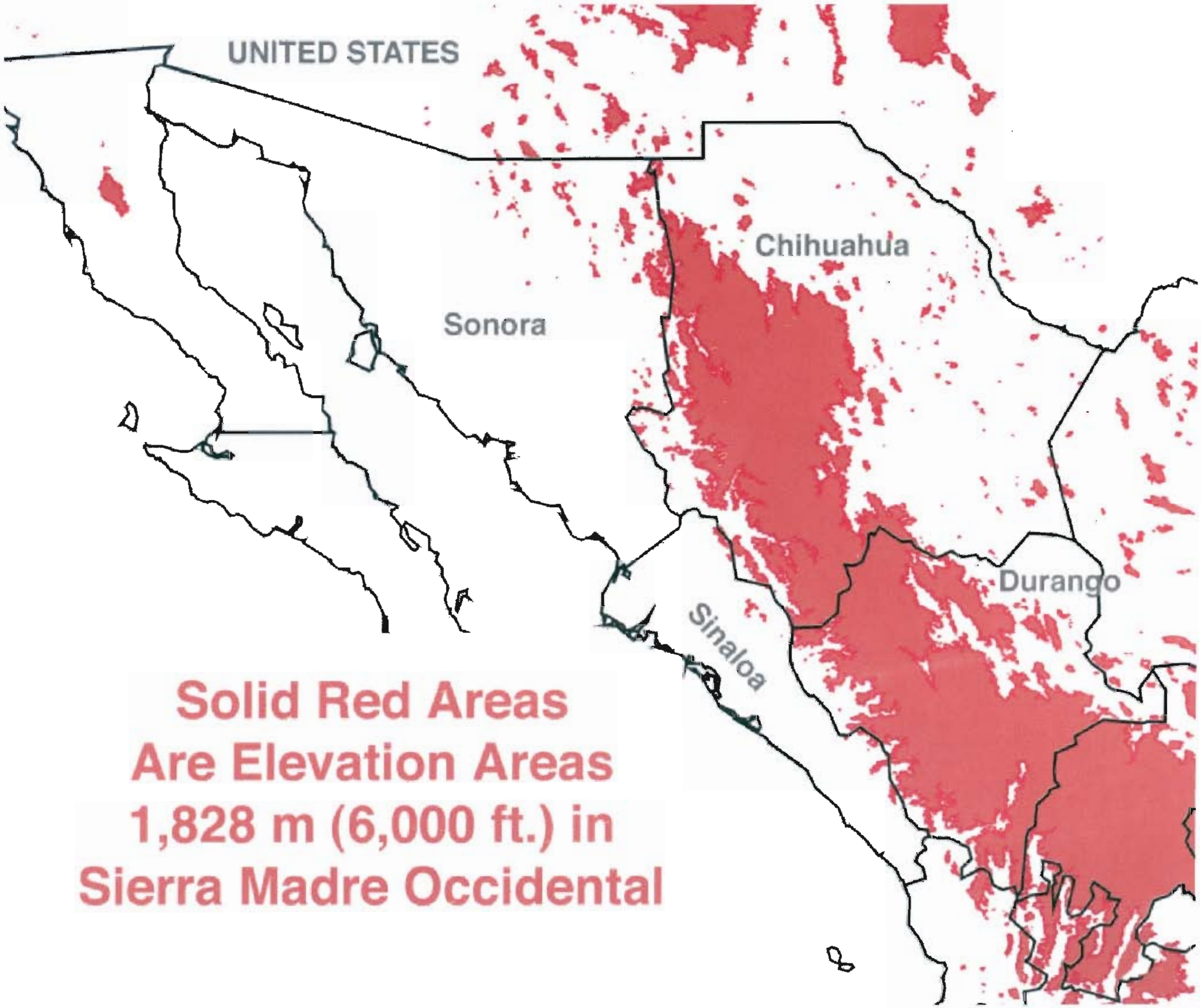

Figure 2. Distribution of high-elevation areas in Sonora, Chihuahua and Durango, Mexico, showing areas likely to contain isolated populations of native trout.

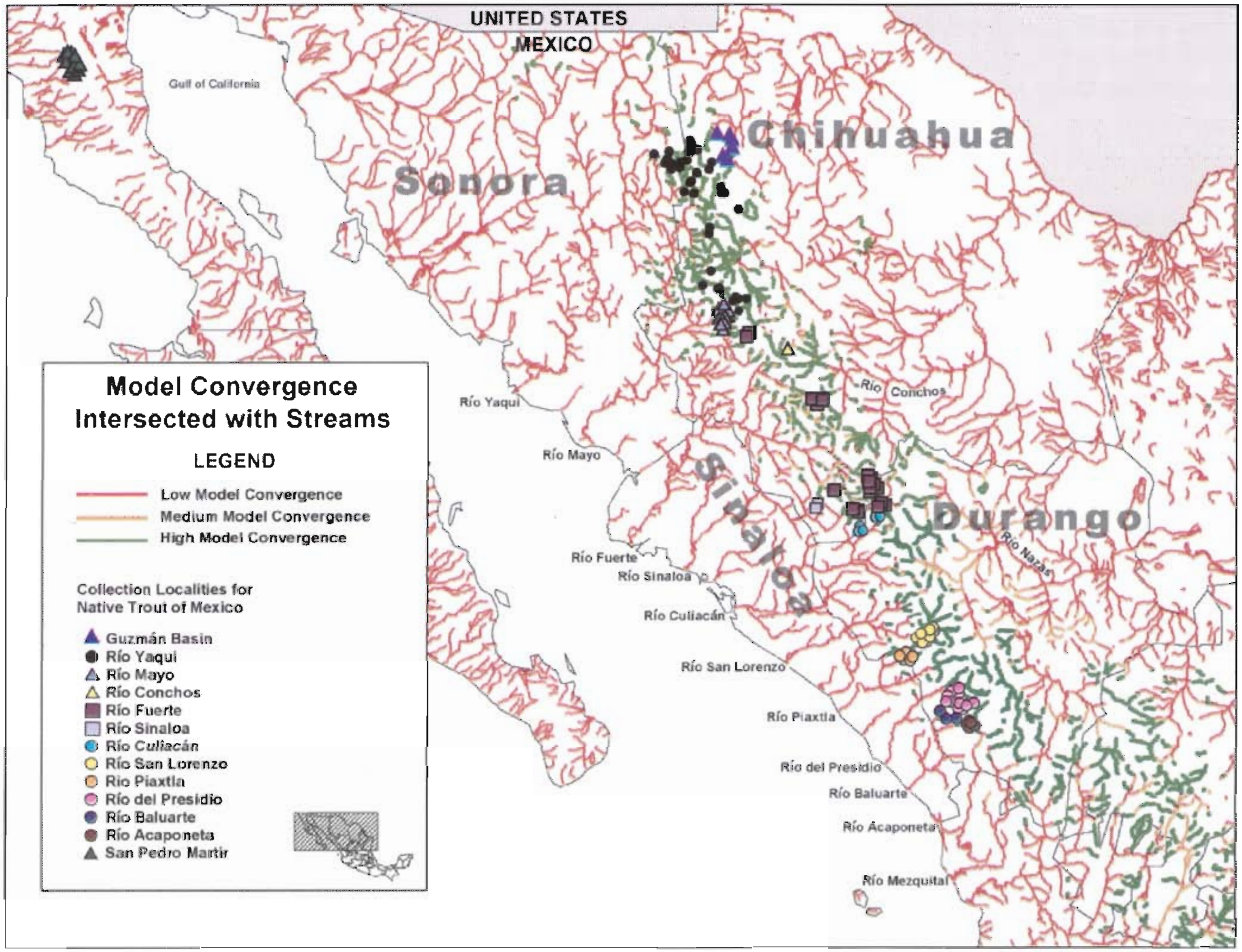

Figure 3. GARP map of the Sierra Madre Occidental with stream segments scoring a perfect fit with the model highlighted in green. Black circles represent the known Yaqui Trout sites used for model development.