

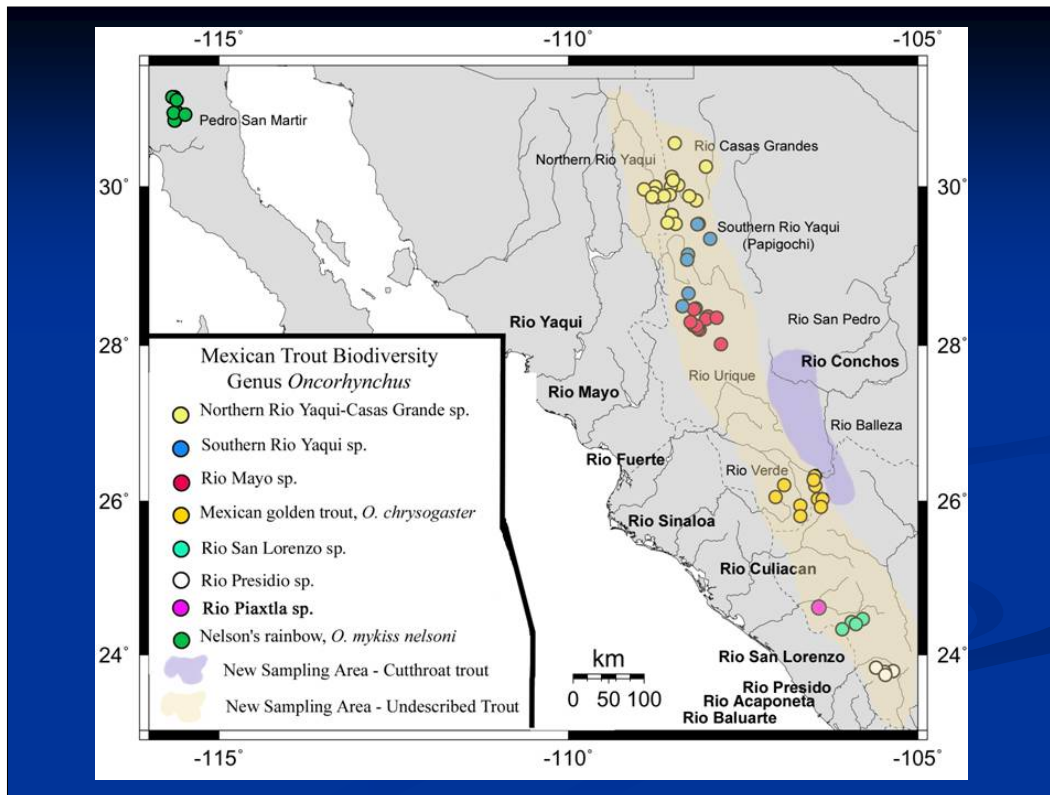
Truchas Mexicanas: New discoveries and insights into diversity and conservation status of Mexico's native trouts



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I wanted to start out with our project logo, and by pointing out that though we have a long list of co-authors here, this is only a recent subsampling of all of the people who've worked with us in substantive ways in the 7-8 years since we first started to do fieldwork.

In 2004-2005 alone, the principal time period that I'll be covering in this talk, we've worked with 20 Mexican collaborators from 13 institutions, and 24 U.S. collaborators from 12 institutions. So, it's become a pretty good sized project, despite very limited funding.



Northwestern Mexico's Sierra Madre Occidental is our focus. Native trouts are found from not too far south of Arizona in Sonora and westernmost Chihuahua, ranging southward through Chihuahua, Sinaloa and Durango to the mountains just east of the resort city of Mazatlán. That's just about straight east of the tip of Baja, and just south of the Tropic of Cancer.

The fairly well studied native trout of Baja California is not a focus of our work and you won't hear anything more about it today.

History

- Cope 1886 – trout from Lupton
- Nelson. Late 1890's saw (but didn't collect) trout in Río Presidio (24 N). 1906 Walter Bishop sends him specimens but they were subsequently lost.
- Needham and Gard 1959
- Needham and Gard 1964 – *O. chrysogaster* described
- R. R. Miller – Presidio trout not native



Río del Presidio trout, *Oncorhynchus* sp.



Mexican golden trout, *Oncorhynchus chrysogaster*

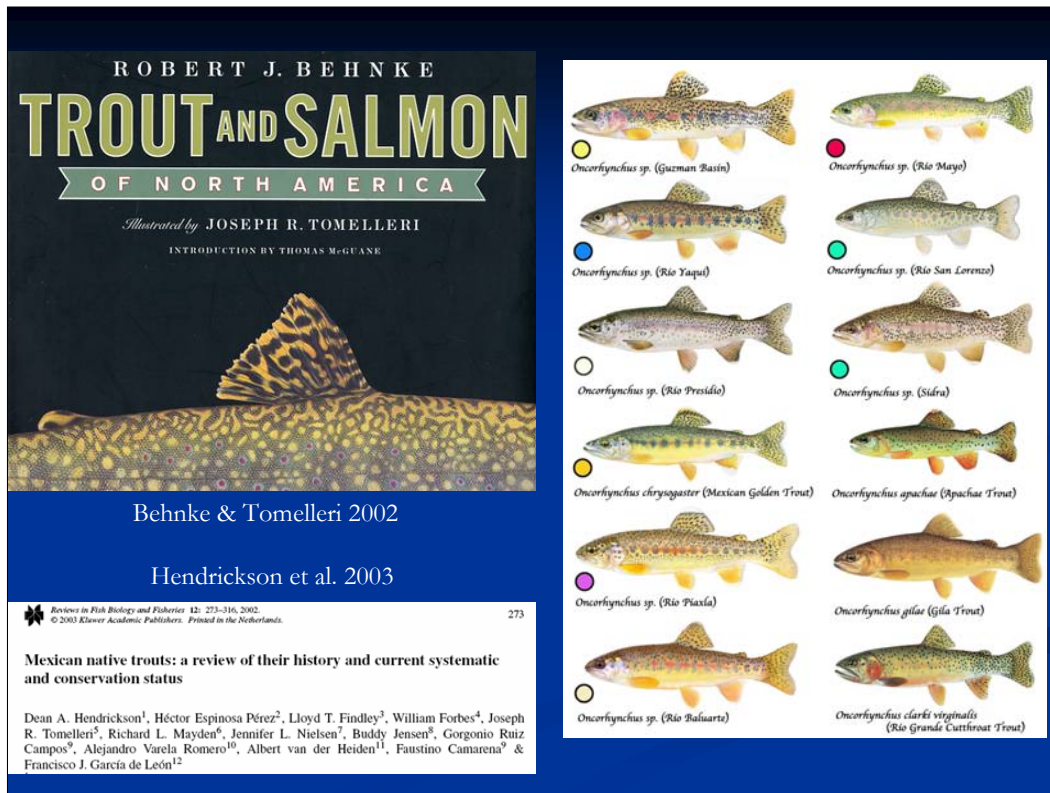
In 1886 Cope published a few sentences describing 2 specimens of a trout collected and sent to him by a professor Lupton. He was clearly looking at a new cutthroat, a group he knew, having described a subspecies a few year earlier, but instead of attaching a name, Cope instead simply lost the specimens.

A few year later, Nelson reported seeing, but not collecting, trout in the upper Río Presidio. In 1906 Walter Bishop sent him some specimens from there, but they too were quickly lost.

So, the earliest collections of Mexican trout were apparently hard to hold on to, but then Needham and Gard started collecting trout in Baja California in the 1930's and in the 1950's expanded their search for high temperature tolerant trout to the mainland, finding trout as far south as the Río Presidio. Their vouchers are still available.

In 1964 they described the Mexican golden trout from the Rios Fuerte, Sinaloa, and Culiacán. It remains the only formally named Mexican trout species.

Bob Miller was well aware of this history, of course. He had examined the undescribed trout of the Rios Yaqui and Mayo, and recognized them as new taxa, but without formally describing them. He also looked at the more southern Río Presidio and San Lorenzo trouts, but was convinced they were non-native rainbows introduced in the late 1800's by foreigners working on railroad, logging and mining projects.

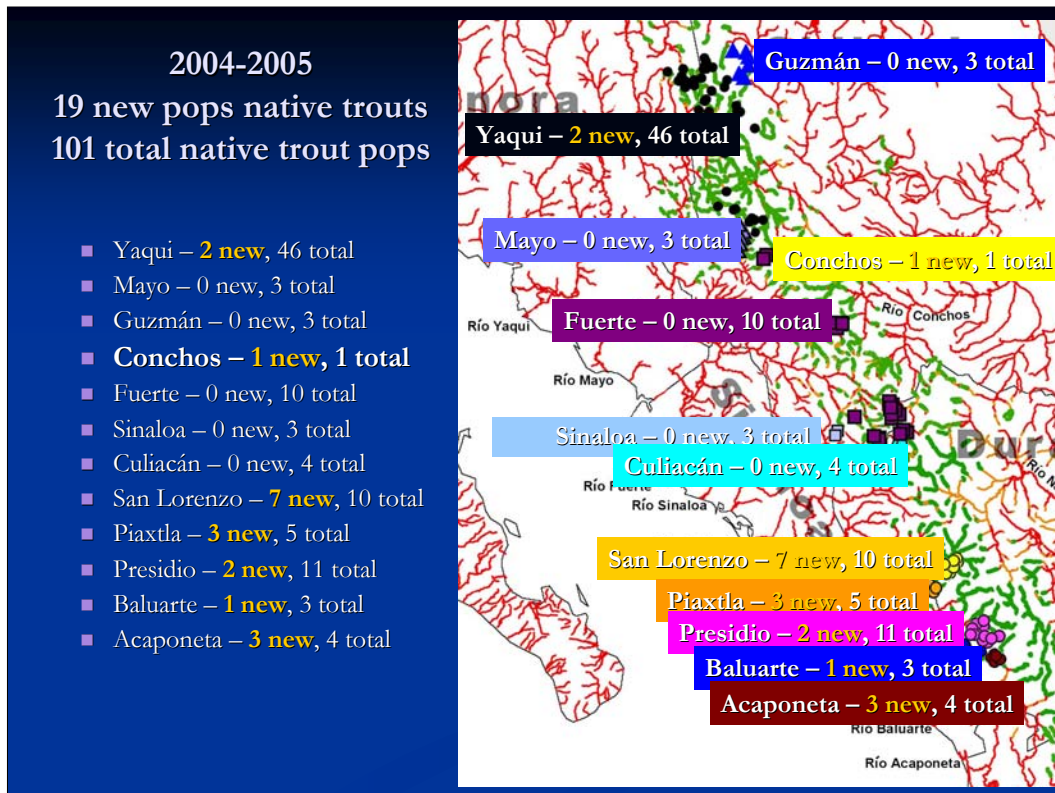


More recently, the beautiful 2002 Behnke & Tomelleri book covered Mexican trout, treating them as 2 species – the Mexican golden trout and all others lumped into “Mexican rainbows”. Within the Mexican rainbow group they recognized 3 undescribed, sub-specific groups

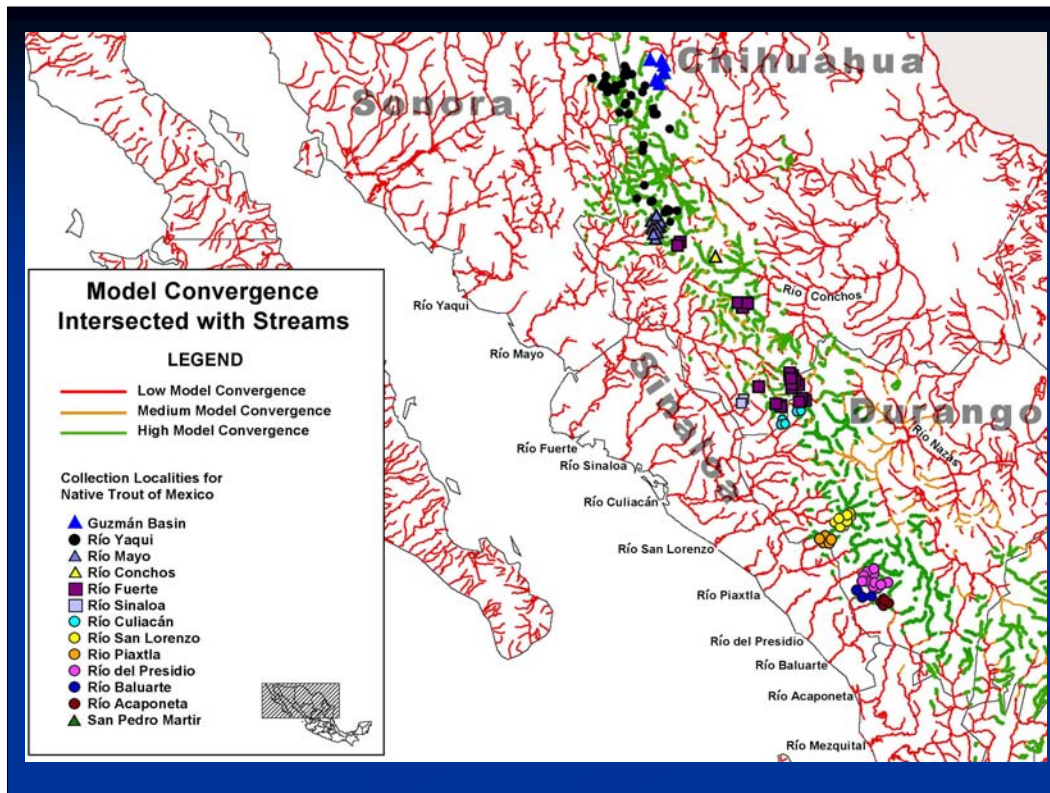
- Yaqui/Mayo/Guzmán (agreeing with Miller)
- Rio San Lorenzo
- Rio Presidio.

They thus disagreed with Miller and considered the southernmost trouts to be native, and we do too, as you’ll see.

In 2003 our comparatively very drab looking (but thrilling to read) paper reviewing what we had found since 1997, came out. It provided a review of the history of explorations and collections of Mexican trouts, georeferenced all collectdions, and reviewed the history of introductions. Archival research allowed us to trace Lupton’s travels and figure out that the long-lost specimens that Cope had examined were almost certainly from the Conchos, not a Pacific drainage as the literature was erroneously telling everybody. We also discussed the conservation status of native trouts throughout the Sierra Madre Occidental and reported our collections from drainages to the south of the Río Presidio, in the Baluarte and Acaponeta drainages, extending the range of native trouts further south than had previously been known.



And, we've stayed busy. In the last couple of years we've discovered 19 more new populations of native trouts, bringing the total count of Sierra Madre Occidental populations to 101.



So, in the last couple of years we've increased the trout locality database by about 20%, and we had pretty good sampling of all basins except for the Conchos, so we started focusing more field effort there. Now armed with a reasonably decent database of trout localities from elsewhere in the region, with some help from the GARP/Lifemapper folks at University of Kansas, we started playing with Desktop GARP to see if it could help us narrow our search in the huge and difficult to negotiate Conchos basin.

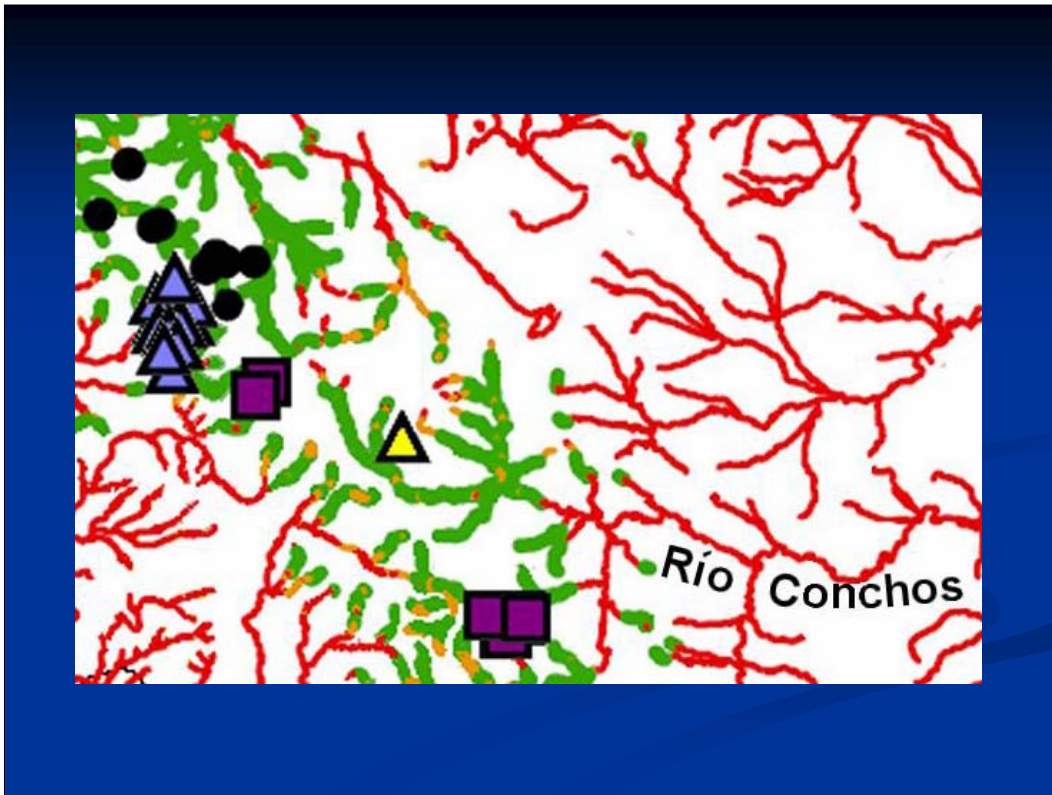
In a nutshell, GARP works by seeking environmental similarities across collection locations to draw conclusions about the total potential range of species. It iterates through analyses of the intersection of environmental data and presence only locality data for the taxon of interest. The environmental data we used were standard GARP overlays for climate (including things like cloud cover, temperature, and precipitation), as well as topography (things like aspect, flow direction and slope), and vegetation and land use coverages, all at 1 km resolution. We ran ten iterations of the GARP rule-sets and summed them. Then, since fish are restricted to water, we intersected the model convergence map with stream coverage to produce maps like you see here.

This particular model was developed using only the 46 known Yaqui trout localities (black dots). Green stream reaches are those with the highest probability of having Yaqui trout habitat, yellow depicts lower probability reaches, and red depicts stream reaches where GARP says Yaqui trout would be very unlikely to make it.

The prediction was reasonable. Very few of our native trout collections fell outside of predicted, high probability reaches, and these maps were far superior to pouring over topographic maps and guessing.

So, we played more with GARP and gained more insights. We found, for example, that if we used other subsets of data to develop models, we started getting predictions that differed a fair bit from the initial Yaqui trout model. GARP thus seemed to be indicating species-specific habitat preferences, but such predictions with our still relatively small data set are surely confounded by small sample sizes, and I'm not going to pursue any of these ideas beyond simple mention of them here.

GARP also tells us that potential trout habitat extends well south of the areas we've sampled. Though there are no native trout records there, in general there are precious few collections of any fishes in this area, so we would certainly not be surprised to find native trouts here. There are, after all, fossil trout from Lake Chapala in central Mexico.



GARP also looks to be more than a simple heuristic tool. Here I've zoomed in on a piece of the map you were just looking at. Before messing with GARP we had already made a couple trips to the Rio Conchos basin with no luck, but finally in February of this year, we went to the area GARP told us ought to be good, and ended up securing the first vouchered collection of native Conchos trout at the yellow triangle.

We can also use this closeup to talk about where trout are not. Recall that the black dots represent Yaqui trout localities on which the model was based (only some of the 46 are visible here, though). You can also see Mayo (blue triangles) and Fuerte (purple squares) collections. Remember, GARP uses only presence data, and so it had no knowledge of the many other fish collections that have failed to turn up trout in the uppermost Río Papigochic tributary of the Yaqui. This is high elevation area, has some places that look like they could support trout, and there are records of non-native rainbows here, but so far native trout have not been found there. GARP would suggest that's simply because the habitat is not adequate.

Rio Conchos trout habitat



This is that Rio Conchos trout locality. It's obviously rough terrain, and in the left picture you see Dave Neely working hard at catching specimens the easy way, sitting on his ass with a spinning reel, while Bernie hauls the shocker around....

Conchos trout



Though it does have a “cutthroat mark” (as do other native Mexican trouts), it’s clearly not a cutthroat, but a Yaqui trout or close sister of it.

BUT SURPRISE! This was **NOT** the trout we were expecting to find. Cope had clearly been looking at a cutthroat, and the only trout previously known from the Rio Grande basin (from New Mexico, Colorado and formerly Texas) is the Rio Grande cutthroat.

Both morphology and genes clearly tell us **THIS** is a Yaqui trout.

That a Yaqui trout or close sister to it occurs in the Conchos is not too surprising, though, since a number of other fishes echo this distribution.

- *Catostomus bernardini* / *conchos* (now generally both considered as a single species – *bernardini*)
- *Catostomus plebeius*, *Codoma ornata* and *Campostoma ornatum* all span both drainages, as do closely related members of the genus *Gila*.
- *Ictalurus pricei* is in the Yaqui and *punctatus* and *lupus* in the Conchos

Rio Grande cutthroat



Rio Grande cutthroat, *Oncorhynchus clarkii virginalis*

So, discovering **ANY** native trout in the Conchos was really cool by any measure, but we're still left wondering - Is the Lupton / Cope cutthroat still out there somewhere? We certainly wouldn't be too surprised – the Conchos above 1600 m (and there's **lots** of that) is still **INCREDIBLY** poorly sampled.

Preliminary molecular work

- 1999 – 2002 collections
 - 246 specimens from 20 populations of Mexican *Oncorhynchus* + 31 specimens from 3 Mexican hatcheries
- 2004 collections
 - 305 specimens - 257 from wild & 48 hatchery
- Outgroups from GenBank – *O. clarkii*, *O. masoa*, *O. keta*.

Our older collections provided a pretty good number of specimens from 20 populations, including samples of several hatchery stocks from trout culture facilities in the Sierra Madre

The 2004 trips down south were especially productive, and included hatchery samples.

And we could also get outgroup data from GenBank

Microsatellites

- Francisco García de León – ITCV and CIBNOR
 - 12 loci used in previous studies (Nielsen and Sage 2001)
 - 2 others added for 2004 specimens
 - No linkage disequilibrium
 - All in HWE except two in San Lorenzo basin:
 - Granja Truticola (hatchery)
 - La Sidra stream pop immediately below another hatchery
 - Factorial Correspondence Analysis – 3 groups
 - Yaqui/Guzmán/Mayo
 - Mexican golden trout
 - Piaxtla/San Lorenzo populations + hatcheries

Paco Garcia de León, now at CIBNOR in La Paz, is our microsatellite guy.

He looked at 12 microsatellite loci used in an earlier study and, for just our 2004 specimens, two new ones.

He found no linkage disequilibrium and all populations but two were in Hardy Weinberg Equilibrium. Those two were hatchery samples, or from a stream adjacent to a hatchery, so we weren't surprised by this finding

He determined that the microsatellites grouped the specimens into 3 groups:

Yaqui/Mayo/Guzman – the northernmost drainages

Fuerte/Sinaloa/Culiacan - Mexican goldens

Southern drainages

Microsatellites (cont'd)

- two groups within Mexican golden trout group
- Significant differences between all population pairs
- Some signs of introgression between hatcheries and adjacent wild populations
- Also significant differences in some hatchery/adjacent stream sample pairs (i.e. no introgression)
- 2004 samples – 2 loci
 - Significant differences among all drainages.
 - Some indication of Acaponeta basin fish being moved into hatchery and to San Lorenzo
 - No evidence of hatchery *O. mykiss* alleles in either of the rather strongly divergent Baluarte or Piaxtla samples

Paco also found evidence for divergence within golden trout.

He found significant differences between all population pairs (except in a couple cases and again those were not surprising – 2 populations within the Bavispe sub-drainage of the Yaqui were very similar to one another, and 2 separate hatchery populations were very similar to one another)

Regarding the question of introgression of non-native genes into native populations, we got mixed results. We clearly need more samples, but in at least some cases where they could be mixing with hatchery stocks, native trouts appear like they may be pretty good at avoiding introgression. At other places the microsatellites tell us that at least some introgression has occurred.

Piactla trout



I thought maybe it might help some of you stay awake through my talk about the genetics if I were to throw in some of Joe Tomelleri's striking depictions of some of these gorgeous critters. This one's from one of the southern rivers – the Piactla.

Sequence data

Mayden lab

- Little variation in Control Region – 91 of 1008 characters parsimony informative
 - Mexican golden trout (*O. chrysogaster*) always embedded within *O. mykiss*, as were *O. apache/gilae*
 - Relationships within *O. mykiss* are not resolved, but U.S. redband, steelhead and rainbow samples (Bagley and Gall 1999) all consistently resolved with Mexican “rainbows”
 - Two southern clades (Acaponeta/Baluarte/Presidio and San Lorenzo/Piactla) are strongly divergent (almost 100% bootstrap), supporting hypothesis that they are native

Mayden's lab did the sequencing.

Phylogenetics analyses with Control Region data always nest Mexican goldens, Apache and Gila trouts within *O. mykiss*

Though we get poor resolution within *mykiss*, Mexican natives always fall in with the U.S. “rainbows”

These analyses prove Miller wrong – two southern clades of Mexican trout are clearly native.

Sequence data (cont'd)

- Little variation in ATPase 6/8 – 59 of 858 characters parsimony informative
 - *O. apache/gilae* sister to rainbow trout clade
 - Groupings of Mexican trouts similar to that obtained from control region
- Nuclear GH1C and GH2C not informative

Trees based on ATPase data do not tell us anything much different from what Control Region said, and Growth Hormone proved uninformative in this application.

Baluarte trout



Here's the most southern native Mexican *Oncorhynchus*, - the one from the Rio Baluarte

Genetics summary

- 3 – 5 major lineages of *native* trouts in Mexico
 - Northern (Yaqui / Guzmán / Mayo)
 - Mexican golden
 - Piaxtla / San Lorenzo)
 - Presidio / Baluarte / Acaponeta
- All Mexican lineages conflated with *O. mykiss*
 - Continued taxonomic treatment of *O. chrysogaster* as species requires taxonomic revision of several “rainbow trout” lineages

So, in short, more samples are needed and everything here is definitely preliminary, but it's looking like there are these 3 – 5 major lineages of native Mexican trouts

And, phylogenetically, all Mexican trouts are conflated with *O. mykiss*. Continuing to treat the only named Mexican species as a species requires a large-scale revision of other “rainbows”

La Sidra (San Lorenzo) trout



Arroyo La Sidra trout, *Oncorhynchus* sp.

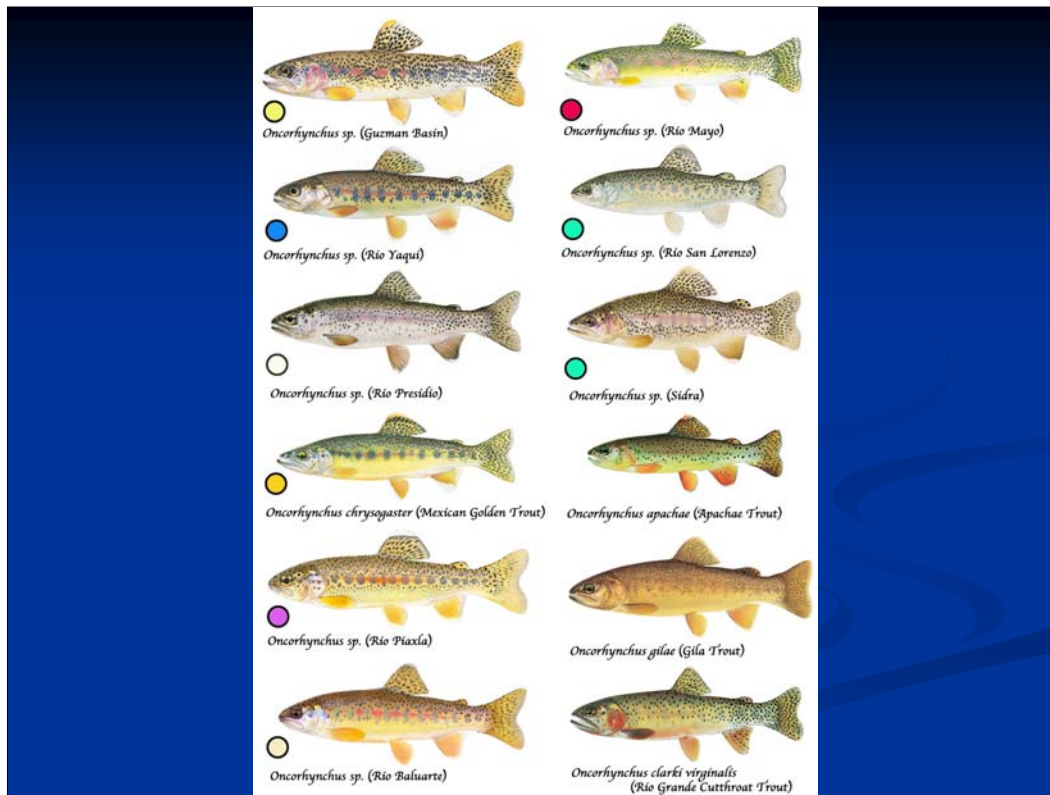
Another of the southern trouts

This area has yielded a number of larger specimens, such as this, and might likely have significant potential for development of sport fishing programs

Morphology

- Mexican trouts all have anal, pelvic and dorsal fins with opaque white tips (orange or salmon sometimes)
- Mexican trout taxa differ in:
 - body coloration
 - Disposition and color of lateral stripe
 - Arrangement/size/shape of black spotting
 - Number of parr marks
 - Height of parr marks and relationship to lateral stripe
 - Number, shape, size of auxiliary parr marks
 - Vertebral, fin, scale and other counts

We've also taken a fresh look at morphological and color characters. Though morphology is anything but easy to deal with in these fishes, these are some of what we see as potentially useful characters



You can contemplate the phenotypic variation of Mexican trouts and some selected others from the Western U.S. (lower right) while I start talking a little bit about conservation issues.

So, you now realize, I hope, that a very large chunk of the total diversity of the genus *Oncorhynchus* is endemic to Mexico. Unfortunately, compared to the extensively studied diversity of trouts in the U.S., we still know almost nothing about the Mexican taxa. This is a bit surprising given the incredible world-wide economic value of salmonids and general interest in them as food and sport fishes and culture organisms, not to mention highly controversial endangered species. But, on the other hand, once one starts chasing Mexican trouts in their incredibly remote and difficult to access part of the world, dodging drug growers and runners who also love the same areas, this lack of information becomes more understandable.

These are definitely not easy critters to collect, but it's important to obtain extensive collections as soon as possible. They are clearly in trouble. Rainbow trout culture is being very actively promoted by the Mexican government. Rudimentary growout facilities are popping up everywhere in every basin we have visited. We've already seen signs of introgression of escaped hatchery genes into native populations, and non-native rainbows will undoubtedly impact native stocks in many other ways. At the same time, habitats are being quickly altered by logging, road building and other forms of development.

Conservation issues

- Habitat degradation / fragmentation
- What are habitat preferences?
- Ecological work lacking.



Habitat degradation is rampant. But, what is the preferred habitat of these unstudied taxa? I can certainly tell you that it's not what many familiar with the more northern cousins of these critters might expect. This stream, for instance, at least in winter, supported significant numbers of Mexican golden trout hiding under rocks. Lots of room for ecological research here....

Conservation issues

- Hatcheries and small growout facilities expanding rapidly with diverse impacts
- Diseases
 - IPN recently introduced to N. Mexico
 - Has shut down primary production facilities in Central Mexico
- Logging and road building expanding
- Local pollution issues

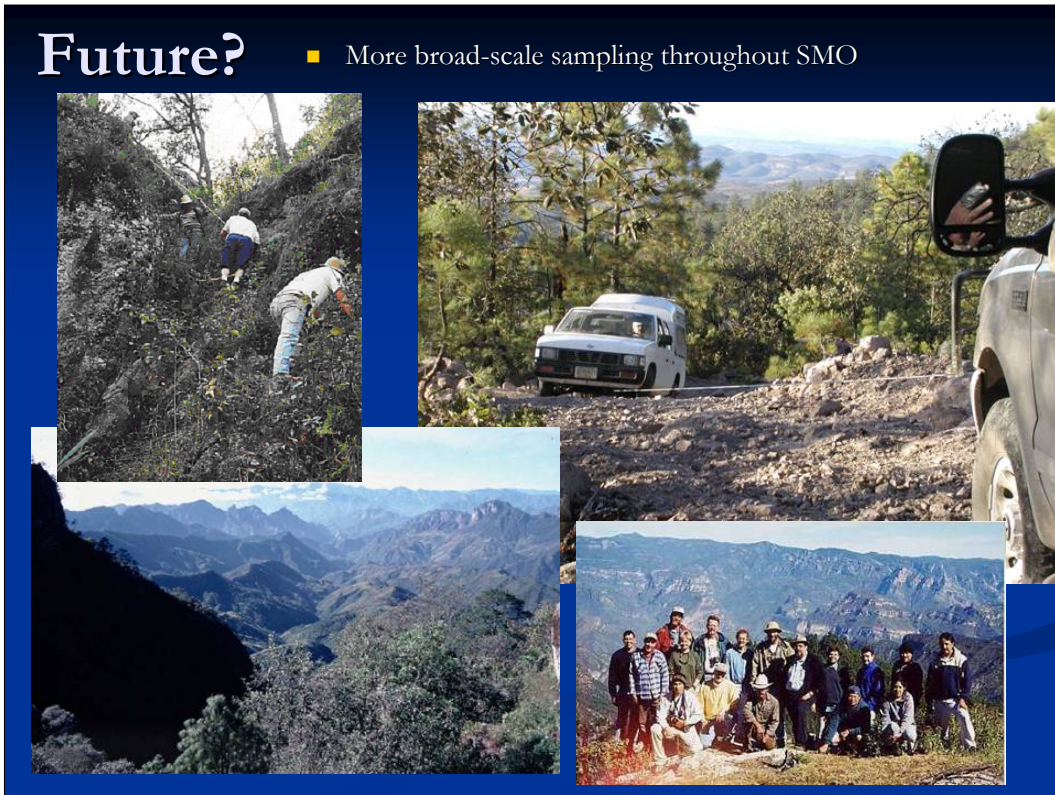
As I've said, hatcheries are rapidly expanding – SAGARPA, the Mexican Fisheries Department, is very actively promoting and funding new rainbow trout culture facilities.

If introgression doesn't get 'em, other things likely will – Infectious Pancreatic Necrosis is a nasty disease that was recently introduced to the Sierra Madre Occidental with hatchery rainbows. It has almost surely escaped to wild streams by now. It completely shut down Mexico's major egg and fry production facilities, so local hatcheries and growout facilities are now shopping elsewhere and bringing in other strains and who knows what else.

Logging is pervasive, with lots of new roads and the increased erosion and other impacts those activities bring, not to mention better access to formerly remote headwaters so new little rainbow growout facilities can go in. And this industry has some pretty heavy, albeit localized, point pollution impacts, such as those related to sawmills.

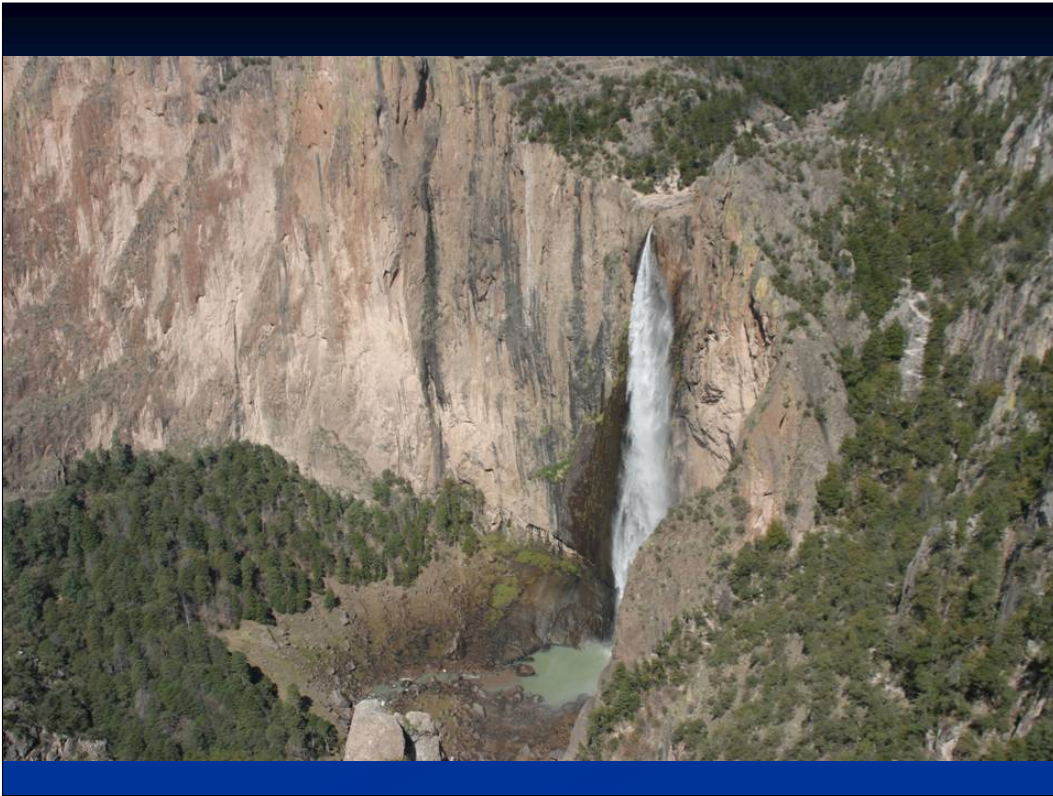
Future?

- More broad-scale sampling throughout SMO



We need to continue sampling, but that's not going to be easy. As I've already mentioned, and as you can see here, this is rough country. Our winch gets a lot of use and getting from one stream to the other is never quick.

A helicopter would be great, but the drug lords might not allow it to stay in the air for long.....



Basaseachic falls, though clearly at the extreme end of rugged, much of the region is not much further down the curve. To give you an idea of scale here, from this vantage point, people on the lip of the falls are little more than specks, and when you hike to the base of the falls, what appear to be “small” boulders in the spay zone are actually house-size.

Just to get to edge of the canyons where we would like to sample is always an ordeal in this part of the world. Then comes the big hike, often through lots of marijuana growing along the way.

Outreach

- Education of local residents
 - Value of native trouts
 - Impacts of rainbows
- Possible sport fishing
- Possible aquaculture with native stocks
- SAGARPA (Mexican Fisheries Dept.)
 - native / non-native conflicts
 - Value of natives

We've done some outreach and hope to pursue more of this soon. It's especially important that fisheries people become better informed regarding the conflicts between natives and introduced rainbows, and regarding the potential values of natives in fish culture and / or sport fisheries.

Acknowledgements:

- Personal investments of all participants
- NSF SGER DEB 0240184 to Rick Mayden
- Permits – INE, SEMARNAT, SAGARPA, PROFEPA, USFWS, USDA
- Dozens of interested local residents who helped us by serving as guides, translators (Rarámuri – Spanish) and kept us from stumbling into too many things we really didn’t care to stumble into...
- “Watchale” and her wench

Dedicated to Gerardo Zamora Balbuena

Personal investments – much of what I’ve presented was the result of “vacation” trips on our own personal nickels.

Permitting for fieldwork is frankly a nightmare that has definitely slowed us down – I’ll say no more, and please don’t even ask me about this **unless you’re pouring me tequila as you do**.

Many locals have helped us in many ways, including keeping us out of trouble that we could easily have stumbled into if we tried to do this without them

Our primary field vehicle, affectionately named **Watchale!** certainly deserves acknowledgement. Picture, if you can, a very drunk cowboy, and not just any old drunk cowboy, but one blasted on **Isopropyl** alcohol (**REALLY**), madly spurring his burro in tight circles next to our campfire yelling repeatedly “**Watchale!**”. This is obviously “Spanglish” term that that I eventually figured out means “Watchout!”. So, that memorable event became not only the name of the truck, but also the trip slogan, and it’s really appropriate since you never can tell what’s going to happen next with this project and always have to be “watching out”. Rick wisely equipped the truck with what quickly became a well-used, and clearly indispensable “winch”, but he typoed the word in an email describing the truck when he ordered it, so that stuck too.

Gerardo Zamora was one of our collaborators and our first and very important link to SAGARPA, the national Fisheries agency within which he worked. Gerardo succumbed at an early age to cancer just a few months ago. He was very enthusiastic and a hard worker who we had sent up to visit a number of native trout hatcheries in the western US. He established captive stocks of Yaqui trout at his hatchery on the edge of Mexico City and was doing great things with them. He surely could have contributed much more had he lived and he will be missed.



Not sure you can see detail here, but I'll end with this poster that Dave Neely put together with a bunch of field pictures of just the southern-most (San Lorezo, Baluarte and Acaponeta) specimens, compared with a few specimens of Mexican golden trout (2nd – 4th from bottom in the second column).