FISHING FOR ANSWERS:
Status and Trends for Coldwater Fisheries Management in Colorado

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> Epifanio, J. and D. Nickum. 1997. Fishing for Answers: Status and Trends for Coldwater Management in Colorado. Trout Unlimited Technical Report. 74 pp.

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[1] Additional copies of this report may be obtained by writing Trout Unlimited, 1500 Wilson Boulevard, Suite 310, Arlington, Virginia, 22209, or by calling (703) 522-0200.

Acknowledgements

We wish to thank those individuals who contributed, cooperated, or reviewed earlier drafts of this report. Many of their ideas improved the quality of the reporting; any shortcomings in prose or content remain the responsibility of the authors. We also wish to thank staff with the Colorado Division of Wildlife for providing data and philosophical perspective on fishery management in Colorado. In particular, we would like to acknowledge Robin Knox, Tom Powell, and Bill Weiler for providing much of the information used for this report; and Dr. Robert Behnke, Dr. Charles Gowan, Dr. John Nickum, Clee Sealing, John Trammell, and several anonymous reviewers for their feedback and criticism. Finally, we thank the David and Lucille Packard Foundation, the Educational Foundation of America, the Weeden Foundation, the Orvis Company, and TU's Coldwater Conservation Fund for providing funding for this review.

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EXECUTIVE SUMMARY

This Trout Unlimited study was designed to examine the core assumptions and attributes underlying the Colorado Division of Wildlife's (CDOW's) current management practices regarding native, wild, and artificially-propagated fish; to examine Colorado's fishery policies from a resource conservation perspective; and to offer a constructive critique regarding Colorado's use of propagated fish as a management tool. Colorado's program was chosen for a detailed case study as part of Trout Unlimited's National Fish Hatchery Assessment because a sizable proportion of focus, effort, funding, and activity within the CDOW concerns the artificial propagation – hatchery culture and stocking – of trout.

In the context of a carefully managed fisheries program, hatchery-reared fish can play vital roles in endangered species restoration, maintaining urban fisheries, and providing angling recreation in degraded or heavily altered habitats that would otherwise not support fisheries. However, there are real risks associated with stocking fish that must be taken into account when making stocking decisions.

Hatchery-raised fish compete with wild and native fish for space, food, spawning and nursery habitats and other important resources. They may prey on wild fish directly. Introduction of non-native species or sub-species can disrupt natural ecosystems, can lead to loss of genetic integrity through hybridization, and may result in local extinction. Stocked fish can also spread or introduce diseases into the wild. One dramatic example of the risks inherent in widespread stocking is the role of hatchery propagation in the spread of whirling disease in Colorado. Stocked fish are sometimes advertised to "buffer" wild populations from harvest. In fact, they may attract far greater numbers of anglers to a water and thus "prime the pump" for greater harvest of wild fish. In a more subtle fashion, heavy reliance on stocked fish can mask serious environmental degradation by maintaining supplies of fish for harvest while doing nothing to address the continuing loss of wild trout habitat.

By contrast, the benefits provided by self-sustaining ecosystems go far beyond their "worth" to human-kind, although such utilitarian values are real and measurable. Many "products" of natural systems – including things like recreational fisheries, reliable supplies of clean water, and the revenue generated by tourism – can be quantified in dollar terms. In addition, healthy natural systems embody an array of other values that are no less significant. These include "amenity values" – the value of things that provide spiritual, aesthetic, or recreational benefit. Many people find value in simply knowing that healthy systems exist, whether or not they ever visit or use them. "Contributory value" is an indirect valuation, based on the notion that a whole, functioning, and integrated ecosystem is more valuable than the sum of its individual parts. Finally, natural systems, and their parts, can be said to have "intrinsic value" in and of themselves independent of their imposed or recognized societal benefits. In this sense, many believe we have a moral responsibility to conserve such systems regardless of their utilitarian value.

Given the dynamic and fragile nature of biological systems and the ever-changing state of scientific knowledge, and the existence of alternative approaches to resource management, it is important to periodically review the consequences of any fisheries management strategy, and Colorado's hatchery-oriented management strategy deserves careful scrutiny. Of particular concern is that Colorado's emphasis on stocked fish diverts personnel and funding that could be devoted to sustainable goals of habitat and species protection and restoration.

Trout Unlimited's examination of CDOW's coldwater fishery management practices uncovered 42 individual findings, which are grouped under eight major headings: management strategies, stocking decisions, use of propagated fish, native fish, wild trout management, fish health, angler attitudes, and economics and angler demand.

The key findings of this assessment can be summarized as follows:

- **Colorado annually stocks a large number of catchable-sized trout into its streams and lakes;** of the 15.9 million fish stocked in 1995, 4.6 million were catchable-sized trout. Although fisheries managers cite a multitude of justifications for stocking fish, it is well documented that stocked fish can have dramatic impacts on the biological and physical attributes of the ecosystems into which they are planted. CDOW's focus on propagating and stocking catchable fish has reduced the resources available for habitat protection, stream rehabilitation, and enforcement.

- **A large percentage of CDOW's fisheries budget and personnel are devoted to hatchery and stocking operations.** In the current budget year (FY 1997-98), the CDOW's budget for hatchery operations is $2.2 million, as compared to $1.6 million for the Aquatics Section, which carries out other fisheries management activities. Similarly, hatchery and stocking programs are allotted 88 full-time equivalent employees; the Aquatics Section accounts for 70.

- **Colorado's emphasis on stocking catchable trout is based on an invalid assumption: that there is a direct and equal relationship between catchable stocking levels and angling recreation.** This assumption is largely unsupported by the evidence, and is at odds with the CDOW's own survey of angler attitudes in Colorado, which show that aesthetic values top the list of most important angling variables. Recent research by CSU economist John Loomis has found no statistically significant relationship between historic levels of stocking and fishing license sales.

- **The CDOW lacks adequate creel and inventory data, and some of its assumptions are not supported by peer-reviewed science**. The CDOW has inadequate inventory and creel census data to evaluate the impacts and effectiveness of its management activities for many waters. Some stocking has also been based on erroneous assumptions, for example, that stocking fish exposed to whirling disease poses little risk to wild trout populations. The CDOW itself found that a 273 percent increase in catchable stocking at Rifle Gap in the mid 1980s increased angling hours by only 5 percent.

- **Few waters have been designed for "wild trout" management -** only one percent of those with average or better habitats are so designated. While many other waters are managed as "de facto" wild trout habitats, they have gotten relatively little management attention.

- **The CDOW places little emphasis on native trout production.** In addition it has engaged in some stocking practices that may jeopardize populations of Colorado River cutthroat trout. Native trout represented less than one percent of CDOW's coldwater hatchery production in 1995. Stocking of non-native trout over native populations has persisted into the 1990s. Non-native trout represent one of the primary threats to the continued survival of Colorado's three native cutthroat subspecies, and historical stocking of non-natives contributed to the extirpation of a fourth subspecies (yellowfin cutthroat). Moreover, the CDOW has not consistently managed for local strains in its native trout stocking programs.

- **CDOW's catchable trout program is not economically justifiable over the long run. The average total cash cost to produce a catchable trout exceeds the perceived benefit to the angler by a full 75 percent.** It costs the CDOW $2.22 per trout caught by an angler, while the average benefit to the angler, as calculated by the DOW's own research, is only $1.27. When the costs of replacing or retrofitting facilities and modernizing practices to minimize risks from whirling disease are included, the gap between cost and benefit widens.

- **The CDOW has played an important role in saving the greenback cutthroat trout from extinction.** The CDOW has been an active partner in efforts to restore populations of greenback cutthroat trout, and has managed for distinct stocks in the Arkansas and South Platte drainages.

- **The CDOW has greatly strengthened its programs for fish health**. Past CDOW regulations allowed stocking of WD+ fish throughout drainages where the parasite had already been found, facilitating the spread of the disease. In recent years, stocking of WD+ trout has been greatly reduced, *but continues in an number of trout waters (particularly lakes)*. Biologists from the CDOW have been in the forefront of research on whirling disease, and the CDOW has an aggressive program for hatchery inspection.

- **The Colorado Wildlife Commission recently adopted a statewide Fish Management Policy that reflects much of the latest knowledge about coldwater conservation.** The new policy takes a progressive approach to making stocking decisions. However, in the past such directions have not always been aggressively or consistently implemented, and the CDOW must be encouraged to put its policies into practice.

PREFACE

The National Resource Board of Trout Unlimited, along with its member Councils, identified the potential misuse of hatchery-produced fish as an issue of concern facing the conservation of coldwater fisheries and their ecosystems. TU's leadership deemed it appropriate to take stock of coldwater fisheries management in the U.S. and the status and effectiveness of artificial propagation as one of its many tools. To accomplish this goal, we are conducting two kinds of analysis for programs across the country. One is the gathering of information from all of the states regarding a wide range of topics in fishery management and conservation. A questionnaire was sent to each state requesting basic and descriptive information about its fishery management program. The intent was to gather like kinds of information from every state program. As of July 15, 1997, 49 of the states had responded to our request for information.

The second analytical approach is to choose several state programs – California, Colorado, New Hampshire, Wisconsin, and Washington state – for more intensive case study. Individual programs were chosen because they either typify some issues of national concern, face unique challenges, or achieve a more rigorously substantiated balance of artificial and natural production (e.g., Washington state's efforts to develop a Wild Salmonid Policy and Wisconsin's traditional wild trout waters program and recent reorganization).

This case study is intended to provide an overview of Colorado's coldwater fishery and artificial propagation activities. Colorado was selected as a case study for several reasons. One, Colorado is recognized as an important coldwater state from the perspectives of both recreational fisheries and salmonid biodiversity. Two, some Colorado coldwater watersheds have been greatly affected by the parasite causing whirling disease, whose introduction and spread has been linked to artificial propagation and stocking. Three, Colorado extensively uses fish that are not native to the state's watersheds in order to support recreation.

Statement of Purpose

This case study provides an overview of the Colorado Division of Wildlife (CDOW) programs for fish culture, stocking, and coldwater fishery management. Colorado's program was chosen because a sizable proportion of focus, effort, funding, and activities within the CDOW concern the artificial propagation of "catchable-size" (hereafter, catchable) and "subcatchable-size" (hereafter, subcatchable) trout[2]. For many of the waters managed intensively with hatchery-reared trout, there is no intent to create or maintain self-supporting fish populations that complement or strengthen the health of an ecosystem. One reason often cited for this emphasis on stocking is that many of Colorado's waters lack the capacity, either naturally or because of habitat alteration, for native or wild trout production–at least at levels sufficient to support a recreational fishery acceptable to the public.

As one of several tools available to fishery managers, artificial propagation has been used in North America for more than 125 years[3]. Although there are a multitude of reasons for employing this tool in various aquatic ecosystems and with different species, one of the most basic reasons cited is that *more* fish are needed to maintain satisfactory catch rates. Regardless of the reasons for their use, propagated fish can affect the biological and physical attributes of the ecosystems into which they are planted. The nature, extent, and persistence of these effects depend on the scale and makeup of the stocking program and the nature of the receiving ecosystem. Given the dynamic nature of biological systems and the ever-changing state of the science, it is important to periodically review the consequences of any management strategy.

The primary *purposes* of this case study are (1) to examine the core assumptions and attributes of Colorado's current management practices including native, wild, and propagated fish; (2) to examine fishery policies from a resource perspective; and (3) to offer a constructive critique regarding Colorado's use of propagated fish as a management tool.

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[2] In some states, "subcatchable" is used to describe a larger size of fish used in put-grow-take management and is distinguished from fry and fingerling. For the purposes of this review, however, "subcatchable" will refer to any fish planted at a size where they are not intended for immediate harvest.

[3] Bowen, J.T. 1970. A history of fish culture as related to the development of fishery programs. In Benson, N. G. (ed.). pp. 71-93. A Century of Fisheries in North America. American Fisheries Society Special Publication No. 7.

Methods

This report was compiled using publicly available information (documents, policies, stocking records, and other data) concerning the CDOW's philosophy and practice of fishery resource stewardship. Additional information was obtained through direct communication with agency staff and others familiar with CDOW's management programs. Where appropriate, we direct interested readers to additional sources of information which expand upon our discussions.

Threats to Colorado's Aquatic Heritage

Healthy fish communities and their ecosystems are no accident. Those that we consider to be in healthy condition are usually characterized by having (1) a stable, albeit dynamic, interrelationship among trophic levels within an ecosystem, (2) biological diversity that changes slowly and at normal background levels, and (3) a mosaic of interconnected functional habitats. These operate and integrate such that the biological, chemical, and physical elements of the aquatic (and surrounding terrestrial) ecosystem can buffer the continual string of environmental challenges brought on naturally and by humans. Healthy ecosystems have a diverse suite of values (commodity, amenity, aesthetic, service, existence, etc.) that are important and beneficial to humans[4]. The benefits or values of naturally-productive ecosystems are described further in Box 1.

The expansion of Colorado's human population has led to the direct and indirect alteration of watersheds, including the rivers themselves (e.g., through channelization, impoundment, or filling) and the surrounding landscapes (e.g., through urbanization, agricultural development, or deforestation). Although these activities have occurred throughout recorded human history, the rate and scale of change has accelerated in modern times. As a result, we have witnessed drastic alterations in the landscape and biological character of our watersheds. Future development and human expansion will require some planning if local natural heritage is to persist.

In addition to the simplification, fragmentation, or loss of habitat, aquatic life can also be threatened by overharvest and the erosion of genetic variation and organization. All of these threats can result in the alteration of ecological integrity[5]. For further discussion of these issues, refer to Appendix III.

[4] For further discussion, see Hallerman, E. J. and J. M. Epifanio (1995). Human dimensions of biological diversity. In Philipp, D.P. et al. Proceedings of the World Fisheries Congress, vol. 3. Oxford Press International. New Delhi, India.
[5] Philipp, D. P. et al. 1995. A synthesis of threats to aquatic biological diversity. In Proceedings of the World Fisheries Congress, vol. 3. Oxford Press International. New Delhi, India.

Box 1. Values[6] associated with biological diversity and ecosystem integrity.

The benefits provided by living resources and ecosystems can be divided into three major kinds of value.

A. **Instrumental value** – anthropocentric or utilitarian values based on their worth to human-kind.

1. Commodity value – value of something if it can be used as or turned into a product or goods bought and sold in the market place (e.g., fuel, fiber, medicine), services (e.g., pollination, nutrient recycling, nitrogen fixation, buffering capacity, etc.[7]), or information (e.g., biotechnology, applied and basic scientific values).

2. Amenity value – value of something if its existence improves our lives in a nonmaterial way. For example, anything that imbues a spiritual, aesthetic, or recreational benefit. These values can be both for ongoing use and for potential use ("option value").

B. **Intrinsic value** – anything that has a value in and of itself and whose existence is independent of its imposed or recognized societal benefits, often for moral reasons.

C. **Contributory value** – an indirect valuation, such that the perceived value of some things are that they contribute to the health, well-being, and integrity (and direct value) of other things. This leads to the notion that the value of a whole, functioning, and integrated ecosystem is more valuable than the sum of its individual parts.

In the face of these pressures, there are four primary elements of fishery management that can be integrated and balanced for the benefit of aquatic life. These are (1) harvest management, (2) habitat protection and remediation, (3) maintenance of more natural hydrological features, and (4) artificial propagation and stocking. Unfortunately, an emphasis among many jurisdictions on this final element has raised serious concerns that we may be ignoring deeper threats to aquatic systems, and even intensifying problems through inappropriate uses of propagated fish[8].

[6] Adapted from Callicott, J. B. 1994. Conservation Values and Ethics. Pp. 24-49. In Meffe, G.K. and C. R. Carroll. Principles of Conservation Biology. Sinauer and Associates, Inc. Sunderland, MA. Norton, B. 1988. Commodity, amenity, and morality, the limits of quantification in valuing biodiversity. pp. 200-205. In Wilson, E. O. Biodiversity. National Academy Press, Washington, DC. Hallerman, E. J. and J. M. Epifanio (1995). Human dimensions of biological diversity. Pp. 199-212. In Proceedings of the World Fisheries Congress, vol. 3. Oxford Press International. New Delhi, India.

[7] See also Daily, G. C (editor). 1997. Nature's Services. Island Press. Washington, DC. and references therein for recent descriptions and case studies of service values. For specific case study applicable to Colorado, see especially Wilcox, A. and J. Harte. Ecosystem services in a modern economy: Gunnison County, Colorado. pp. 311-328.

[8] Schramm, H. and R. Piper (Editors). 1995. Uses and Effects of Cultured Fishes. American Fisheries Society Symposium No. 15. Other national and international symposia and workshops have addressed the concerns and components of artificial propagation as well.

What Is Artificial Propagation?

In this report, we consider not only **artificial propagation**[9] (hereafter, "propagation") in the sense of the husbandry, culture, and rearing of fish, but also the full range of activities associated with decision-making, transport and release of fish, and monitoring and evaluation. The majority of issues raised within this document have more to do with the *use* of cultured fish than with the effects of culture and rearing themselves. This is not intended to suggest that there is no need to monitor fish husbandry or culture effects, but for this report, we will focus on the ways in which cultured fishes are used and how the decisions to use them are made.

For sake of discussion, the use of propagation in fish management can be broadly categorized into six kinds of activities (though a stocking program may have attributes of more than one of the following): (1) conservation; (2) supplementation; (3) mitigation; (4) recreation; (5) introduction; and (6) food-fish aquaculture. [10]

> ***"Conservation" stocking*** – the release of fish for the purposes of restoring, re-establishing, or recovering reproductively capable and self-sufficient populations of fish. Generally, this form of propagation is used to assist recovery of a degraded population after the cause of decline has been removed (or as it is being removed). Examples of this kind of activity would include the reintroduction of a native species into a restored or intact habitats (e.g., greenback cutthroat trout stocking in the South Platte and Arkansas River drainages) or the reseeding of an introduced wild population following an environmental catastrophe (such as a chemical spill resulting in a fish-kill) to accelerate recolonization.
>
> ***Supplementation stocking*** – the release of fish for the purpose of increasing recruitment to a harvestable size in an existing population. This form of propagation is often used for populations for which fishing pressure is allowed to exceed levels which can be supported by a wild population. In this case, natural recruitment is "supplemented" or "enhanced" by the planting of individuals, thereby increasing the size of the harvestable population. One reason sometimes cited for this strategy is that artificially-produced fish can be selectively harvested to reduce pressure on the natural pool of reproducers. However, this requires some method of discrimination between wild and stocked fish by those conducting the harvest. An example of this approach is the stocking of catchable and fingerling rainbow trout over wild trout populations in the Cache la Poudre River.
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> ***Mitigation stocking*** – the release of fish to compensate for the harm to or loss of an aquatic ecosystem function following a human-related perturbation (e.g., the

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[9] Selected terms in boldface are defined in Appendix I.

[10] For sake of completeness, baitfish or forage base production should be included as well. In general, salmonids are not produced as bait or forage. A stocking program also may have attributes of more than one of the categorical uses.

construction of a dam, destruction of spawning beds, etc.). This form of propagation and stocking tends to be a closed-loop because some part of the original population's life cycle requirements have been lost or greatly reduced. Often there are no immediate or long-term plans for re-establishing a self-sufficient population. An example would be the stocking of rainbow trout fingerlings in Blue Mesa Reservoir to mitigate for riverine populations lost when the dam was built.

Recreational stocking **–** the release of fish for the purpose of providing an immediate, impending, or temporary recreational harvest. Individuals may be planted at "catchable" size or at sizes intended to be grown and recruited into a harvested size. This approach is often used in waters that receive intensively focused harvest pressures but where natural reproduction is limited or nonexistent. An example would be the put-and-take stocking of catchable-size trout in urban lakes.

Introduction **–** the release of fish derived from a gene pool that is non-native or otherwise divergent from that in a recipient watershed. These activities can be one-time or continuous events for the purpose of "diversifying" the fishery by providing additional species or populations characteristics that do not already occur in the wild. An example of an introduction is the release of largemouth bass into Colorado reservoirs to create novel warm water sport fisheries.

Food-fish aquaculture **–** the culture and rearing of fish in captivity as an agricultural commodity. Individuals or whole lines are often specifically bred for specific traits that are economically beneficial to the grower or desirable to the consumer as a source of protein. This form of propagation is beyond the scope of this document and will not be considered further[11].

The CDOW's management programs include each of these kinds of propagation, except for food-fish aquaculture. This reflects the variety of purposes for which the propagation tool is used in Colorado. It is important to note that, in general, only conservation stocking (and sometimes introduction) is intended to establish or increase the self-sustaining character of fish communities and aquatic ecosystems. The other forms of propagation are intended to promote recreational use and/or harvest, or provide fisheries where existing habitats cannot support self-sustaining populations at desired levels.

[11] Colorado has a sizable private aquaculture industry (~34 operations are presently permitted by the state). The practices and consequences of these private operations are beyond the scope of this review.

Concerns With Propagation

Any management tool should be monitored carefully to determine its impacts on the ecosystem. Propagation is no different. The specific concerns with propagation raised by conservation and environmental organizations, professional fisheries societies, and various user groups can be grossly categorized as biological (ecological, genetic, disease, etc.), economic (direct costs, opportunity costs, etc.), social (primarily ethical), and political (access, availability, ownership, etc.). These concerns raise two fundamental questions: (1) is a propagation strategy likely to support the long-term viability of aquatic resources in a watershed? and, (2) is propagation delivering its intended benefits (or can it do so)?

Resource management is often an exercise in risk assessment. Managers establish goals (based on agency mandate, public opinion, historical practice, etc.); consider the costs and risks of different management options; and (in theory) choose options that achieve management goals while minimizing risks and costs. In this process, it is critical to recognize the full range of effects and costs, short and long term, that may result from management actions. The way in which goals, costs, and risks are defined ultimately colors the choice of management alternative.

The biological and social risks associated with the stocking of fish are summarized in Box 2. The importance of these risks in a particular situation will depend on the biological specifics of both donor and recipient populations (e.g., size, life stage, density, timing, stock or species, health, etc.). These issues are discussed in greater detail in Appendices II and III.

Box 2. Biological Risks to Aquatic Ecosystems from the Culture and Release of Fish

Ecological Risks:

1. Competition for resources, space, and food.

   a. Interspecific (between species) – Niche overlap among native and introduced species. Generally speaking, two species cannot utilize the same resource in identical ways (that is, occupy the same niche simultaneously)[12]. There will either be a shift away from the overlap by one or both competitors, a movement of one or both toward more marginal habitats or resources, or the complete displacement (or local extirpation) of one of the competitive species.

   b. Intraspecific (between individuals within a species) – Increase in density of the species beyond the sustainable carrying capacity of the ecosystem. Not only is the food base of a species generally limited (especially for ecological specialists), but there are also limits for spawning or nursery habitats and other important resources.

2. Predation – Introduction of novel predators (or prey) or change in concentration of existing predators (or prey), which alter community composition and structure.

[12] This is not always the case. If an outside factor (e.g., predation) keeps two species at low density, they may be able to persist without the effects of competition described above.

3. Trophic – Shifts in trophic organization (i.e., changes in the nutrient base or energetic pathways in a system). These result from changes in the balance of primary and secondary production (or "food chain" effects). For example, the decline of migrating salmon along the western coast has been accompanies with a loss of system nutrients from decaying carcasses.

4. Environmental – biological or chemical pollution (point source) as a by-product of metabolic waste from thousands or millions of fish[13].

5. Alteration of habitat – introductions of nonindigenous species, or stocking in excess of habitat or carrying capacity, may result in damage to aquatic habitat. For example, introduction of benthic foragers, such as grass carp can mechanically change lake substrates.

Genetic Risks:

1. Interspecific

a. Direct – loss of a gene pool identity (or genetic integrity) due to hybridization. Among-group community diversity is lost through a blending effect. If crossbreeding is sufficiently common, the parental species' identity may be lost entirely resulting in a local extinction, even though both sets of parental genes are still present in hybridized (introgressed) population. Examples of this phenomenon have occurred where rainbow trout have been introduced on top of cutthroat trout, brook trout on top of bull trout, rock bass on top of Roanoke bass, smallmouth bass on top of Guadeloupe bass, and so on.

b. Indirect – loss of within-population diversity due to small population size reduced primarily through habitat loss, competition, predation, or other ecological processes. For example, the reduction of a population's range (due to predation or competitive displacement), can reduce its population size. A reduction in population size can cause a reduction of the genetic effective population size[14]. This reduction, if severe, can lead to a further risk of local extinction or population reduction leading to what has been called an *extinction vortex*[15].

2. Intraspecific – due to gene flow among divergent genomes. Different populations of the same species may have very different patterns of genetic diversity – differences that can be lost through mixing. Conceptually, this risk is the same as that described above for interspecific gene flow; the difference between genetic divergence at the population level and that at the species level is one of degree rather than kind. At one level, the introgression of divergent genomes effectively represents an extinction of one or both genomes[16]. At another level, such introgression can also reduce long-term fitness due to loss of local adaptation[17].

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[13] For a case study and discussion on chemical effluent and biological effects of culture facilities, see Perry and Vanderklein, 1996. Water quality: management of a natural resource. Blackwell Science.

[14] See Gall, (G. A. E. 1987. Inbreeding. In Ryman, N. and F. Utter. Population Genetics in Fishery Management. University of Washington Press., Seattle, WA) for a description of the effective population sizes, the processes which affect it, and the consequences of a reduction in Ne.

[15] For a description, see Gilpin, M. E. and M. E. Soule. 1986. Minimum viable population size: Processes of species extinction. In Conservation Biology: The Science of Scarcity and Diversity, pp. 19-34. Sinauer Associates, Sunderland, MA.

[16] Leary, R.F., F. W. Allendorf, and G.K. Sage. 1995. Hybridization and introgression between introduced and native fish. American Fisheries Society Symposium 15:91-101.

[17] Waples, R.S. 1995. Genetic effects of stock transfers in fish. In Proceedings of the World Fisheries Congress, vol. 3. Oxford Press International. New Delhi, India. and references therein.

Disease Risks:

1. Introduction of non-endemic pathogens – due to transport of live fish (and sometimes gametes) across watershed boundaries. In areas where pathogen and fish have co-evolved, a pathogen may be relatively benign with the local population serving as a carrier but not displaying serious disease impacts. If these carriers are transported to a region devoid of the pathogen, the carriers can facilitate spread, perhaps into other populations lacking prior adaptive immunities.

2. Increased abundance of pathogens in systems where they are already endemic. Even in systems where a pathogen is already found, introduction of fish carrying the pathogen can increase the incidence (% of population carrying the pathogen) and severity (extent of pathological impacts) of infection. For example, stocking of salmon exposed to bacterial kidney disease in the Great Lakes has been implicated in increasing the severity of disease problems in lake trout populations.

Social risks:

1. Increased harvest of naturally-reproducing populations. Stocked fish are sometimes advertised to "buffer" wild populations from harvest. In fact, they may attract far greater numbers of anglers to a water and thus "prime the pump" for greater harvest of wild fish, especially where discrimination between wild and propagated fish is difficult. This is a particular concern for states (including Colorado) where stocking locations are widely publicized in the popular press.

2. Habitat damage caused by excessive fishing pressure. In some sensitive habitats (such as high mountain lakes) stocking may attract sufficient numbers of anglers to damage aquatic and terrestrial habitat (e.g., through trampling of fragile soils or plants).

3. "Techno-arrogance[18]" reducing public concern for habitat degradation due to an unsubstantiated belief that the technology can circumvent the problems with a technical or engineering solution.

[18] This term was introduced in Meffe, G. K. 1992. (Techno-arrogance and halfway technologies: salmon hatcheries on the Pacific coast of North America. Conservation Biology 6:350-354).

Policy Framework for Colorado's Fisheries Management

To assess aquatic resource management in Colorado, it is important to understand the structure of management authority within the state. Appendix IV describes elements of law and policy which bear on fish management. The following is a summary of that discussion.

General Aquatic Resource Management Authority

In Colorado, the General Assembly has established general guidelines for wildlife management in statute. Beyond defining basic principles, the legislature generally defers to the Colorado Wildlife Commission (Commission) in setting wildlife policy for the state and to the CDOW for executing those policies.

The goals for wildlife management in Colorado are described in law:

> It is the policy of the state of Colorado that the wildlife and their environment are to be protected, preserved, enhanced, and managed for the use, benefit, and enjoyment of the people of this state and its visitors. It is further declared to be the policy of this state that there shall be provided a comprehensive program designed to offer the greatest possible variety of wildlife-related recreational opportunity to the people of this state and its visitors and that, to carry out such program and policy, there shall be a continuous operation of planning, acquisition, and development of wildlife habitats and facilities for wildlife-related opportunities. (§33-1-101)

From this basis in statute comes what is sometimes referred to as the CDOW's "dual mission": to protect and manage wildlife and to provide recreational opportunities.

The CDOW is staffed by professional fish managers, planners, and administrators charged with the daily conduct of wildlife management. The CDOW is under the direction of a Director, who serves essentially as the chief executive of the agency. Within the CDOW, specific divisions involved with aquatic resource management include a Hatchery Section (responsible for fish culture operations); an Aquatics Section (responsible for fish management and research activities); and a Habitat Section (responsible for CDOW involvement with in-stream flow programs, land use planning, and other activities that impact on wildlife habitat). The CDOW is also divided into three geographic regions: Western (Colorado River drainages), Northeastern (Platte River drainages), and Southeastern (Arkansas and Rio Grande River drainages).[19]

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[19] While the CDOW is currently divided into three regions, prior to its recent reorganization it was split into five regions: the Central (surrounding the Denver metropolitan area), and the Northeast, Southeast, Northwest, and Southwest regions (encompassing the four "quadrants" of the state implied by their

Fisheries Management Policies

(Editor's Note: Since this document was completed, Colorado has adopted a new statewide fisheries policy, which supersedes many of the following policies and which places a greater emphasis on wild and native trout resources.)

Fish stocking decisions are guided by five Commission policies (D-1, D-2, D-4, D-6, D-9) and an administrative directive issued by the Director (F-1). The policies are generally complementary, but they embody are some inconsistent messages. For example, certain policies make recreation the priority, while others emphasize resource protection.

Management of aquatic wildlife (D-1, 1975) – The Commission established a goal to "provide optimum fishing recreation . . . within the limits of the resource and available funding." The policy calls for stocking in waters where a fishery would not otherwise exist or where the existing wild fishery would not support "adequate fishing recreation." The policy calls for caution in making new introductions.

Fish stocking (D-2, 1975) – The Commission reiterated its intent to "provide anglers in Colorado with the best fishing opportunity possible" and noted the need for stocking if "all waters are to be utilized to an optimum extent for fishing recreation purposes." However, the policy notes that catchable stocking should not take place in waters which can be managed without stocking or with subcatchable stocking.

High lake management (D-4, 1975) – This policy addressed management of high elevation lakes, both natural and man-made, where water levels do not fluctuate greatly (i.e., *not* water supply reservoirs). The policy reemphasized the use of stocking in providing fishing recreation, but also elevated ecosystem protection as a primary consideration in stocking decisions.

Fish management and stocking (F-1, 1976) – The Director issued this guidance for fish management decisions. It states that the "primary functions of Fish Management are to provide optimum fishing recreation . . . and to maintain aquatic wildlife for consumptive and non-consumptive use within the limits of the resource and available funds." Much of the directive reiterates the Commission policies adopted in 1975. It specifically endorses put-and-take stocking into waters containing or capable of supporting wild fish.

Wild trout and gold medal waters (D-6, 1992) – In this policy, the Commission formally recognized its responsibility to protect both native and non-native populations of wild trout. The focus of the policy is on designating and managing relatively large, accessible wild trout waters. While recognizing that many small tributary streams and high lakes support wild trout, the Commission felt that they did not receive enough angling pressure to require specific management. The Commission also set guidelines for designating and

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names). Much of the data referenced in this report predates the reorganization and will be organized according to the five historic regions.

managing “gold medal” waters, which provide some of the state’s best opportunities to catch larger trout.

Whirling disease (D-9, 1996) – In response to broad concern about stocking of fish exposed to whirling disease (“WD+ fish”), the Commission issued this policy outlining how such fish could be used. The policy precludes stocking of WD+ fish in “protected” habitats. WD+ fish *can* be stocked into positive standing waters or low-risk habitats that are deemed “not to present a further threat to the expansion of the parasite.”

Management Principles

In 1991, the Commission approved a series of management principles[20] regarding topics ranging from outreach to habitat protection to human use of wildlife resources. In these principles, the Commission focused on managing recreation in a manner that preserves wildlife resources:

> Recreational hunting, fishing, trapping, and viewing wildlife are important parts of Colorado’s outdoor heritage and economic future. We . . . will plan and conduct programs that protect those qualities and diversity of opportunities. However, the primary consideration in any wildlife management decision will be to maintain healthy wildlife resources.

Whereas previous policies placed great emphasis on providing “optimum” recreation, these principles made it clear that emphasis was now to be directed at the resource itself. However, this principle was not applied wholly to fisheries resources. The Commission specifically exempts fish stocking from its guidance for other wildlife stocking programs:

> We will generally stock wildlife only to bypass problems which limit reproduction, assist the natural expansion of a species/subspecies into available habitat, or to reestablish extirpated populations of native species … *Stocking of catchable fish is a traditional exception to this policy because many of Colorado’s accessible waters cannot sustain natural sport fisheries which are acceptable to the public*. [emphasis added]

While the Commission otherwise emphasized resource management, fish stocking to support recreation remained the “traditional exception.”

Long Range Plan

The LRP is the CDOW’s highest-level planning document. The 1994 edition offers a general sense of how the CDOW will contend with emerging challenges, particularly the tremendous increase in Colorado’s human population, over a 15 year period.

[20] Included in 1994 Long Range Plan, Division of Wildlife.

The plan states that the CDOW's "foremost aim" will be to protect and enhance the viability of all Colorado's wildlife species. The plan further states that "the Division will provide quality opportunities for hunting, fishing, wildlife viewing, and other forms of wildlife recreation and enjoyment, consistent with the goal of protecting the wildlife resource." The implication is that long-term and sustainable resource management will be paramount, and that recreational opportunity will ensue if that task is done well.

The plan (Goal 12) also directs the CDOW to "increase participation in fishing as the state's population grows." However, it can be argued that this objective provides an incentive to manage some waters to provide harvest beyond their natural capacity, through increased stocking.

Scope of Stocking in Colorado

Propagation and its related support activities use a large portion of budgetary and human resources from fisheries programs nationwide. For example, $3.40 of Federal Aid in Sport Fish Restoration funds are invested in coldwater fish culture for every $1.00 spent on coldwater habitat activities[21]. One of the most common statistics offered to the public that state fishery management agencies are doing their job is the number (or weight) of fish produced or released[22].

If one accepts this questionable measuring stick of performance, then Colorado's fish management programs are an unparalleled "success." On a per capita basis, Colorado leads the nation in trout production[23].

The numbers of trout produced by the CDOW is staggering: over the years 1991-1995, trout production averaged 4.9 million catchables and 12.2 million subcatchables per year. Peak production was 5.4 million catchable trout in 1992 and 14.1 million subcatchable trout in 1991. In 1995 (with production slightly below the averages cited above), the CDOW produced nearly 2.2 million pounds of trout. Catchable trout represented the vast majority of that production (over 90% by weight).

It is not only the magnitude of CDOW stocking that is notable, but also the agency's relative emphasis on stocking programs. CDOW budgets for the current fiscal year (1997-98) show that 88 full-time equivalent employees (FTEs) are allocated to the hatchery section. In contrast, the aquatics section (responsible for other fishery management activities and fishery research) has only 70 FTEs.

Non-personnel operational expenditures have followed a similar path. The hatchery program was allocated $2.2 million for operational expenses in the CDOW's 1997-98 budget. Aquatics section funding for operations was considerably less, $1.6 million.

In short, the CDOW has invested considerably more staff and financial resources in its hatchery programs than in its other aquatic resource programs. This hatchery emphasis has enabled Colorado to claim the dubious distinction of being "Number One" among the states in per capita trout stocking.

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21 Nickum, D., J. McGurrin, and D. Duff. 1994. Wild Trout and Wallop-Breaux: Restocking or Restoring Fish? in Proceedings of Wild Trout V: Wild Trout in the 21st Century

22 For example, see Fish and Wildlife Service. Fish and Egg Distribution Report, FY 1995. FWS Report No. 30. Also, see August 1996 Press Release by FWS, accompanying report release. Both are available from FWS, Division of Fish Hatcheries, Mailstop 833-Arlington Square, 1849 C Street, NW, Washington, DC 20240.

23 Newman, Cathy. A Passion For Trout. National Geographic. April 1996. pp. 68-85

FINDINGS

In this section, we will present our findings on the observed practices of the CDOW's coldwater fishery management program. Findings are grouped under eight major headings: management strategies, stocking decisions, use of propagated fish, native fish, wild trout management, fish health, angler attitudes, and economics and angler demand. *(Editor's Note: Since this document was completed, Colorado has adopted a new statewide fisheries policy, which supersedes many of the following policies and which places a greater emphasis on wild and native trout resources.)*

Management Strategies

1.1 The CDOW's management categorization system is a response to management desires rather than being directly based on the biological or ecological conditions of the waters being classified.

In order to better characterize and monitor its fish management activities, the CDOW developed a management categorization system. Under this system, every water open to public fishing and managed by the CDOW is listed under one of three categories: intensive management, optimum management, or special management. Within those categories, further subcategories define the type of water more specifically (e.g., put-and-take lakes under 30 acres; wild trout streams, etc.).

The categorization of a water is not directly based on its physical or biological capabilities, but rather by the manner in which the water is managed. The CDOW's 1996 "blue-ribbon panel report"[24] noted that "although there is often a link between the two, the *inclusion into a specific category is based on a management strategy that is largely at the discretion of the fishery manager*" (emphasis added). Thus, while categorization generally reflects the judgments of individual managers in regard to the biological capacity of waters to provide a fishery, the biological significance of categorization is complicated by social and political elements which also influence the choice of management strategy.

"**Intensive**" management waters are managed to provide the highest possible level of fishing recreation within the limits of the facilities and physical environment to support such use, at the least cost. In other words, these waters are managed based on their recreational use potential instead of their biological capabilities (which are presumably limited). The primary objective is to provide fish for anglers to catch and keep through catchable trout stocking rates that ensure full use of available facilities and maximize return to the creel. With very few exceptions, waters that are stocked with catchable trout

[24] Bennett, J. R., D. A. Krieger, T. P. Nesler, L. E. Harris, R. B. Nehring. 1996. An Assessment of Fishery Management and Fish Production Alternatives to Reduce the Impact of Whirling Disease in Colorado. Division of Wildlife. Hereafter, referred to as the "blue ribbon" panel report.

are characterized as intensively managed, though some such waters also are stocked with sub-catchable trout or have self-sustaining populations of warmwater or coldwater fish. These waters receive the greatest numbers of stocked fish and have the greatest stocking cost per recreation day ($1.53) associated with them[25].

"**Optimum**" management waters are managed to provide fishing recreation within the limits of the habitat to produce fish at the least cost while allowing harvest within the water's natural productivity. In other words, management actions are directly tied to the biological capabilities of the water. Stocking, where necessary, is at a level similar to what would be produced naturally if habitat requirements were satisfied. Optimum management waters include both those where put-grow-and-take stocking is used to overcome reproductive "bottlenecks" and those which are dependent solely upon natural reproduction. These waters receive nearly half of the CDOW's subcatchable trout and have a somewhat lower stocking cost per recreation day ($1.24) than intensively managed waters.

"**Special**" management waters are managed to preserve and enhance selected species or to provide specialized fishing recreation, within the biological and physical capability of the environment and at the least cost. In other words, management is directed at special objectives such as native fish conservation or "trophy" trout fishing. "Gold Medal" and native cutthroat trout waters are examples. Most of these waters are not stocked, but where stocking is considered necessary it is at a level similar to what would be produced naturally. Special regulations are frequently used. Special management waters have the lowest stocking cost per associated recreation-day ($0.19).

[25] Cost figures are from the "blue-ribbon" panel report (footnote 19). To date, the CDOW has only been able to calculate average stocking expenditures associated with (rather than responsible for) recreation day, not total management costs to adequately run these programs.

Table 1a. Acreage, stocking, expenditure, and recreation days by resource management category. (1992 acreage and recreation-day data from unpublished CDOW records; expenditure and trout-use data from 1996 Blue Ribbon Panel Report).

Management category	~ Acres	% of CDOW trout used in each management category	CDOW stocking expenditures/ recreation-day	Total associated recreation-days with category
Intensive Use	70,000	Catchable: 98% Subcatchable: 48%	$1.53	4.1 million
Optimal Use	99,000	Catchable: 1% Subcatchable: 49%	$1.24	1.7 million
Special Use	11,000	Catchable: 1% Subcatchable: 3%	$0.19	0.4 million
Total	180,000			6.2 million

Table 1b. Acreage and recreation days by resource management category, with warmwater sub-categories removed[26]*. (1992 data from unpublished CDOW records).*

Management category	~ Acres	% of total acres	Total associated recreation-days	Recreation-days per acre
Intensive Use	52,537	45%	2,346,913	44.7
Optimal Use	56,546	49%	969,365	17.1
Special Use	6,740	6%	385,375	57.2
Total	115,823	100%	3,701,653	32.0

1.2 A substantial portion of the state's coldwater habitats (45%) are managed intensively, as "recreational" rather than as "natural" resources. Slightly more waters (49%) are managed for optimum use, intended to provide recreation more in line with the biological capacity of the ecosystem. Few of the state's waters (6%) are managed for special use, and only 1% are managed for native or unique species.

Categorization data demonstrate that, when looking at acres of coldwater habitats managed statewide, 45% are managed intensively (with stocking to the capacity of the water to provide recreation). This represents a sizable portion of the state's waters which

[26] The CDOW categorization data included listings for intensively-managed warmwater lakes (i.e., which receive plants of catchable trout), for optimum-management warmwater lakes and streams, and for special management of warmwater native fish in the Northeast Region. Collectively, these make up 64,295 acres of the approximately 180,00 acres categorized by the CDOW. These warmwater habitats provide 2.5 million recreation days. All other categories remain included in the figures from Table 1b.

are managed primarily as *recreational* rather than naturally-productive *biological* resources. Waters vary greatly from region to region, and so too does the extent of intensive management – from 29% (Southwest) to 61% (Northwest).

Optimum management is used for the largest share of the waters managed by the CDOW. Statewide, 49% of coldwater habitat falls into the optimum management category, where natural reproduction and put-and-grow stocking are used to maintain harvestable fisheries in line with the biological and physical capabilities of the receiving ecosystem. Again, there is great variability within the state, from 30% in the Southeast region to 68% in the Southwest.

Special management (e.g., designating wild trout or gold medal waters) is used in very limited situations. Statewide, only 6% of coldwater habitat managed by the CDOW falls into this category. Looking at waters specifically managed for native fish, only 1.2% of the state's coldwater habitats are managed for native or unique species. This percentage includes all waters managed for native cutthroat trout as well as some managed for unique non-native species such as grayling or golden trout.

1.3 Intensive management waters support the greatest fraction (63%) of total recreational use statewide. However, special management waters provide greater levels of recreation per acre.

While the largest portion of coldwater habitat is classified as optimum management, the largest share of recreational use takes place on intensively managed waters. Slightly under two-thirds of coldwater recreation days occur on intensive use waters, ranging from 44% in the Southwest region to 79% in the Central region.

Stocking of catchable trout in warmwater habitats is also quite common. Over 17,000 acres of warmwater lakes (out of just over 60,000 acres statewide) are stocked with catchable trout. These intensively managed waters provide a large amount of recreational opportunity–over 1.7 million days–but it is unclear how much of this use can be attributed to catchable trout stocking by the CDOW and how much is (or could be) provided by other self-sustaining fishery resources[27].

While intensively managed waters account for the greatest amount of total coldwater recreational use, special use waters provide greater levels of recreation per acre. Special management waters provide approximately 57 recreation days per acre (as opposed to 45 days per acre for intensive use waters).

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[27] Intensively-managed warmwater lakes provide 99.5 recreation days per acre (compared to 44.7 days per acre for coldwater intensive management waters). While much of this disparity is likely due to the presence of intensively-managed warmwater lakes near urban areas, it does suggest that the warmwater component is contributing significantly to recreation. M.E. McAfee (1991) reports that surveys of urban lake anglers indicated that 88-97% of anglers would continue to fish for warmwater species even if catchable trout stocking ceased. (Coldwater Lakes and Reservoirs. Job Final Report, Federal Aid Project F-59. Colorado Division of Wildlife.)

1.4 Intensively managed waters have the greatest direct stocking expenditure per recreation day provided, nearly 25% greater than for optimum management and eight times the expenditure per day of special management.

As highlighted in Table 1a, the stocking costs for intensive management are significantly greater than for optimum management. Special management waters, which generally utilize natural reproduction and depend less on hatchery-reared fish, provide recreation with much lower stocking costs. Where this management approach can be used, it will reduce fish culture and stocking expenses by taking advantage of natural productivity.

Stocking Decisions

2.1 Decisions on where to stock, with what size and species of fish, and in what numbers effectively rest with the senior fish biologists.

While there is no shortage of CDOW policy and direction for propagation and stocking, final decisions are ultimately made by area and senior biologists. Stocking requests are submitted by the state's three senior fish biologists based on input from area biologists within their regions. These requests are made on the basis of data (or where data are lacking, assumptions) about the biological capacity of waters, existing fish populations, and the recreational "demand" on those waters. A variety of interests (e.g.: local resorts and businesses, interest groups, legislators, etc.) apply political pressure on the managers as well. The regional requests are compiled into a state stocking schedule, which is modified depending on the general availability of fish from the state hatchery system (or from other sources – state, federal, tribal, or private). Ultimately, the stocking schedule is presented to the Director for final approval.

Regional biologists are arguably in the best position to make specific, local management decisions due to their experience and knowledge of the status and needs for a given water. However, rational decisions should be based upon reliable monitoring data on the productivity of a water, the likely impacts of stocking or other management practice (or the observed impacts for waters where stocking already takes place), and creel census data. These decisions should also permit adjustment based on assessment and evaluation of success in meeting resource objectives. This approach is referred to as "adaptive management."

2.2 Comprehensive data (both biological inventory and use data) are not available for many waters, making it difficult to evaluate the impacts (both beneficial and adverse) of stocking.

Direct communications with CDOW biologists suggest that biological data are generally gathered on an "as-needed" basis – for example, in conjunction with habitat improvement projects or imposition of special regulations. Where field biologists perceive that "things are doing OK," they generally do not conduct survey work. While this is a reasonable approach given the limited resources provided for such work, it raises the concern that more gradual changes in an aquatic community – or even the early stages of a catastrophic change -- could go undetected.

For some key fisheries – both rivers (e.g., South Platte, Gunnison) and lakes (e.g., Twin Lakes, Taylor Reservoir) – population counts are made on a more regular basis. However, the CDOW has not conducted systematic biological evaluations of fisheries statewide since its surveys after passage of S.B. 97 in 1973 [28]. While an extensive survey would be expensive (both in terms of funds and staff time), systematic surveys for more of the state's waters would provide much-needed information on which to base management decisions. The lack of such information makes it difficult to determine the response of populations to *ongoing* management activities (as opposed to changes in management).

Creel census data are also limited, especially for remote waters where such studies would be more expensive. As with biological surveys, creel efforts are generally focused on a small number of high-priority waters and on waters where shifts in management have occurred.

The problems posed by limited creel and inventory data were summarized by the Colorado State Auditor in 1995[29]:

> Regional biologists may not have suitable data upon which to base their [stocking] requests . . . Requests are, therefore, based (in part) upon individual preferences rather than empirical information. Consequently, there is no way to determine whether stocking activities and associated hatchery production are at appropriate levels.

The CDOW's 1996 "blue-ribbon" panel report also acknowledged that stocking and hatchery production decisions were not always based on a rigorous collection of empirical data. The panel noted that "DOW data is lacking in some areas," forcing biologists to use assumptions and imprecise estimates in setting stocking levels. In the case of catchable trout, the connection between stocking levels and empirical data was especially absent. The panel stated that, rather than being driven by biological needs or analysis of angler demand, catchable stocking levels are based upon hatchery capacity:

> Historically, hatchery production has responded to requests from biologists for fry, fingerling, and sub-catchable fish that were based on a given water's productivity and meeting perceived angler demand. *Catchable trout production, on the other hand, has been driven by a desire to maximize the productivity and efficiency of the remaining hatchery system potential*. What we would prefer is an objective decision-making process founded on empirical data and robust estimates of other key variables . . . We need more information to guide good decisions. [emphasis added]

As the CDOW faces an array of new fisheries management challenges, it will be vital that it gather adequate empirical data–both biological (ecosystem impacts/needs) and economic (angler demand)–on which to base its decisions.

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[28] S.B. 97 established instream flow as a beneficial use and authorized the Colorado Water Conservation Board to hold instream flow rights (within the state's prior appropriation system) on behalf of the public. Inventories were used to help identify priority stream reaches for protection.

[29] Division of Wildlife Performance Audit, February 1995.

2.3 The CDOW has reduced its investment in creel surveys, and data are especially sparse for native trout waters and high mountain lakes.

In recent years, CDOW efforts to gather creel census data have declined. From 1989-1992, the CDOW conducted creel census for an average 58 waters per year. From 1993-1996, that number has dipped to 39 surveys per year – a decline of approximately one-third. Declining creel census data would seem to make it more difficult for ground-level managers to make informed judgments on the effects of their management activities. Creel census data have been especially sparse for undesignated wild trout waters, native trout waters, and high mountain lakes.

2.4 Efforts to inventory coldwater resources have fluctuated annually and vary widely among management regions.

In terms of raw numbers, the CDOW's inventory efforts have fluctuated from year to year. The extent of inventory efforts also varies widely among regions. The numbers of coldwater lake and stream inventories conducted by each region since 1990 are summarized in Table 2.

Table 2. Coldwater lake and stream inventories conducted by region and year (CDOW data).

Coldwater lake inventories

Region	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96
Central	18	12	24	27	31	16	10
Northeast	17	20	23	19	19	22	22
Northwest	10	50	14	11	28	8	11
Southeast	24	20	17	13	10	14	11
Southwest	9	19	40	14	19	6	8
TOTAL	78	121	118	84	107	66	62

Coldwater stream inventories

Region	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96
Central	72	92	50	27	29	17	25
Northeast	36	9	26	19	25	19	19
Northwest	3	21	22	73	250	26	31
Southeast	33	14	9	18	13	14	9
Southwest	25	23	43	34	42	35	65
TOTAL	169	159	150	171	359	111	149

The number of lake inventories has declined in recent years, particularly in the Central and Southwest regions. Stream inventories have also declined in the Southeast and Central regions, but increased in the Southwest region.

2.5 The CDOW contends that moderate levels of catchable stocking over wild populations have no adverse impact on the wild fish and that they may in fact buffer wild trout from fishing pressure. Some reports in the scientific literature suggest the opposite.

A review of the peer-reviewed published literature[30] demonstrates significant variation in the reported impacts of stocking catchable fish on naturally-reproducing trout populations found in the receiving waters. Carline et al.[31] observed increases over 100% in wild trout density and biomass after elimination of stocking and harvest in Spring Creek, PA. Vincent[32] observed significant declines in wild trout numbers following stocking of catchable trout in Montana's Madison River. In contrast, Petrosky and Bjornn[33] report that wild trout were unaffected by stocking in two Idaho streams (one fertile, one infertile), except at the very highest stocking rates. The "gray" literature (e.g., see proceedings from Wild Trout symposia I through V) also reflects this mixed experience. As a result, it is difficult to make universally-applicable statements about the biological

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[30] A number of studies have examined or reviewed the differences between hatchery and wild fish and the ecological effects of stocking, introduction, and their related activities. For example: Dowling, T. E., and M. R. Childs. 1992. Impact of hybridization on a threatened trout of the southwestern united-states. Conservation Biology 6:355-364. Fleming, I. A., and M. R. Gross. 1992. Reproductive behavior of hatchery and wild coho salmon (Oncorhynchus kisutch) - Does it differ? Aquaculture 103:101-121. Fleming, I. A., and M. R. Gross. 1993. Breeding success of hatchery and wild coho salmon (Oncorhynchus kisutch) in competition. Ecological Applications 3:230-245. Hindar, K., N. Ryman, and F. Utter. 1991. Genetic effects of cultured fish on natural fish populations. Canadian Journal of Fisheries and Aquatic Sciences 48:945-957. Knox, D., and E. Verspoor. 1991. A Mitochondrial DNA Restriction Fragment Length Polymorphism of Potential Use for Discrimination of Farmed Norwegian and Wild Atlantic Salmon Populations in Scotland. Aquaculture 8:249-257. Leary, R.F., F. W. Allendorf, and G.K. Sage. 1995. Hybridization and introgression between introduced and native fish. American Fisheries Society Symposium 15:91-101. Philipp, D.P. and J. E. Clausen. 1995. Fitness and performance differences between two stocks of largemouth bass from differenct drainages within Illinois. AFS Symposium 17. Pp. 236-243. Philipp, D. P. et al. 1995. A synthesis of threats to aquatic biological diversity. In Proceedings of the World Fisheries Congress, vol. 3. Oxford Press International. New Delhi, India. Riddell, B. E., and D. P. Swain. 1991. Competition Between Hatchery and Wild Coho Salmon (Oncorhynchus kisutch) - Genetic Variation for Agonistic Behaviour in Newly-Emerged Wild Fry. Aquaculture 98:161-172. Swain, D. P., and B. E. Riddell. 1990. Variation in agonistic behavior between newly emerged juveniles from hatchery and wild populations of coho salmon, Oncorhynchus. Canadian Journal of Fisheries and Aquatic Sciences 47:566-571. Verspoor, E. 1988. Widespread hybridization between native Atlantic salmon, Salmo salar, and introduced brown trout, S. trutta, in eastern Newfoundland. J.Fish Biol. 32:327-334. Waples, R. S. 1991. Genetic interactions between hatchery and wild salmonids - Lessons from the Pacific Northwest. Canadian Journal of Fisheries and Aquatic Sciences 48 (Suppl. 1):124-133. In reviewing these studies, it is vital to recognize that demonstrating cause and effect (rather than simply correlation) is a difficult task, though not impossible.

[31] Carline, Robert F., Thomas Beard, Jr., and Bruce A. Hollender. 1991. Response of Wild Brown Trout to Elimination of Stocking and to No-Harvest Regulations. North American Journal of Fisheries Management 11: 253-266.

[32] Vincent, E. R. 1987. Effects of Stocking Catchable-Size Hatchery Rainbow Trout on Two Wild Trout Species in the Madison River and O'Dell Creek, Montana. North American Journal of Fisheries Management 7: 91-105.

[33] Petrosky, C.E. and T.C. Bjornn. 1988. Response of Wild Rainbow (Salmo gairdneri) and Cutthroat Trout (S. clarki) to Stocked Rainbow Trout in Fertile and Infertile Streams. Canadian Journal of Fisheries and Aquatic Science 45: 2087-2105.

impacts of stocking catchable trout over wild populations. However, the significant impacts documented in some studies suggest that fishery managers should be cautious when stocking over wild trout. Carefully designed monitoring is needed to determine whether adverse (or beneficial) impacts have resulted in a particular water and to determine the extent of those impacts.

The CDOW operates under the assumption that stocking catchables over wild populations, at least at "moderate" stocking levels, does not have any measurable adverse impacts on wild trout[34]. CDOW researchers attribute the lack of observed impacts to the use of "reasonable" rates for stocking and stocking only in streams where wild populations cannot provide the level of angling harvest or yield desired by the public; spreading stocked fish over the entire stream section being stocked; spreading stocking out over the entire season; and discontinuing stocking when return to the creel is poor. Unfortunately, as noted previously, it is unclear whether the CDOW has adequate data or a validated decision model on fish populations, angler demand, and return-to-creel to ensure that its stocking practices conform to that model statewide.

The CDOW also asserts that in some cases stocking of catchables may buffer the effects of angling on wild trout. This perspective is reflected in CDOW Administrative Directive F-1, which specifically endorses put-and-take stocking over wild fish in high-use areas. Many waters around the state (e.g., South Platte River, Cache la Poudre River) have self-sustaining populations of trout, but also receive plants of catchable sized trout to augment numbers of fish available for harvest and thereby "buffer" the wild fish. As noted before, there is considerable disagreement within the scientific community about the effectiveness of this strategy. Some argue that such stocking increases or focuses pressure in these areas, "priming the pump" for harvest rather than buffering wild populations[35]. This is argument is especially plausible in a state like Colorado, where the popular press regularly carries information on stocking locations[36].

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[34] e.g., see Nehring, R. Barry and Tom Powell. 1991. The Catchable Trout/Wild Trout Conundrum: The Colorado Experience. in Going Wild? symposium sponsored by Colorado Trout Unlimited.
[35] e.g., see White, R. J., J. R. Karr, W. Nehlsen. 1995. Better roles for fish stocking in aquatic resource management. American Fisheries Society Symposium 15:527-547.
[36] For example, newspapers regularly print stocking reports in the sports pages.

Use of Propagated Fish, 1991-1995

The extent of fish stocking in Colorado is impressive because of its scale, magnitude, and emphasis on recreational stocking. CDOW records document that millions of trout are stocked into Colorado waters every year. The risks and historic effects of stocking on recipient and native biota are well-recognized. In Colorado, the most notable impact has been a contribution to the elimination of native cutthroat trout populations from most of the state's waters. In this section, we will focus on more recent stocking practices. The following represents a "snapshot" of the CDOW's stocking program as reflected in records from 1991-1995.

3.1 Stocking of catchable-size trout in streams, after peaking in 1993, dropped dramatically, apparently as a consequence of changes in whirling disease policy. Total stocking of catchable-size trout has fluctuated, while subcatchable-size trout stocking has declined.

Stocking of catchable trout in streams has declined significantly since 1991 in association with changes in whirling disease policy. Catchable stocking levels in streams peaked in 1993 (971,000 fish), dipped in 1994 (887,000 fish), and then plummeted in 1995 (336,000). The number of streams stocked with catchables in 1995 represented a decline of 100 streams from 1991 levels (177 vs. 77); the number of stream segments had dropped from 224 to 104 over the same period (segments may constitute the whole length of smaller streams or defined portions of larger rivers such as the Colorado).

As Table 3 reveals, total catchable stocking (i.e., in streams *and* lakes) has fluctuated between 4.5 and 5.4 million fish. Total subcatchable stocking declined significantly after 1991, but has been relatively stable since 1993. However, whirling disease, by wiping out year classes of fish, may increase the demand for put-and-grow stocking to maintain fisheries until longer-term solutions can be found. Catchable production will decline significantly for 1997 (over 25%). The Commission (in May 1996) instructed the CDOW to reduce WD+ catchable production by 1.3 million fish for the upcoming year. The CDOW responded by changing production at some facilities and closing the Watson fish culture unit.

Table 3: Numbers of catchable and subcatchable trout stocked by year.

	Number of fish stocked (in millions)				
	1991	1992	1993	1994	1995
Catchable	4.5	5.4	5.2	4.9	4.6
Subcatchable	14.1	12.5	11.6	11.6	11.3
TOTAL	18.6	17.9	16.8	16.5	15.9

3.2 The vast majority of the CDOW's propagation efforts have been directed at producing and stocking non-native (sub)species. Stocking of native trout (sub)species by the CDOW has been limited, with the Colorado River cutthroat being the most widely stocked.

The CDOW stocked relatively few waters with native trout during the 1991-1995 period. The most extensive stocking was of Colorado River cutthroat trout, though in a few cases they were stocked into basins to which they are not native[37]. The largest portion of Colorado River cutthroat production used the Trappers Lake strain, a genetically-altered strain which has been introgressed with Yellowstone cutthroat and possibly rainbow trout[38]. "Pure" Colorado River cutthroats (Nanita Lake strain)[39] were produced at much lower levels, but production has increased in recent years. Stocking of greenback and Rio Grande cutthroat trout was far more limited than stocking of Trappers Lake cutthroats.

Table 4 outlines the portion of subcatchable production that has been dedicated to native species. Overall, native trout represent only a minor portion of the CDOW's subcatchable trout production (and an even smaller subset of the CDOW's total trout production). Although propagation does not reflect the entirety of management effort for native trout, the lack of emphasis on rearing native fish is a concern.

Table 4. Production of native trout as a percentage of total subcatchable production.

	Year				
	1991	1992	1993	1994	1995
% of total subcatchable numbers represented by native trout	1.7%	3.1%	2.9%	4.7%	0.7%

The obvious corollary to this is that non-native species make up the vast majority of fish reared and stocked by the CDOW. Rainbow trout (especially the Tasmanian strain) are the most common species used, though the Snake River cutthroat (native to the Snake River basin and not to Colorado) has also been used widely in both catchable and subcatchable programs. The use of these fish outside of their native range represents a form of *stock transfer* between basins. Ongoing examples of stock transfers include the statewide use of exotics including rainbow, brook, and brown trout; stocking of Snake

[37] For example, into the Rio Grande drainage.

[38] Martinez, A. M. 1988. Identification and Status of Colorado River Cutthroat Trout in Colorado. AFS Symposium 4: 81-89. Leary, R. F. 1990. Genetic and Meristic Analysis of Colorado River Cutthroat Trout. Population Genetics Laboratory Report 90/2. University of Montana.

[39] Nanita Lake is located in Rocky Mountain National Park. While Nanita Lake cutthroats are considered "pure," there are genetic concerns with their universal use in recovery efforts, since more local strains may be more appropriate for reintroduction into specific waters. For a more detailed discussion, see "Findings: Native Trout."

River cutthroat in watersheds formerly occupied by other cutthroat subspecies; and introduction of Colorado River cutthroats in the upper Rio Grande drainage.

3.3 Native salmonids have been stocked primarily into headwater streams and high lakes (including several in wilderness areas), where they are more likely to find refuge from non-native trout populations.

Generally, native trout have been stocked in headwater streams and high lakes, often in designated wilderness areas. For example, Colorado River cutthroat trout have been stocked in the upper drainages of Slater Creek, Elkhead Creek, and Cochetopa Creek, as well as in wilderness lakes in the Flat Tops, Eagle's Nest, and Mt. Zirkel Wilderness Areas (these lists of waters are illustrative, not exhaustive). Rio Grande cutthroats have been stocked in high lakes along the west side of the Sangre de Cristo Mountains. Greenback cutthroats have been stocked in Rock Creek and high lakes in the Arkansas River headwaters. Native fish stocking has been concentrated on relatively remote habitats because the potential for interaction with non-native trout is less (and perhaps because the habitats are less disturbed, at least in some cases). Often, established populations of non-native fish must be eliminated prior to reintroduction of natives.

3.4 Major reservoirs are a significant focus of CDOW stocking programs. The most common management strategy is a combination of put-and-take (catchable-size rainbow trout) and put-grow-and-take (subcatchable-size rainbow, kokanee, etc.) of non-native species or subspecies. Returns to creel on some large lakes fall below the CDOW's objective of 70%.

A major focus of the CDOW's fishery management program is stocking of large (and usually high-use) standing waters. These lakes are managed with a variety of species and sizes. Catchable stocking is very common, but is often supplemented with stocking of subcatchable fish. Since the advent of whirling disease in Colorado hatcheries, many of these waters have been (and continue to be) heavily stocked with WD+ trout, partly because stocking of infected fish in these highly-altered systems has been deemed a relatively low risk, and partly because there are not enough WD-negative fish available to maintain what the CDOW considers adequate catch rates for these waters.

Contrary to a common perception, it is not true that all large reservoirs must be stocked with catchable trout to maintain a fishery; some are managed with subcatchable fish stocking only. The most prominent example is Blue Mesa Reservoir on the Gunnison River. The fishery has historically been maintained through a large kokanee component (spawned at Roaring Judy SFH on the East River) and stocking of subcatchable rainbow trout provided by the U.S. Fish and Wildlife Service. Other large lakes which were stocked with subcatchable fish only include Steamboat Lake (rainbow trout), Morrow Point Reservoir (kokanee and Colorado River cutthroat trout), and McPhee Reservoir (kokanee and rainbow trout).

The most common management approach for large lakes has been a combination of catchable and subcatchable stocking. In these waters, the CDOW has concluded that its put-and-grow fisheries can make important contributions but would not support current levels of angling without the use of catchable trout as a supplement. Many of the state's most popular (and most utilized) lake fisheries fall into this category. Examples include Lake Granby, Rifle Gap Reservoir, Spinney Mountain Reservoir, and Pueblo Reservoir.

CDOW biologists indicated that return to creel for catchable trout in some of these large lakes is low, considerably below the CDOW's stated objective of 70% return to creel. Large lakes stocked with catchable trout generally have a lower return to creel, while smaller lakes have a much higher return. While many large waters do not meet the standard for return-to-creel, they are nonetheless stocked to maintain catch rates that managers deem acceptable. Many of these reservoirs have significant "destination" traffic, creating strong local constituencies for stocking among those who benefit economically from the tourism generated.

3.5 High-mountain lakes have been widely stocked with non-native species including brook trout, rainbow trout, and hybridized cutthroat trout (e.g., Pikes Peak).

A wide range of high-mountain lakes (both natural and man-made) are stocked by the CDOW. Given the fact that many of these lakes (especially at high-elevations) have a very limited carrying capacity and are also subject to relatively light fishing pressure, the CDOW has generally stocked them with low numbers of subcatchable trout. (There are exceptions with greater fishing pressure where heavier stocking or stocking of catchables takes place, for example, the Mesa Lakes area). The primary species used include brook trout, rainbow trout, and the so-called "Pikes Peak Native" (actually a cutthroat trout hybrid). The Pikes Peak cutthroat has been used extensively in high-lake stocking east of the Continental Divide. In some high lakes east of the Continental Divide, Colorado River cutthroat (native only west of the Divide) have also been stocked. Snake River cutthroat have been used in many high lakes in western Colorado.

High lake environments can be very fragile. Stocking of fish into historically fishless environments[40], or at rates exceeding historical or ecologically supportable abundances may damage portions of these ecosystems, either directly through ecological interactions or indirectly by human use. In some cases, stocking may also attract enough anglers to remote lakes so as to cause habitat damage–the unintended costs of success.

3.6 Non-native trout have been stocked in many waters within wilderness areas. Wilderness areas have also been common sites for native species recoveries.

While CDOW policy (Policy D-4, high lakes management) calls for the use of native species when stocking lakes in designated wilderness areas, non-native fish have been

[40] Fishless lakes often have been erroneously called "barren." A lake without a native fish population may support important ecological aquatic communities (for example, these lakes often support a variety of amphibian or other species affected by the presence of fish).

stocked extensively in wilderness areas managed by the U.S. Forest Service and Bureau of Land Management. From 1991-1995, more than 180 waters in over 20 different wilderness areas were stocked with non-native fish. This practice has increasingly fallen from favor within the conservation community, which generally deems that wilderness should be managed for native assemblages of fish and wildlife.

Some examples help to illustrate the CDOW's use of propagation in wilderness fisheries management:

The Indian Peaks Wilderness runs along the Continental Divide south of Rocky Mountain National Park. Several high lakes in the wilderness are stocked with non-native trout, primarily the Pikes Peak cutthroat (e.g., Banana, Coney, Devils Thumb, and Skyscraper Lakes). Colorado River cutthroat have also been stocked both in the Colorado River drainage (e.g., in Paiute and Thunderbolt Lakes), a drainage to which the species is native, and east of the Continental Divide (e.g., in Banana, Betty, and Bob Lakes), where it is not native. A similar pattern of stocking has been followed in the Mt. Evans Wilderness (east of the Continental Divide, south of Interstate 70). Some lakes in the Mt. Evans Wilderness (including Abyss, Frozen, and Upper Beartrack Lakes) have had truly unusual stocking histories, receiving Pikes Peak, greenback, *and* Colorado River cutthroats.

The Flat Tops Wilderness (in northeastern Garfield and Rio Blanco Counties) has been home to extensive Colorado River cutthroat stocking – some Nanita Lake strain and some Trappers Lake cutthroats. Literally dozens of lakes have been stocked with the Colorado River cutthroats, as have sections of streams including the White River (South Fork), Wagonwheel Creek, and Fraser Creek. At the same time, other lakes (e.g., Skillet and Mosquito Lakes) have been stocked with non-native species such as Snake River cutthroat and brook trout.

The Weminuche Wilderness has had extensive stocking of non-native trout. Dozens of high lakes, particularly among the Needle Mountains, have been stocked with Snake River cutthroat or rainbow trout (Tasmanian strain). Colorado River cutthroat (Trappers Lake) have been stocked into Vallecito Creek and Los Pinos River, and also into several streams in the Rio Grande drainage (including the Rio Grande itself).

These are only a few of Colorado's wilderness areas, but they exemplify the statewide wilderness stocking experience. There has been considerable stocking of native trout, particularly Colorado River cutthroats (though not always using "pure" strains). At the same time, a potpourri of non-native trout has been stocked within wilderness areas.

3.7 Stocking of trout exposed to or carriers of whirling disease in standing waters (especially low-elevation or dead-end lakes) has increased significantly, while stocking of disease exposed trout in streams declined dramatically in recent years.

The CDOW significantly increased its stocking of WD+ catchable trout in standing waters from 1991-1995. Stocking of WD+ catchables in streams – after increasing steadily through 1994 – dropped dramatically in 1995, below even 1991 levels. In contrast, both streams and standing waters had major increases in WD+ subcatchable stocking from 1991 through 1995.

Another way to look at WD+ stocking trends is the number of waters stocked with WD+ fish. In recent years, the CDOW has emphasized protection of coldwater streams over protection of standing waters, on the premise that the resources most in need of protection are the wild trout populations found in Colorado's rivers and streams. In 1994, some 125 streams (ranging from smaller streams to mainstem rivers) were stocked with WD+ fish. In 1995, this number declined to 39 streams. Under new CDOW policy, WD+ stocking was limited to only 11 streams in 1997, all of which have been historically stocked with WD+ fish: the Arkansas, Colorado, Conejos, East, Gunnison, Middle Fork South Platte, Poudre, Rio Grande, South Fork South Platte, South Platte, and Taylor. Of these, CDOW biologists actually planned to stock WD+ fish in only 6 (Arkansas, Colorado, East, Gunnison, Poudre, South Platte).

Standing waters have seen much greater use of WD+ fish. In recent years, there has been some shift towards stocking WD+ fish in "dead-end" lakes and ponds and low-elevation lakes (out of wild trout habitat). However, even in 1995, many lakes and reservoirs along coldwater streams were stocked with WD+ fish – for example, Elevenmile Reservoir, Stagecoach Reservoir, Tarryall Reservoir, and Twin Lakes. In terms of numbers, more than 3.7 million WD+ catchable trout were stocked into standing waters in 1995, more than in 1991 and 1992 combined.

Native Trout

4.1 Despite the close geographical proximity of their headwaters, different Colorado watersheds contain distinctive communities of native species.

Colorado is unusual because several major watersheds have headwater streams in the state (e.g., the Colorado, Rio Grande, Arkansas, and Platte Rivers). Although these rivers lie in close physical proximity of each other as the "crow flies," the outlets for the these rivers are hundreds to thousands of miles apart which, as the "fish swims" is a vast distance. Distance, like other physical boundaries, can be a strong mode of isolation, allowing for genetic and evolutionary divergence. The result has been that many Colorado watersheds contained rather distinct assemblages of native fish species and aquatic life. Even where they contain isolated populations of the same species, the "genetic distance" (a measure of evolutionary divergence that reflects both the intensity of isolation and time since sharing a common gene pool) between populations is sufficiently great to warrant treatment as distinct management units (a.k.a., genetic stocks, races, subspecies)[41].

4.2 In Colorado, 30 non-native game species have been introduced - more than in any other state in the U.S. Extensive introductions of non-natives places native species at risk.

Horak (1995) published information concerning the make-up of fish species across the U.S. including Colorado (summarized in Table 5[42]). Bear in mind that the numbers included in this table are indicators of presence or absence (rather that abundance, distribution, or richness) and are therefore crude estimates of species composition.

Table 5: Summary of native and introduced species in Colorado.

Total Number of Fish Species	**113**
All Native Species	**51[43] (45%)**
Native Game Species	**6 (5%)**
Introduced Species	**60 (55%)**
Introduced Game Species	**30 (27%)**
"Naturalized" Game Species[44]	**18 (16%)**

Among the fifty United States, *Colorado ranks No. 1 for occurrence of non-native game species* (in terms of species counts). The CDOW estimates that 99% of the fishing effort in Colorado was for non-native fish (tied with Arizona for highest percentage). Examples of introduced coldwater species include rainbow trout (including multiple "strains" or subspecies)[45]; brown trout; brook trout; lake trout; splake (a brook trout/lake trout hybrid); kokanee; Arctic grayling; Arctic char; Chinook, coho, and Atlantic salmon; Dolly Varden; and several whitefish species. This engineered variety clearly overwhelms the native diversity (i.e., four cutthroat subspecies and mountain whitefish) in terms of species counts or size and distribution of these species. Colorado's native salmonids have been relegated to mere vestiges of their former range.

Whether these introductions should have been made is now largely moot, but future action with regard to introduced species remains an open issue. An examination of the ecological

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[41] This is commonly referred to as the "stock concept" of fisheries management, where a) species are recognized to be composed of mosaics of evolutionarily divergent and adaptively unique groups (or "stocks"); and, b) the stock, rather than the species as a whole, is the appropriate unit of management.
[42] Horak, D. 1995. Native and non-native fish species used in state fisheries management programs in the United States. AFS Symposium 15:61-67.
[43] The 1996-2000 Colorado Fishing Season guide lists only 44 species.
[44] Horak cites the Webster's New International Dictionary, 3rd edition: naturalized species – any non-native species that has been caused to adapt and grow or multiply as if native.
[45] The 1996-2000 Colorado Fishing Season guide lists 7 subspecies.

and evolutionary literature regarding the consequences of introductions supports the conclusion that non-indigenous species are *overwhelmingly* likely to contribute to a loss of native diversity[46]. This does not imply that introductions are *never* successful, beneficial, or a natural occurrence; they certainly can be. However, it is the *rate* and *scale* at which ecosystems are being biologically manipulated with introductions that conveys the risk for damage. A study on intentional introductions reported that introductions of non-natives were a "factor for decline" in 68-70% of Endangered Species Act fish listings[47]. On a more global scale, introductions have been repeatedly identified as a major threat to biodiversity, which in some instances threatens food or resource security rather than merely recreational opportunity[48].

4.3 Historic introductions of non-native salmonids contributed to the extirpation of yellowfin cutthroat trout, a subspecies endemic to Colorado.

The potential impacts of introductions on native species in Colorado is shown most vividly with the yellowfin cutthroat trout, a subspecies historically found in Twin Lakes (sympatric with greenback cutthroat trout) that has since gone extinct. Introductions of non-native species, coupled with a very small historic range, appear to have been the critical factors in its extirpation. When late 19th-Century efforts to captively breed and culture the fish at the Leadville National Fish Hatchery failed (ending opportunities to establish new populations), this subspecies was effectively extinct[49].

4.4 Non-native trout pose a serious threat to the continued existence of Colorado River cutthroat. In a few instances, stocking of non-natives "over" cutthroat populations has persisted into the 1990s.

Introductions of non-native trout (and their subsequent spread) may be the greatest threat to the continued existence of Colorado River cutthroat populations. Of the 152 populations listed by Young et al.[50] for Colorado waters, 55 had sympatric populations of non-native trout (mostly brook trout). Seventy of the 152 waters have been stocked with

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[46] For example, see the report on nonindigenous species developed by the independent Congressional Office of Technology Assessment (1994). Also see Courtney, Jr. W.R. 1984. Distribution, Biology, and Management of Exotic Fishes. Johns Hopkins University Press.

[47] Lassuy, D. R. 1995. Introduced species as a factor in extinction and endangerment of native fish species. American Fisheries Society Symposium 15:391-396. Op cit. Miller et al. 1989. Extinctions of North American fishes during the last century. Fisheries 14:22-38. OTA 1993. Harmful nonindigenous species in the United States. USGPO, Washington, DC.

[48] Philipp, D. P. et al. 1995. Proceedings of the First World Fisheries Congress. Oxford Press, New Delhi, India. Bartley, D. 1994. Proceedings of the Expert Consultation on Genetics in Fisheries. Food and Agriculture Organization of the United Nations. Rome, Italy. 1997. Report of the CITES Invasive Species Specialist Group to the 1997 convention (Harare, Zimbabwe). Convention on the International Trade of Endangered Species (CITES). Geneva, Switzerland.

[49] Behnke, R. 1992. Native Trout of Western North America. AFS Monograph 6. American Fisheries Society, Bethesda, MD.

[50] Young, Michael K., R. Nick Schmal, Thomas W. Kohley, and Victoria G. Leonard. 1996. Conservation Status of Colorado River Cutthroat Trout. U.S. Forest Service. Rocky Mountain Range and Experiment Station. Laramie, WY.

non-natives since 1973 – eight of these waters held pure populations, 33 had hybridized populations, and 29 had populations that were either of unknown purity or had mixed results. Sixty-three of the 70 waters were stocked with species or subspecies likely to hybridize with Colorado River cutthroat trout (rainbow trout or exogenous stocks or subspecies of cutthroat trout).

While one might expect non-native impacts on native trout to be a relic of past mistakes, in fact, the CDOW's 1991-1995 stocking records show several instances where non-native species were stocked over native populations of Colorado River cutthroats, or in nearby and presumably connected waters[51].

Big Beaver Creek (White River drainage) – Lake Avery stocked with rainbow trout and Trappers Lake cutthroat trout
Poose Creek (Yampa River drainage) – Vaughn Lake stocked with rainbow trout
Freeman Reservoir (Yampa) – stocked with rainbow trout and Trappers Lake cutthroat trout
First Creek (Yampa) – stocked with brook trout
Armstrong Creek (Yampa) – stocked with brook trout
Beaver Creek (tributary Willow Creek, Yampa) – stocked with brook trout
Dome Creek (Yampa) – Yamcolo Reservoir stocked with rainbow trout
Middle Thompson Creek (Colorado River drainage) – stocked with rainbow trout
Egeria Creek (Colorado) – Harper Reservoir stocked with brook trout
North Fork Elliott Creek (Colorado) – Mahan Lake stocked with brook trout

Of these 10 waters, five contain populations of unknown purity while the remainder have populations believed to be hybridized to some extent.

More extensive than stocking of non-natives such as brook or rainbow trout has been use of the Trappers Lake cutthroat, a Colorado River cutthroat that has hybridized with Yellowstone cutthroat trout and possibly rainbow trout. These less-than-pure Colorado River cutthroats have been stocked over several existing populations in the Little Snake River, Yampa River, and Colorado River drainages. In total, Trappers Lake cutthroats were stocked over three pure Colorado River cutthroat populations, 11 populations of unknown purity, and 14 populations that were considered hybridized or had mixed results. Martinez (1988) cautioned against this practice, warning that "continued stocking of the progeny of these hybridized fish may contaminate any pure populations that may exist."[52]

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[51] The restricted movement paradigm has been demonstrated to be untenable (e.g., Gowan, C., M. K. Young, K. D. Fausch, and S. C. Riley. 1994. Restricted Movement in resident stream salmonids: a paradigm lost? Canadian Journal of Fisheries and Aquatic Sciences 51:2626-37). Trout, including cutthroat trout, likely migrate considerable distances and have home ranges larger than previously thought, thus enabling "contact" and interaction with resident or wild fish. For the waters listed here, Young et al. (see footnote 45) did not indicate that a migration barrier was present to prohibit such movement.

[52] Martinez, A. M. 1988. Identification and Status of Colorado River Cutthroat Trout in Colorado. AFS Symposium 4: 81-89.

Based on the 1997 draft stocking schedule, the CDOW appears to be reducing the stocking of non-native trout (or mixed origin strains) over Colorado River cutthroats. Many of the waters described above were scheduled to receive only "pure" Colorado River cutthroat trout (or no fish at all) on the 1997 schedule. Some, however, remain scheduled to receive non-natives. These include: Big Beaver Creek (rainbow trout in Avery Lake), Armstrong Creek (brook trout), Dome Creek (brook trout, rainbow trout in Yamcolo Reservoir), and Egeria Creek (brook trout in Harper Reservoir). Moreover, as discussed below, even stocking with "pure" strain cutthroats can pose other threats to genetic diversity.

4.5 The CDOW is working to reestablish Colorado River cutthroat populations in their native range. However, the CDOW not consistently used local strains for reintroduction efforts.

Discussions with CDOW managers indicate that, aside from problems with stocking non-native or hybridized strains, the CDOW has not always done a good job of managing for diversity between populations of Colorado River cutthroats. Patterns of genetic variability can be significantly different between populations of Colorado River cutthroats[53]. Rangewide use of one donor population as a source for fish and/or gametes to use in re-introductions could result in homogenization and loss of this between-population variability. As a result, reintroduction projects should generally use (where possible) donor populations from nearby waters within the same drainage.

While the CDOW continues recovery efforts for Colorado River cutthroats[54], the agency has not consistently managed with local stocks. Plants of Nanita Lake cutthroat (and before them, Trappers Lake cutthroat) have commonly been used. While there is certainly value in establishing additional populations of Colorado River cutthroats regardless of strain, use of local stocks should be the preferred option over statewide use of a single "one size fits all" broodstock. CDOW managers indicate that they are moving in this direction; for example, reintroduction efforts in Carr Creek (1997) will use a donor population from nearby Roan Creek. As additional wild populations are identified and evaluated for genetic purity and health, it will be possible to more broadly use fish and/or gametes from local stocks.

4.6 Rio Grande cutthroats are also jeopardized by non-natives; only 40% of populations evaluated in the 1990s are stable, free of non-natives, and above known barriers.

[53] Michael Young, USFS, personal communication.
[54] e.g., see the 1992 "Conservation Plan for Colorado River Cutthroat Trout in Northwest Colorado" prepared by the CDOW, Forest Service, and Bureau of Land Management.

Harig and Fausch[55] found that non-natives represent a major threat to the stability of existing Rio Grande cutthroat populations in Colorado. Of the 25 streams with populations whose status was documented in the 1990s, 60% had stable populations. All but six of the streams had natural or man-made barriers. However, 44% had sympatric populations of nonnative salmonids. Only 40% of populations were stable, above known barriers, and free of nonnative salmonids. When looking at the 28 populations present in collections that were last taken prior to 1990, sixteen (57%) had sympatric populations of nonnative salmonids. Only one was stable, free of nonnative salmonids, and secured above a known barrier. Most disturbingly, Harig and Fausch reported that among the eight populations of historic origins that have been recently extirpated, seven became unstable due to nonnative salmonids (primarily brook trout).

4.7 For the threatened greenback cutthroat trout, 12 of 51 recovery populations have non-natives present. The CDOW is an active participant in recovery efforts for the species, and has managed for different greenback strains in the South Platte and Arkansas drainages.

Greenback cutthroat trout, Colorado's state fish, are native to the headwaters of both the Arkansas and the South Platte Rivers. They were first listed as endangered and entitled to protection and recovery through authority of the federal Endangered Species Act in 1973 (they were later down-listed to threatened status in 1978, primarily to allow for greater flexibility in management). The drastic population declines were attributed to a host of factors including habitat degradation, unsustainable harvest of adults, and ecological interaction with non-native species. The pattern of decline for greenbacks was apparently one of loss of whole populations (as well as reduction of remaining populations) such that the greenback occurred in less than 5% of its former range[56].

The CDOW has been an active partner in reintroduction efforts under the greenback recovery plan. Reintroduction efforts have used different strains of greenbacks in the Arkansas and South Platte drainages, in order to better maintain genetic diversity. While current efforts have attempted to protect the known remaining populations of greenbacks, wild non-natives (mostly brook trout) are nonetheless present in 12 of the 51 populations listed in the recovery plan (including both historic and restored populations).

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[55] Harig, Amy L. and Kurt D. Fausch. 1996. Compilation of Data on Colorado Waters Containing Rio Grande Cutthroat Trout. Final Report to Division of Wildlife, MOU Project 904-96.

[56] Behnke, R. 1992. Native Trout of Western North America. AFS Monograph 6. American Fisheries Society, Bethesda, MD.

Wild Trout Management

In its policy D-6[57] (1992), the Commission formally recognized its responsibility to preserve and protect both native and non-native populations of wild trout. In lakes and streams designated as wild trout waters, the policy calls for habitat protection, special regulations as needed to protect and perpetuate the wild population, and no stocking of hatchery-reared fish except to restore or reestablish a wild population.

5.1 The CDOW has designated very few waters as "wild trout" – only one percent of coldwater streams with average or better habitat are so designated.

Few wild trout waters have been designated, perhaps due to the focus on large, accessible waters. Some of these designated waters (e.g., South Platte, Cache la Poudre, Gunnison) have been compromised by whirling disease and may be subject to put-and-grow stocking in order to replace lost year classes.

Designated wild trout waters generally meet some basic standard for "quality." Under current policy, many waters containing stable, self-sustaining populations of wild trout may not be eligible for designation. To qualify, a water must have a standing stock of at least 40 pounds per acre (or be a native cutthroat water), though wild populations can stablely exist at under 40 pounds per acre[58]. Further, meeting the criteria is no an assurance of designation; it merely makes a stream eligible should the CDOW wish to list it.

Waters designated as wild trout in the most recent CDOW regulations are listed in Table 6, along with a listing of what special regulations (if any) are in place for those waters. In total, the CDOW has designated 96.2 miles of stream and 560 acres of lakes as "wild trout" water. A statewide analysis (Nehring 1990)[59] found that some 9,300 coldwater stream miles had average to excellent habitat, that is, habitat of suitable quality to support a trout population and fishery using no stocking and special regulations. Only 1% of streams with suitable habitat for wild trout are managed under the wild trout policy.

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[57] For more on policy D-6, refer to Appendix IV.

[58] Platts, W. S., and R. L. Nelson. 1988. Fluctuations in trout populations and their implications for land-use evaluation. North American Journal of Fisheries Management 8:333-345. Scarnecchia, D. L., and E. P. Bergersen. 1987. Trout production and standing crop in Colorado's small streams, as related to environmental features. North American Journal of Fisheries Management 7:315-330.

Nehring, R. Barry. 1990. Coldwater Streams and Special Regulations: Management Assessment Report for the 1990s. Division of Wildlife.

Table 6. Wild trout waters and associated special angling regulations.

RIVER	REGULATIONS
Cache la Poudre - from Pingree Park Road to Hombre Ranch & Black Hollow Creek to the Big Bend Campground	Terminal tackle Bag and size limits
Cascade Creek - from headwaters to confluence with Rio De Los Pinos	None listed
Cochetopa Creek - within the Cochetopa (Coleman) State Wildlife Area	Terminal tackle No harvest
Conejos River - from Menkhaven Ranch to Aspen Glade campground	Terminal tackle Bag and size limits (on specific properties)
Conejos River, Lake Fork - from headwaters through Rock Lake	Terminal tackle No harvest for cutthroat trout
East River - from Roaring Judy Hatchery downstream one mile	Terminal tackle No harvest for kokanee
Emerald Lakes - in Weminuche Wilderness Area	Terminal tackle Bag and size limits Seasonal closure for part of lake
Gunnison River - North Fork Confluence to upstream boundary of Black Canyon National Monument	Terminal tackle No harvest for rainbow trout Bag and slot limits for brown trout
Laramie River - in Hohnholz State Wildlife Area	Terminal tackle Bag limit
Los Pinos Creek - on Cochetopa (Coleman) State Wildlife Area	Terminal tackle No harvest
North Platte River - from Routt National Forest to WY line	Terminal tackle Bag limit
Osier Creek - from headwaters to Rio de Los Pinos	None listed
Roaring Fork River - from Holum Lake to upper Woody Creek bridge	Terminal tackle No harvest
St. Vrain Creek, North - from Horse Creek to Button Rock Reservoir	Terminal tackle Bag limit
South Platte - from Beaver Creek to South Platte Arm gauging station	None listed
South Platte - from Cheesman Dam to Wigwam Club	Terminal tackle No harvest
South Platte, Middle Fork - in Tomahawk State Wildlife Area	Terminal tackle Slot and bag limits
Tarryall Creek - From Pike National Forest to South Platte confluence	None listed
Trappers Lake - Garfield County	Terminal tackle Size limit Partial closure

5.2 *Many more waters are managed as "de facto" wild trout waters, but receive relatively little active management attention.*

While “wild trout” designations under policy D-6 are conspicuously rare, the CDOW does manage a large share of Colorado’s waters solely through natural reproduction. These “de facto” wild trout waters make up more than 40% of coldwater stream acres under the CDOW’s categorization system. The bulk of these waters receive little management attention (in terms of regulation, population monitoring, and user surveys).

5.3 The CDOW’s statewide trout limit is based only to a limited extent on biological data as to what levels of trout harvest are sustainable for wild populations.

We were unable to locate any published studies by the CDOW indicating that the statewide eight trout limit (plus 10 bonus brook trout) is sustainable for wild populations (i.e., fishing mortality low enough to permit reproductive recruitment). However, the CDOW’s practice of stocking catchable trout over wild populations suggests that harvest (in some waters) is not at a level that is sustainable.

Given the relative dearth of information available on angler use of “de facto” wild trout waters, it is difficult to determine whether harvest impacts could be a significant problem for these fisheries. The statewide trout limit of eight fish per day raises the specter of heavy harvest on some of these relatively small waters. Because many of these waters get very little fishing pressure, the eight per day (or 18 per day with the brook trout bonus) limit may be sustainable. However, should fishing pressure increase on any such streams (particularly those closer to front-range urban centers), overharvest could be a threat.

It would be helpful to have additional adaptive monitoring regarding the levels of harvest that can be supported by wild trout populations, providing a stronger basis for management judgments on this issue. It is important that statewide limits be sustainable for wild trout, not just for waters supplemented with catchable or subcatchable fish.

5.4 CDOW is not systematically examining possibilities for new “wild trout” designations.

Direct communication with CDOW managers revealed that there are neither institutionalized nor informal efforts underway to identify additional waters for management under the “wild trout” policy. The general sentiment was that those waters appropriate for designation have already been listed. This suggests that the policy is being used for a fairly limited purpose – to guide management on a few of the state’s most popular wild trout fisheries.

5.5 Both within CDOW and among the public, there is some confusion regarding the purpose of the wild trout policy. This makes it unlikely that the policy will be a useful tool for further improvement of Colorado’s wild trout.

The combination of the policy itself and the way in which it has been implemented leaves some unanswered questions. The chief question remains: what is (and what should be) the purpose of the CDOW’s “wild trout” program? Is the purpose to enhance wild populations through habitat improvement, monitoring, and regulation? Or to increase the number of fisheries managed solely through natural reproduction? Or to focus management attention on, and protect through special regulations, heavily-utilized wild populations that provide "quality" or trophy size trout? Until confusion on this core question of purpose is resolved, the wild trout program is unlikely to support further improvements in Colorado's wild trout resources.

Fish Health

Driven largely by concerns about whirling disease, fish health has become a major program focus in Colorado. The CDOW's investment in fish health has increased dramatically since the late 1980s, and the fish health program appears to be stabilizing as a significant element of fish management efforts. While fish health programs have grown steadily, the policy response to whirling disease has fluctuated widely over the past decade.

6.1 After initially placing quarantines on WD+ hatcheries, the CDOW relaxed regulations to allow stocking of WD+ fish in drainages where the parasite had already been found. This facilitated the spread of WD by allowing stocking of infected fish throughout drainages, even where the parasite was found only in part of that drainage.

The organism that causes whirling disease (WD) in salmonids, *Myxobolus cerebralis*, was first found in Colorado in November 1987. By early 1988, 11 fish culture units (two state, nine private) had tested positive for *M. cerebralis*. All sites found positive were immediately quarantined by order of the director.

After internal and external discussion, the CDOW established criteria for fish stocking from quarantined facilities in March 1988. Stocking of WD+ fish was allowed only within drainages where the presence of *M. cerebralis* has been confirmed. Drainages were defined broadly, with Colorado being divided into 15 major drainages. As a result, once WD was found in a drainage, infected fish could be stocked in waters throughout that drainage (regardless of whether the specific water was WD+). Stocking was *not* allowed in waters adjacent to negative fish culture facilities; in any west-slope drainages; in waters where migration into greenback cutthroat trout habitats could take place; or in waters where migration could readily occur into waters supporting wild rainbow, brook, or cutthroat trout.

Later in 1988, following an emergency conference convened by the Colorado River Fish and Wildlife Council, CDOW policy was liberalized by allowing WD+ stocking in west-slope drainages and removing protection for wild brook and rainbow trout populations. By 1992, stocking was allowed in all waters except in proximity to fish culture facilities (unless the owners of the facility grant permission in writing) or within native cutthroat trout habitats. This was the CDOW's least restrictive policy on whirling disease.

`The liberalization of stocking policies in the late 1980s and early 1990s seemed to reflect two major ideas: (1) maximum flexibility should be provided to use WD+ fish to provide fishing recreation; (2) stocking of WD+ fish poses little risk to wild trout. The latter idea was based on the *absence of evidence* that whirling disease threatened wild fish, not any *evidence of absence* of impacts. The distinction between the two seems to have been blurred.

6.2 More recently, the Commission adopted a more restrictive policy on whirling disease. The policy calls for no stocking of infected fish in coldwater streams; the Commission later issued regulations making exceptions to allow WD+ stocking in several Colorado rivers.

In May 1996, the Commission adopted a new, more stringent policy on stocking of WD+ fish[60]. By this time, research had clearly documented severe impacts of whirling disease on wild trout[61]. The new policy precluded stocking from protected habitats, including native cutthroat trout waters, waters in wilderness areas, and all coldwater streams "with few exceptions." Stocking of lightly infected fish was allowed for "restricted habitats" – mostly WD+ reservoirs where the risks of spreading disease further were deemed low. Stocking of WD+ trout regardless of their level of infection was allowed in "unrestricted habitats," generally low-elevation waters which could not support salmonids year-round. In September 1996 the Commission approved a regulation including a list of several coldwater stream exceptions in which WD+ fish could be stocked. The list included portions of several of Colorado's major trout rivers: the South Platte, Gunnison, Rio Grande, Conejos, Arkansas, Colorado, Cache la Poudre, Taylor and East Rivers. For some of the exceptions listed[62], the presence of *M. cerebralis* in the water had not yet been confirmed.

In February 1997, the CDOW issued maps and lists identifying the protected, restricted, and unrestricted habitats. Lower-elevation waters (in the Grand Valley and east of the I-25 corridor) are listed as unrestricted. Most of the remainder of the state is listed as protected habitat. Restricted habitat includes the coldwater stream exceptions mentioned above and a number of WD+ lakes and reservoirs, especially in the Arkansas, South Platte, and Gunnison River drainages[63].

The CDOW's current policy with regard to whirling disease states that their primary objective should be the continued protection of the health of the aquatic resources of the state. However, this policy could be eroded as the CDOW attempts to balance it with

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[60] Policy D-9; refer to Appendix IV.
[61] e.g., see Walker, Peter G.., and R. Barry Nehring. 1995. An Investigation to Determine the Cause(s) of the Disappearance of Young Wild Rainbow Trout in the Upper Colorado River, in Middle Park, Colorado. Colorado Division of Wildlife.
[62] Portions of the Conejos and the Middle Fork of the South Platte were opened to WD+ stocking though *M. cerebralis* had not yet been found in samples of free-ranging fish from those waters.
[63] Stocking of WD+ fish continues in many high-use lakes along the Arkansas River, the major reservoirs along the South Platte River, and in Blue Mesa, Morrow Point, and Taylor Park reservoirs in the Gunnison drainage.

their goal of maintaining or increasing current levels of recreational angling opportunities throughout the state. *The CDOW appears committed to using WD+ fish to generate recreational opportunity. If that interest is not carefully balanced by a responsibility to protect wild and native trout resources then a gradual process of liberalization in stocking restrictions may take place again.* Recent decisions by the CDOW offer hope that greater protection will be extended to Colorado's native and wild trout in the future.

6.3 Since the detection of whirling disease in Colorado, the CDOW has greatly expanded its investment in fish health programs.

When whirling disease was first found in Colorado, the state fish health program consisted of only one fish pathologist and relied primarily on assistance provided by the U.S. Fish and Wildlife Service's Fish Health Laboratory (then located in Ft. Morgan). Since 1987, the program has grown tremendously. The state operates a small but professional laboratory in Brush. By 1997, the staff consisted of five FTE positions – two fish pathologists, one biologist (serving as a lab manager and bacteriology technician), one lab technician (working primarily with whirling disease), a 1/2 time pathologist (doing virology work), and a 1/2 time secretary. The program operates under a research leader located in Ft. Collins and also gets some time from a wildlife technician located at the Fish Research Hatchery. In addition, the lab employs anywhere from one to three temporary employees to assist with its case load.

Currently, the lab manages about 500 cases per year – nearly double the case load from FY 94-95. The state now does much of its own fish health analysis (bacterial and parasitic pathogens). It still relies on the U.S. Fish and Wildlife Service for most of its virology work, but maintains the capability to do virology at the Brush laboratory as necessary. The fact that the CDOW is now able to conduct most of its own disease testing, and has even developed improvements in the methods used to detect *M. cerebralis*, illustrates how far the CDOW has come in assembling a dedicated and professional staff to address fish health management. This reflects a high level of commitment to an important element of fish management that has, in some other states, received relatively little attention.

6.4 Colorado requires regular fish health inspections for public and private hatcheries. For some pathogens of concern not known to occur in Colorado, inspection is only required for imports. This could allow for spread of these pathogens should they become established in the state.

Colorado has strict inspection requirements for both public and private fish culture facilities. Annual inspections performed by a qualified fish pathologist are mandatory for any facility that sells or stocks live salmonids. Sample sizes are selected to detect a 5% prevalence at 95% confidence. Virology work is done on a per lot basis, while bacterial kidney disease (BKD) and whirling disease (WD) are tested on a per water supply basis. In terms of virology, fish are tested for infectious hematopoietic necrosis (IHN), infectious pancreatic necrosis (IPN), and viral hemorhagic septicemia (VHS). Additionally, fish are tested for furunculosis, enteric redmouth, bacterial kidney disease, and whirling disease.

Regular inspections are not conducted for *Ceratomyxa shasta*, proliferative kidney disease (PKD), or epithelial epizootic disease (EED) which are not found in the region. When fish are imported from areas where these pathogens are endemic they are inspected. This approach leaves open the possibility that, if one of these pathogens did enter Colorado despite the import restrictions, they could spread within the state before their presence was detected.

6.5 Inspections are conducted with a sharing of responsibility (and cost) among the CDOW, Fish and Wildlife Service, and the hatcheries.

Colorado has developed a three-way sharing of responsibility/costs in conducting these inspections. The CDOW provides analysis for regulated bacterial and parasitic pathogens. The U.S. Fish and Wildlife Service provides lab testing for viruses. Hatchery owners pay for sample collection, which must be conducted by qualified sample collectors. In addition to the state pathologists, private citizens can become certified collectors if they are AFS certified fish health inspectors, Doctors of Veterinary Medicine, or Certified Veterinary Technicians. Currently, seven private-sector collectors are authorized in Colorado.

6.6 Fish health staff have contributed to ground-breaking research and intend to expand research efforts, but lack adequate wet lab space.

The fish health program is also involved in research, though staff time dedicated to this element of the fish health program has been somewhat limited. Pathologist Pete Walker has collaborated with aquatic researcher Barry Nehring on studies of the Colorado River, documenting for the first time significant WD impacts on wild populations of trout. WD testing and histology have also been conducted on feral fish sampled from a wide range of Colorado waters. Fish health staff have also contributed to research on issues such as species susceptibility. Research on wild fish health should be an area of increasing emphasis now that two full-time pathologists are on staff. Current plans call for one pathologist to focus on hatchery fish health management, while the other will do more work with wild fish health research and monitoring. This shift in staff emphasis is a positive step. However, research efforts remain limited by a lack of wet lab space available for experiments relating to whirling disease or other fish health questions. Additional lab space for such experimentation is a significant unmet need.

6.7 CDOW hatcheries use a variety of measures to minimize the likelihood of disease outbreaks. However, reliance on suspect water supplies places many fish culture units at risk.

State fish hatcheries in Colorado take some precautions to minimize the risks of disease. Several state hatcheries had incidents with enteric redmouth disease from the late 1970's through the mid-1980s. Now, all state fish culture units vaccinate for enteric redmouth. A trial vaccination program for bacterial coldwater disease is also being developed. These measures minimize the possibility of disease resulting from pathogens that are practically ubiquitous.

Management practices also help to reduce the chances of spreading disease within the hatchery environment. For example, disinfection of vehicles and tools helps minimize the possibility of inadvertently transferring pathogens into (or within) a facility. The CDOW's November 1995 report on disease prevention in state fish hatcheries briefly describes the preventive activities used at each state hatchery[64].

While precautions have been taken, a scarcity of good water supplies increases the risks of fish disease spreading in Colorado's hatcheries. Most of the CDOW's fish culture units depend upon surface water for at least a portion of their water supply. This makes them vulnerable to pathogens found in those surface waters. Some state hatcheries also use recirculated water. This also increases the risks of disease. For example, it appears that recirculating water through a settling pond (presumably laden with *Tubifex* worms, a host organism for *M. cerebralis*) was responsible for introducing the parasite to the Fish Research Hatchery. The unit has since eliminated the settling pond from its recirculation system.

6.8 The percentage of the CDOW's trout production which is WD+ has increased dramatically during the 1990s.

From 1991 through 1995, stocking of WD+ catchable trout (in numbers) increased by over 120%. Stocking of WD+ subcatchable trout increased by 110%. This disturbing trend reflects the ongoing erosion of the CDOW's WD-negative production capabilities and an assumption that stocking is necessary to maintain license sales and programmatic funding. Table 7 demonstrates the growing proportion of the CDOW's hatchery production that is classified as WD-positive.

[64] Division of Wildlife. 1995. State Fish Hatcheries: Disease Prevention and Construction Project Recommendations. Available from Colorado Department of Wildlife.

Table 7: Percentage of total CDOW trout production taking place at WD+ facilities.

	Year				
	1991	1992	1993	1994	1995
% Catchables WD+	40%	46%	46%	75%	87%
% Subcatchable WD+	15%	28%	23%	36%	40%

Currently, only the Crystal River, Glenwood Springs, and Pueblo[65] hatcheries are WD-negative, while the Bellvue, Buena Vista, Chalk Cliffs, Durango, Finger Rock, Fish Research, Mt. Ouray, Mt. Shavano, Pitkin, Poudre, Rifle, Roaring Judy, and Watson hatcheries are all WD-positive.

6.9 The CDOW has begun investing in hatchery clean-up. After an initial focus on technological fixes, the CDOW now appears to be focusing on securing water supplies. However, the costs of clean-up and prevention need to be factored into costs of production and distribution.

In response to public concern over whirling disease, the CDOW has proposed and/or undertaken several projects intended to eliminate *M. cerebralis* from WD-positive units or increase production at units that are free of the parasite. At the Roaring Judy hatchery, an ultraviolet disinfection system has been installed to treat water before it enters the hatchery building. Early reports suggest that the system has been effective in reducing infection, but the unit remains WD-positive. The CDOW's "blue-ribbon" panel report cautioned against widespread use of UV and other expensive technical "fixes" until they have been tested and proven effective.

In line with that recommendation, current CDOW proposals for hatchery clean-up get back to basics – securing clean water supplies and breaking the WD parasite's life cycle. Future projects proposed by the CDOW include developing additional enclosed springs at Rifle Falls, sealing springs at Mt. Shavano and Finger Rock, and augmenting the ground water supply at the Buena Vista unit (in order to boost production at that WD-free unit).

6.10 CDOW policy for other pathogens in private operations grants considerable decision-making authority to the Director without specific guidance on priorities and without similar internal checks.

While whirling disease has been a focus in recent years, the CDOW also has relevant fish health policies for many other pathogens. The CDOW has broad authorities to address

[65] While the unit has tested WD-negative, the presence of *M. cerebralis* in the Arkansas River leads CDOW pathologists to consider adding the unit to the WD-suspect list.

fish health concerns, but at the Director's discretion rather than in accordance with any specific policy. CDOW regulations state:

> If any diseased wildlife, which would have a significant detrimental effect on Colorado's wildlife as determined by the Director or the state veterinarian, are found such wildlife may be destroyed or held in quarantine at the owner's expense until disposition is determined . . . The Director shall determine when destruction of wildlife, a quarantine or disinfection is required at any federal, state, private or commercial fish or wildlife production facility.

This leaves a great deal of discretion with the Director. Private or commercial facility owners can appeal decisions on these matters to the Commission by filing notice of appeal within 24 hours of receiving the CDOW's order.

Fish culture units positive for BKD have a prescribed process for determining where they may stock fish. The positive hatchery has 30 days to submit a management plan outlining how they plan to eliminate or operate in the presence of BKD. The plan is reviewed by the Fish Health Board, which makes a recommendation on the proposal to the Director within 60 days. The director then either approves or rejects the proposed management plan.

In general, the CDOW's policy for pathogens should work adequately when leadership appreciates the importance of disease risks and ecosystem health. On the other hand, if leadership lacks concern for fish health matters, there is obvious potential for abuse of discretion.

Angler Attitudes

In assessing its stocking programs and options for the future, the CDOW has at times assigned an overly simplistic (and unsupported) cause and effect relationship in assessing its goal of maintaining angler satisfaction: catchable trout = satisfied anglers. For example, the 1996 "blue-ribbon" panel report claims that there is a direct and equal relationship between the numbers of catchable trout stocked and recreational use (though the authors admit this is an oversimplification). In a similar vein, the CDOW has argued that if stocking is reduced (or eliminated), fewer anglers will purchase licenses and less revenue will be available for all fishery programs[66]. In fact, studies of angler attitudes in Colorado have generally contradicted the idea that catchable trout stocking equates with angler satisfaction.

[66] e.g., see Kochman, Eddie. 1991. Fish Management in Colorado. in *Going Wild?* Colorado Trout Unlimited.

7.1 Anglers generally prefer quality of experience over quantity of fish. They rate factors such as scenery and solitude as most important for angler satisfaction, while catching a limit of trout is relatively unimportant.

Bergersen et al.[67] conducted an extensive analysis of angler preferences and attitudes in Colorado. Some of their findings are highlighted below:

- Poorer fishing conditions but higher setting quality (less crowding, clear mountain streams, no interference from others' activities) were preferred over higher quality fishing but lower setting quality.

- Anglers identified the most important attributes of a fishing experience as fishing in areas away from busy traffic, with high scenic beauty, and with opportunities for solitude. Catching trout that were not recently stocked, that were large, or that were not raised in hatcheries all rated as more important than catching the limit.

- When anglers were asked for their preferences among different kinds of management, most did not have strong preferences for any one concept. Among those that did express strong preferences, 51% preferred wild trout management while 30% preferred put-and-take management.

These results imply that the setting in which anglers fish may be more important than the quantity or size of fish caught, and certainly are more important than harvesting a limit of trout. This view of angler preference does not support the hypothetical *catchable trout = angler satisfaction* relationship.

Similar results have been obtained in subsequent research on angler attitudes. A market research project for the CDOW[68] found that relaxation and being close to nature were the most common reasons for fishing, with anglers rating them more important than harvesting fish. Availability of places to fish, absence of over-crowding, and aesthetics of surrounding rated as the most important factors while the number of fish caught was given much less importance. Large creel limits were rated the least important attribute for good fishing experiences.

Studies of angler preferences from other areas have had similar results. For example, 1994 surveys in Wyoming[69] showed that anglers rated the most important elements of quality fishing as being outdoors, relaxation, solitude, viewing wildlife, and "getting out" with family and friends. Catching a limit was among the least important factors.

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[67] Bergersen, Eric P., William J. McConnell, and Charles C. Harris. 1982. Estimating Demand for Colorado Sport Fisheries: A Survey of Angler Preferences and Attitudes. Available from Colorado Department of Wildlife.
[68] Galloway Vigil & Associates. 1986. Market Research Projects for the Colorado Division of Wildlife. Available from Colorado Department of Wildlife.
[69] Wenzel, C. R. and W. A. Hubert. 1995. 1994 Wyoming Anglers Survey. Available from Wyoming Department of Fish and Game.

7.2 CDOW data do not support the assumption of a direct and equal relationship between catchable stocking and recreational use.

Results from some CDOW reports also run counter to the "direct-and-equal" proposition. These include:

- The CDOW's 1986 hatchery review[70] reported that stocked fish provide approximately 30% of the fish caught in the state. While stocking patterns have changed in the past decade, it seems unlikely that stocking could provide only 30% of fish caught and yet be *the* primary determinant of recreational use.

- Surveys of anglers using urban lakes indicated that from 88-97% of anglers would continue to fish for warmwater species even if catchable trout stocking ceased (McAfee 1991)[71].

- In 1984, Rifle Gap Reservoir was stocked with 16,500 catchable trout and provided 58,000 angling hours. In 1987, 61,500 catchables were stocked and Rifle Gap provided 61,000 angling hours. Catchable stocking increased by 273%, while angling hours increased by only 5% (Bennett 1990, cited in McAfee 1991).

- On Bear Lake, catchable stocking rates for 1980-1982 were reduced by 75% for the years 1983-1985. Angling days did decline dramatically (from a three-year average of 20,000 to 11,700 or 42%), but the correlation was not direct and equal. The next year, catchable stocking was increased to 250 fish/hectare (f/ha) for one year, then returned to 100 f/ha. Angling days increased slightly when catchable stocking rates went up, but continued to increase when stocking rates were dropped again (McAfee 1991).

- On Stillwater Lake, research from 1980-1987 showed no correlation between catchable stocking rates and angling days provided (McAfee 1991).

In short, both angler preference data and empirical data gathered by the CDOW cast doubt on the hypothesis of a direct and equal relationship between recreation and catchable trout stocking. It is also important to note that 93% of intensively managed waters (those stocked with catchable trout) contain component fisheries that are *not* dependent on catchable stocking (e.g., put-and-grow, wild trout, or warmwater fisheries).

There is little question that some Colorado waters lack adequate habitat for trout growth and reproduction and may require catchable stocking to maintain a fishery. In such waters, it seems reasonable to expect a strong relationship between catchable stocking and

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[70] Division of Wildlife. 1986. Analysis of the Colorado Division of Wildlife's Trout Hatchery System, and Alternatives for Future Modification: Phase I.
[71] McAfee, M. E. 1991. Coldwater Lakes and Reservoirs. Job Final Report, Federal Aid Project F-59. Colorado Division of Wildlife.

recreational use (though other factors such as accessibility will also play a role). For those waters in which catchable stocking is used to supplement put-and-grow stocking programs or natural reproduction (either of coldwater or warmwater fish), the connection between catchable stocking and recreational use becomes more tenuous.

Sweeping generalizations about the need for more catchables should not be used to dismiss calls for a critical assessment of other management options for many of Colorado's waters.

Economics and Angler Demand

This section provides a brief review of some economic issues related to propagation in Colorado. Additional reports are currently being prepared by an external contractor and will be complete by late 1997[72].

8.1 CDOW estimates of "angler demand" have not been based on usual economic concepts, such as anglers' willingness to pay (unsubsidized, real costs) for various management strategies.

Objectives for the CDOW's fish culture program have generally been set based on perceived angler demand for the hatchery product. The CDOW has not, however, examined demand in an economic sense. Generally, "demand" has been gauged by compiling requests from regional biologists (based on their perceptions of angler demand and resource needs) or by estimating the numbers of fish needed to maintain catch rates as the numbers of anglers changes. From these estimates, the CDOW assesses whether current hatchery capacity is sufficient to meet angler demand.

Some examples:

- The CDOW's 1986 hatchery system analysis[73] estimated future demand for stocked trout by looking at expected growth in the angling population and estimating how many additional fish would need to be produced in order to maintain catch rates of a desired rate (2.3 fish/day) for the increased number of anglers in Colorado. From this review, the CDOW determined that by 1995 production of catchable trout would need to increase by 1.2 million fish and production of subcatchable trout by 400,000.

- The 1995 Deloitte and Touche analysis[74] of the CDOW's hatchery system cites a demand ("trout need") of 5.1 million catchable trout and 11.9 million subcatchable

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[72] One report will explore the full long-term costs of production and stocking; the second will investigate whether there is a relationship between stocking levels and license sales.
[73] Division of Wildlife. 1986. Analysis of the Colorado Division of Wildlife's Trout Hatchery System, and Alternatives for Future Modification.
[74] Deloitte and Touche. 1995. CDOW hatchery system analysis. Available from Deloitte and Touche LLP, Denver, CO.

trout. This number is based not upon economic analysis, but on requests submitted by the regional biologists, long-range plan goals, and historical stocking practices.

These approaches to estimating demand are fundamentally flawed. Under the current system, anglers pay a flat fee for a fishing license but are then permitted to harvest up to eight trout per day throughout the year. Aside from the cost of going fishing itself, anglers do not face any additional cost in order to have additional stocked fish available for harvest. Thus, even if the marginal benefits of having one more fish returned to creel are small, they will likely exceed the marginal costs to the angler and "demand" for additional stocked fish will be practically unlimited.

While stocking additional fish may not be costly to the angler, it *does* require funding from the CDOW. This makes it critical to determine the marginal benefits of stocked fish and compare them to the marginal costs of producing and planting those fish[75]. Obviously, resource management programs should not be driven solely by economic considerations – if the market could take care of everything, there would be no need for a Division of Wildlife at all. However, information on the economic costs and benefits of stocking should be combined with information on biological impacts in order to determine the effectiveness of stocking programs. In waters managed primarily as recreational (rather than natural) resources, economic factors will be especially important. It may be that the CDOW is stocking more or fewer fish than is economically justified, statewide or for specific types of waters.

8.2 Studies on two Colorado rivers found that the CDOW stocked more catchable trout than was economically justified.

In fact, Johnson et al. (1995)[76] found that, from an economic perspective, the CDOW was stocking too many catchable trout on two study streams. For sections of the Cache la Poudre and Taylor Rivers, the authors found that the marginal costs of trout stocking exceeded the marginal benefits (estimated by determining anglers' willingness-to-pay) at the average daily catch levels reported. From an efficiency standpoint, the study suggested that stocking in the rivers should be reduced.

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[75] Interested readers are directed to Loomis J. and P. Fix. 1997. An econometric approach to estimating the short run and long run costs of propagating hatchery trout in Colorado. Available on request to the authors at Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, CO. It is important to consider costs and benefits at the margin, over the short term, and over the long term. For example, the more of a good a consumer has, the less the *marginal benefit* of obtaining another unit of that good will be (i.e., the benefit to an angler of catching the first fish is greater than for the fourth fish). For cost-benefit analysis, one needs to look at the benefits anglers obtain from the *last fish caught,* since changes in stocking will affect anglers at the margin (i.e., they may catch three instead of four fish).

[76] Johnson, Donn M., Robert J. Behnke, David A. Harpman, and Richard G. Walsh. 1995. Economic benefits and costs of stocking catchable rainbow trout: a synthesis of economic analysis in Colorado. North American Journal of Fisheries Management 15: 26-32. These values have subsequently been validated econometrically. A full report is pending the review of the analysis.

The CDOW's "Blue-Ribbon Panel" report highlights the need for greater evaluation of angler demand in an economic sense:

> We do not have enough information to estimate demand accurately and, therefore, production ... Until the DOW has confidence in data describing anglers' demand and willingness to pay (by water category) ... we will not be able to manage our hatcheries proactively.

To address this information gap, the report's authors suggested that the CDOW conduct a study "that examines the cost, benefits, and anglers' willingness-to-pay for hatchery-reared fish in Colorado." In light of the findings reported by Johnson et al. (1995), it is clear that such an economic reevaluation of the CDOW's stocking programs is long overdue.

Along with improving its understanding of the economic benefits of stocking and anglers' willingness to pay, the DOW should also better define the "true" costs of its fish stocking programs. These costs should reflect not only the easily identified costs of fish production and transport, but also the negative externalities that may result. For example, the spread of whirling disease due to past stocking practices has clearly imposed major costs on Colorado which are not generally considered in economic analyses.

Discussion of Findings

Recreational Fishery Management vs. Conserving Native Biotic Resources:

Given the dual mission of the CDOW (conserve fish and wildlife and promote fishing and hunting), it might appear that the agency must balance the desires of a diverse set of anglers with the requirements for a sustainable aquatic resource. When presented in this way, the dual mission becomes a false dichotomy that invites conflict. In fact, the two parts of the CDOW's mission are complementary. Conserving the state's fish and wildlife resources is the best way (and over the long run may be the only way) to sustain wildlife-related recreation. This is the presumed reason why resource protection is given paramount importance in the CDOW's 1994 Long Range Plan. Similarly, wildlife-related recreation benefits the resource by providing essential funding for conservation efforts. If the resource and recreation communities better recognized their interdependence and spent more time focusing on their shared long-term interests in a healthy resource, the fish and wildlife of the state would surely benefit.

Recreational Fishery Management vs. Management of Public Expectations:
Recreational fisheries managers have the unenviable task of acting as front-line stewards of specific aquatic resources to provide healthy fish populations for a diverse set of anglers (and non-users) that have a diverse set of expectations. Inevitably, some anglers (and non-anglers) will become disappointed and disenchanted if they are unable to meet or maintain their expectations (after all, heavy spending on tackle, travel, and associated

expenditures heightens the expectations). Often, stakeholders will blame the resource stewards for their disappointments.

At the ground level, resource stewards must contend with two realities. First, pristine, high quality, and even average quality aquatic habitats are being lost to de-watering; to watershed modification by agricultural and urban development; and to degraded water quality – to name a few of the most prominent problems. Second, the predicted rate of human growth within portions of Colorado will add further stress on aquatic resources (both from accelerating development and from increased angler consumption). As a result, there will be intensified "competition" for the limited aquatic resources because habitats will be lost while the growing population will demand more (if current rates of consumption are maintained).

This leaves us with two (although not mutually-exclusive) options: increase the supply of desired commodities, or decrease demand. To achieve the first option (which, given the CDOW's mission, is presumably preferred), two competing (but again not necessarily mutually-exclusive) models of management are often offered: the natural propagation (or wild population) model and the artificial propagation (or stocking) model. Each model may provide certain benefits, have associated economic costs and carry ecological and genetic risks. The cost/benefit/risk trade-offs are the focal point of current controversies and debates about the use of stocked fish. Clearly, the citizens of Colorado must decide whether the derived benefits are worth the costs and the long-term risks to the integrity of the ecosystems we enjoy and require for our health and livelihoods.

In the artificial production scenario, we essentially "manufacture" the various commodities we desire. We can make the "product" look, feel, smell, taste, or behave in nearly any way we desire (within certain technological limits). The benefits of this model are that we can *theoretically* control the outcome. We can also produce and supply a large number of "products" for distribution to customers who demand the products. These contributions are easily quantified and conveyed to the angling public. The costs for this model include the relatively high costs of rearing and stocking large numbers of fish. Presumably, these costs could be directed fully toward the consumers (i.e., user pays), although this is not currently the case[77]. Unfortunately, other indirect costs are difficult to quantify and are often ignored (i.e., foregone use of ecosystem resources by other biological elements of the ecosystem). The risks associated with planting non-native fish and of stocking at levels beyond the sustainable capacity of the system are further outlined elsewhere in this document.

Alternately, in the natural production model, we rely on the ecosystems themselves to produce commodities. As such, we are less likely to control the production outcome (quantity and perhaps quality) and we are also less able to "direct" the desired dimensions of the product (i.e., we let nature decide the look, feel, smell, taste, or behavior of the products). The benefit of this model of management is that we derive a series of service,

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[77] For example, in CDOW 1996 Annual Report shows that the "fishing" program spent nearly $29 million while generating only $18 million in revenue.

commodity, amenity and aesthetic values from the native and heritage character of the ecosystem. For example, a healthy aquatic ecosystem permits a sustainable harvest of fish (within the system's natural limits). The **costs** of this model include protection of currently pristine habitats (very low direct costs, though foregone opportunities for development may be significant) and recovery/improvement of lost or degraded habitats to good productive condition (can have high front-end costs, but generally low maintenance costs). The biological **risks** of this model are that species or their subunits may decline, albeit for natural causes. Other non-biological risks are related to losses of anglers – the eyes and ears (and pocketbooks) for aquatic resources – due to dissatisfaction with catch levels or to unavailability of places to fish. In this model, angling effort might be redistributed across the state with the costs, benefits, and risks shared differently among anglers and the remainder of the general public than they are now.

The difference between the two models is not subtle; it reflects fundamental questions about how biological resources can be or should be managed. Switching from one model to the other requires some changes in philosophy and expertise within the agency, plus a change in "marketing" to the general and fishing public. Furthermore, the economic and political costs are by no means trivial. There is a recreational and agency infrastructure that has emerged which is dependent on the current artificial production model. The entities within this infrastructure will likely obstruct such changes as financial decisions if it is perceived that changes will specifically cost them. The estimated economic impact of recreational angling in Colorado is nearly $690 million[78]; this level of expenditure and commerce can wield a considerable clout with public policy makers.

Of course, the artificial and natural production models are not mutually exclusive. CDOW biologists utilize both models for some portion of the management program. As documented elsewhere in this report, however, the CDOW is overdue for a careful review of the balance it has struck between the two models. Propagation will remain a vital tool for managing fish populations and angling opportunities. Like any tool, however, it needs to be applied in a rational and objective manner where appropriate and where it would be impractical to use other approaches which are both ecologically safer and longer lasting. Without healthy, functional habitats and other ecosystem components, no management tool will succeed. Our biggest challenge is to ward off the continual threat of a lost, simplified, or fragmented landscape.

[78] Fedler, Anthony J. and David M. Nickum. 1994. The 1991 Economic Impact of Sport Fishing in Colorado. Sport Fishing Institute. Available from the American Sportfishing Association. Alexandria, VA.

References Cited

Angermeier, P. L. 1994. Does biodiversity include artificial diversity? Conservation Biology 8:600-602.

Bartley, D. 1994. Proceedings of the Expert Consultation on Genetics in Fisheries. Food and Agriculture Organization of the United Nations. Rome, Italy.

Behnke, R. 1992. Native Trout of Western North America. AFS Monograph 6. American Fisheries Society, Bethesda, MD.

Bennett, J. R., D. A. Krieger, T. P. Nesler, L. E. Harris, R. B. Nehring. 1996. An Assessment of Fishery Management and Fish Production Alternatives to Reduce the Impact of Whirling Disease in Colorado. Division of Wildlife.

Bergersen, E. P., W. J. McConnell, and C. C. Harris. 1982. Estimating Demand for Colorado Sport Fisheries: A Survey of Angler Preferences and Attitudes. Available from Colorado Department of Wildlife.

Bowen, J.T. 1970. A history of fish culture as related to the development of fishery programs. In Benson, N. G. (ed.). pp. 71-93. A Century of Fisheries in North America. American Fisheries Society Special Publication No. 7.

Callicott, J. B. 1994. Conservation Values and Ethics. Pp. 24-49. In Meffe, G.K. and C. R. Carroll. Principles of Conservation Biology. Sinauer and Associates, Inc. Sunderland, MA.

Carline, Robert F., Thomas Beard, Jr., and Bruce A. Hollender. 1991. Response of Wild Brown Trout to Elimination of Stocking and to No-Harvest Regulations. North American Journal of Fisheries Management 11: 253-266.

CITES. 1997. Report of the CITES Invasive Species Specialist Group to the 1997 convention (Harare, Zimbabwe). Convention on the International Trade of Endangered Species (CITES). Geneva, Switzerland.

Colorado Division of Wildlife. 1986. Analysis of the Colorado Division of Wildlife's Trout Hatchery System, and Alternatives for Future Modification: Phase I.

Colorado Division of Wildlife. 1992. Conservation Plan for Colorado River Cutthroat Trout in Northwest Colorado. Prepared by the CDOW, Forest Service, and Bureau of Land Management.

Colorado Division of Wildlife. 1994. Long Range Plan. Colorado Division of Wildlife.

Colorado Division of Wildlife. 1995. Division of Wildlife Performance Audit, February 1995. State Fish Hatcheries: Disease Prevention and Construction Project Recommendations.

Colorado Division of Wildlife. 1996. The 1996-2000 Colorado Fishing Season Guide.

Courtney, Jr. W.R. 1984. Distribution, Biology, and Management of Exotic Fishes. Johns Hopkins University Press.

Courtney, W. R. 1995. The case for caution with fish introductions. American Fisheries Society 15:413-424.

Deloitte and Touche. 1995. CDOW hatchery system analysis. Available from Deloitte and Touche LLP, Denver, CO.

Dowling, T. E., and M. R. Childs. 1992. Impact of hybridization on a threatened trout of the southwestern united-states. Conservation Biology 6:355-364.

Fedler, Anthony J. and David M. Nickum. 1994. The 1991 Economic Impact of Sport Fishing in Colorado. Sport Fishing Institute. Available from the American Sportfishing Association. Alexandria, VA.

Fleming, I. A., and M. R. Gross. 1992. Reproductive behavior of hatchery and wild coho salmon (Oncorhynchus kisutch) - Does it differ? Aquaculture 103:101-121.

Fleming, I. A., and M. R. Gross. 1993. Breeding success of hatchery and wild coho salmon (Oncorhynchus kisutch) in competition. Ecological Applications 3:230-245.

Gall, G. A. E. 1987. Inbreeding. In Ryman, N. and F. Utter. Population Genetics in Fishery Management. University of Washington Press., Seattle, WA.

Galloway Vigil & Associates. 1986. Market Research Projects for the Colorado Division of Wildlife. Available from Colorado Department of Wildlife.

George, S. 1996. Saving Biodiversity: a status report on state laws, policies, and programs. 218 pp. Available from Defenders of Wildlife, Washington, DC or the Center for Wildlife Law , Albuquerque, NM.

Gilpin, M. E. and M. E. Soule. 1986. Minimum viable population size: Processes of species extinction. In Conservation Biology: The Science of Scarcity and Diversity, pp. 19-34. Sinauer Associates, Sunderland, MA.

Gowan, C., M. K. Young, K. D. Fausch, and S. C. Riley. 1994. Restricted Movement in resident stream salmonids: a paradigm lost? Canadian Journal of Fisheries and Aquatic Sciences 51:2626-37).

Hallerman, E. J. and J. M. Epifanio (1995). Human dimensions of biological diversity. Pp. 199-212. In Proceedings of the World Fisheries Congress, vol. 3. Oxford Press International. New Delhi, India.

Harig, Amy L. and Kurt D. Fausch. 1996. Compilation of Data on Colorado Waters Containing Rio Grande Cutthroat Trout. Final Report to Division of Wildlife, MOU Project 904-96.

Hindar, K., N. Ryman, and F. Utter. 1991. Genetic effects of cultured fish on natural fish populations. Canadian Journal of Fisheries and Aquatic Sciences 48:945-957.

Horak, D. 1995. Native and non-native fish species used in state fisheries management programs in the United States. AFS Symposium 15:61-67.

Johnson, Donn M., Robert J. Behnke, David A. Harpman, and Richard G. Walsh. 1995. Economic benefits and costs of stocking catchable rainbow trout: a synthesis of economic analysis in Colorado. North American Journal of Fisheries Management 15: 26-32.

Knox, D., and E. Verspoor. 1991. A Mitochondrial DNA Restriction Fragment Length Polymorphism of Potential Use for Discrimination of Farmed Norwegian and Wild Atlantic Salmon Populations in Scotland. Aquaculture 8:249-257.

Kochman, Eddie. 1991. Fish Management in Colorado. in *Going Wild?* Colorado Trout Unlimited.

Lassuy, D. R. 1995. Introduced species as a factor in extinction and endangerment of native fish species. American Fisheries Society Symposium 15:391-396.

Leary, R. F. 1990. Genetic and Meristic Analysis of Colorado River Cutthroat Trout. Population Genetics Laboratory Report 90/2. University of Montana.

Leary, R.F., F. W. Allendorf, and G.K. Sage. 1995. Hybridization and introgression between introduced and native fish. American Fisheries Society Symposium 15:91-101.

Loomis J. and P. Fix. 1997. An econometric approach to estimating the short run and long run costs of propagating hatchery trout in Colorado. Available on request to the authors at Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, CO.

Martinez, A. M. 1988. Identification and Status of Colorado River Cutthroat Trout in Colorado. AFS Symposium 4: 81-89.

Mayr, E. 1982. A History of Biological Thought. Harvard University Press. Cambridge, MA) provides a history of species concepts. See also Avise, J. 1994. Markers, Natural History, and Evolution. University of Georgia Press. Athens, Georgia, for a discussion of the various species concepts.

McAfee., M. E. 1991. Coldwater Lakes and Reservoirs. Job Final Report, Federal Aid Project F-59. Colorado Division of Wildlife.

Meffe, G. K. 1992. (Techno-arrogance and halfway technologies: salmon hatcheries on the Pacific coast of North America. Conservation Biology 6:350-354.

Miller et al. 1989. Extinctions of North American fishes during the last century. Fisheries 14:22-38.

Nehring, R. B. 1990. Coldwater Streams and Special Regulations: Management Assessment Report for the 1990s. Division of Wildlife.

Nehring, R. B. and T. Powell. 1991. The Catchable Trout/Wild Trout Conundrum: The Colorado Experience. in Going Wild? symposium sponsored by Colorado Trout Unlimited.

Norton, B. 1988. Commodity, amenity, and morality, the limits of quantification in valuing biodiversity. pp. 200-205. In Wilson, E. O. Biodiversity. National Academy Press, Washington, DC.

Office of Technology Assessment. 1993. Harmful nonindigenous species in the United States. USGPO, Washington, DC.

Perry and Vanderklein, 1996. Water quality: management of a natural resource. Blackwell Science.

Petrosky, C.E. and T.C. Bjornn. 1988. Response of Wild Rainbow (Salmo gairdneri) and Cutthroat Trout (S. clarki) to Stocked Rainbow Trout in Fertile and Infertile Streams. Canadian Journal of Fisheries and Aquatic Science 45: 2087-2105.

Philipp, D.P. and J. E. Clausen. 1995. Fitness and performance differences between two stocks of largemouth bass from different drainages within Illinois. AFS Symposium 17. Pp. 236-243.

Philipp, D. P. et al. 1995. A synthesis of threats to aquatic biological diversity. In Proceedings of the World Fisheries Congress, vol. 3. Oxford Press International. New Delhi, India.

Platts, W. S., and R. L. Nelson. 1988. Fluctuations in trout populations and their implications for land-use evaluation. North American Journal of Fisheries Management 8:333-345.

Philipp, D. P. et al. 1995. Proceedings of the First World Fisheries Congress. Oxford Press, New Delhi, India.

Riddell, B. E., and D. P. Swain. 1991. Competition Between Hatchery and Wild Coho Salmon (Oncorhynchus kisutch) - Genetic Variation for Agonistic Behaviour in Newly-Emerged Wild Fry. Aquaculture 98:161-172.

Scarnecchia, D. L., and E. P. Bergersen. 1987. Trout production and standing crop in Colorado's small streams, as related to environmental features. North American Journal of Fisheries Management 7:315-330.

Schramm, H. and R. Piper (Editors). 1995. Uses and Effects of Cultured Fishes. American Fisheries Society Symposium No. 15.

Swain, D. P., and B. E. Riddell. 1990. Variation in agonistic behavior between newly emerged juveniles from hatchery and wild populations of coho salmon, Oncorhynchus. Canadian Journal of Fisheries and Aquatic Sciences 47:566-571.

Verspoor, E. 1988. Widespread hybridization between native Atlantic salmon, Salmo salar, and introduced brown trout, S. trutta, in eastern Newfoundland. J.Fish Biol. 32:327-334.

Vincent, E. R. 1987. Effects of Stocking Catchable-Size Hatchery Rainbow Trout on Two Wild Trout Species in the Madison River and O'Dell Creek, Montana. North American Journal of Fisheries Management 7: 91-105.

Walker, P. G. and R. B. Nehring. 1995. An Investigation to Determine the Cause(s) of the Disappearance of Young Wild Rainbow Trout in the Upper Colorado River, in Middle Park, Colorado. Colorado Division of Wildlife.

Waples, R. S. 1991. Genetic interactions between hatchery and wild salmonids - Lessons from the Pacific Northwest. Canadian Journal of Fisheries and Aquatic Sciences 48 (Suppl. 1):124-133.

Waples, R.S. 1995. Genetic effects of stock transfers in fish. In Proceedings of the World Fisheries Congress, vol. 3. Oxford Press International. New Delhi, India.

Wenzel, C. R. and W. A. Hubert. 1995. 1994 Wyoming Anglers Survey. Available from Wyoming Department of Fish and Game.

White, R. J., J. R. Karr, W. Nehlsen. 1995. Better roles for fish stocking in aquatic resource management. American Fisheries Society Symposium 15:527-547.

Wilcox, A. and J. Harte. Ecosystem services in a modern economy: Gunnison County, Colorado. pp. 311-328. In Daily, G. C (editor). 1997. Nature's Services. Island Press. Washington, DC. and references therein for recent descriptions and case studies of service values.

Young, Michael K., R. Nick Schmal, Thomas W. Kohley, and Victoria G. Leonard. 1996. Conservation Status of Colorado River Cutthroat Trout. U.S. Forest Service. Rocky Mountain Range and Experiment Station. Laramie, WY.

Appendix i: Definitions and Conceptual Descriptions

Definitions:

Artificial propagation: the husbandry, breeding, culture, and release (in part or in total) of fish. As opposed to "natural propagation," which occurs without the participation of humans. This term has been used at least since 1894 by Marshall McDonald, U.S. Fish Commissioner, who quipped, "we have relied too exclusively upon *artificial propagation* as a sole and adequate means for maintenance of our fisheries . . . We have been disposed to measure results by quantity rather than quality, to estimate our triumphs by volume rather than potentiality." See also Bowen (1970) for a discussion on the differences between culture and propagation.

Culture (or fish culture or aquaculture): the enclosed, captive, or otherwise controlled rearing of individuals.

Ecosystem: the functional and compositional interrelationship of biological communities with chemical and physical processes.

Exotic (in the biological sense): an organism or gene pool that is not native, indigenous, or otherwise present in an ecosystem except through some form of human intervention.

Exotic (in the political sense): a species that was introduced from outside of the United States.

Genetic drift: a change in the frequency of alleles due to unrepresentative transmission of alleles across generations largely as a random "sampling" phenomenon.

Genetic effective population size (N_e): the size of an ideal, randomly-mating, population exhibiting a level of genetic drift similar to a real population of interest.

Husbandry: the practice of choosing individuals for breeding.

Hybridization: (interspecific): the interbreeding of individuals from different recognized species; (intraspecific): the interbreeding of individuals from separate lines or lineages within a recognized species.

Introduction: the accidental or intentional release of an exotic (in the biological sense) organism into an ecosystem in which it did not evolve.

Introgression: the mixing of gene pools due to hybridization and interbreeding beyond a single, first generation.

Native: also called *indigenous* or *natural*, a group (species, subspecies, or stock) that evolved within local ecosystem.

Non-native: also called *non-indigenous* or *exotic*, a group (species, subspecies, or stock) that evolved outside of a local ecosystem and that has been (or potentially could be) transferred or introduced into the local ecosystem.

Recruitment: (the harvest sense), the proportion of a population that reaches a harvested, catchable, or otherwise exploitable size, life history stage, or condition.

Recruitment: (the conservation sense), the proportion of a population that reaches reproductive condition; or the proportion of a population that originates from natural (wild) production.

Species: (the taxonomic sense), a group of interbreeding individuals actually or potentially reproductively isolated from other such groups of individuals that share characteristics which in combination are unique to the group.

Species: (the evolutionary sense), a group of individuals sharing a common lineage, which are also genetically and ecologically divergent from other such groups.

Stock: (n. the population genetic sense), a population which have some form of geographical, ecological, or behavioral isolation and integrity from other such groups and which expresses genetically-determined character divergence from other such groups.

Stock: (n. fisheries sense), a group of fish targeted for capture or harvest in a certain place at a certain time.

Stocking: also called *releasing* or *planting*, the liberation of individuals that were produced and cultured outside of the system receiving them.

Subspecies: the recognized taxonomic hierarchy which clusters individuals based on a suite of shared derived characters (and shared ancestry), yet which are capable of interbreeding with other such clusters when brought in contact. Often defined along geographical lines.

Supplementation: (a.k.a. enhancement, augmentation, or maintenance stocking), an artificial increase in population size (or recruitment to size) to permit harvest.

Conceptual Descriptions:

Risk assessment (or risk analysis): A *risk* is the overall "potential" or chance for some kind of detrimental effect occurring as a response to some action. *Harm* is the realization and effect of that risk; we often think of this as a "cost". Alternately, a *benefit* is the realization of a positive effect of some action. A risk analysis employs formal models that can predict the chances and extent for harm or benefit under variable conditions. These often involve trade-offs over several variables. Not all risk or harm can be avoided (even if monumental efforts were to be directed at identifying them). Therefore, risk, harm, costs, and benefits need to managed (a.k.a., risk management) to minimize the chance of harm and to minimize the extent of harm when it occurs while maximizing the chance and extent of benefit.

Stock concept of fisheries management: Stocks, rather than species (as a whole) are the operational unit of sound conservation and management. This is because 1) species are composed of a patchwork of inter-related stocks; 2) individual stocks have divergent evolutionary histories from others, become adapted to local (and variable) ecological conditions, and behave differentially in response to their niche features; and 3) the admixture (and interbreeding) of divergent stocks can effectively lead to an extirpation of a unique segment of the gene pool (composition or structure), as well as the potential loss of the locally adapted character of the population (functional).

Appendix II: Genetic Impacts of Stock Transfers

Interspecific impacts.

The introduction of "species" taxonomically related to native or resident species can create opportunities for immediate hybridization (i.e., the first generation interbreeding of these once isolated and divergent species) or introgressive hybridization (i.e., the subsequent interbreeding of hybrids among themselves or with the original "parental" species). In Colorado, rainbow trout and cutthroat trout are taxonomically related and are capable of hybridizing and introgressing. This problem is not unique to Colorado, but also appears in other places that have introduced rainbows on top of cutthroats (e.g., within the ranges of Yellowstone, Bonneville, Westslope and other cutthroats).

In such areas, the "cut-bow," a first generation hybrid between cutthroat and rainbow trout, offers an example of interspecific hybridization between native and introduced species. Cut-bows are partially fertile hybrids capable of backcrossing with native cutthroats. This kind of gene flow can have two major effects on gene pool "integrity" of the cutthroat trout: one, the many manifestations that mixing of divergent and incompatible gene pools can have (see intraspecific species discussion below); and two, a form of genomic extinction of native gene pools[79, 80]. In the latter case, the native species' genes may still occur to some extent in the introgressed mixture, however, the combination of genes or genotypes that typified the native species *is extinct*.

Some have proposed that injecting species into a novel ecosystem increases biological diversity, but such proposals belie the diversity-stability concept[81]. One reason for this is that "homogenization" (i.e., the thorough mixing of communities such that any patchiness is diminished) is *counter* to diversity. Biodiversity occurs at and includes multiple levels. Genetic homogenization can eliminate species or stock uniqueness, possibly leading to the loss of valuable traits. Another reason is that outdated concepts of "open niches" are not supported[82]. If species-area relationships hold, for example, an impoverished I area (such as an island) does not acquire colonists continually and in a linear fashion *ad infinitum*, but rather eventually reaches a saturation point such that net gain of new colonists (at the species level) replace or displace other species already present. Therefore, attempts to inject new species may extirpate a species already occurring rather than "upping" the species count.

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[79] Leary, R.F., F. W. Allendorf, and G.K. Sage. 1995. Hybridization and introgression between introduced and native fish. American Fisheries Society Symposium 15:91-101.
[80] Note: Genes are hierarchically distributed (on chromosomes, within individuals, among individuals, etc.). Alleles from different genes can be inherited independently, dependently because of physical proximity on a chromosome, or dependently because of functional interaction (epistasis).
[81] Angermeier, P. L. 1994. Does biodiversity include artificial diversity? Conservation Biology 8:600-602.
[82] See Courtney, W. R. 1995. The case for caution with fish introductions. American Fisheries Society 15:413-424.

Intraspecific impacts.

In the case where watersheds or tributary rivers support or contain divergent stocks, the history of isolation, inter-migration, and gene flow (i.e., interbreeding) is important to understand. As a general rule, geographic barriers such as mountain ranges between rivers or waterfalls between reaches within a river are most effective at isolating stocks. One result of long periods of isolation (and it need not be "absolute"), is that the isolated stocks each experience and accumulate separate sets of mutations (i.e., changes to their genetic make up). After sufficiently long periods of time, these differences (or "divergences") between gene pools can be detected with one or more protein or DNA tools. In some cases the observed divergence is the result of natural selection for the subtle environmental differences experienced by the two stocks[83]. This is often referred to as *local adaptation*, in which the stocks become "tailored" to local environmental conditions. There is no guarantee that a group of individuals will adapt[84] to an environment; this commonly-held view of goal-oriented evolution has repeatedly been shown to be incorrect.

When two isolated populations of the same species are mixed (i.e., interbreeding occurs) several outcomes are possible. Admixture or "secondary contact" can occur naturally, as when river reaches are captured by a different watershed, or as a result of human activities such as the transport of fish across watershed boundaries.

One of the possible outcomes is that the resulting admixture (possibly through a stock transfer) experiences no change in performance (e.g., growth rates, behavioral type, coloration, etc.) or reproductive fitness[85] (number of offspring that live to have their own offspring). In this case, it is likely that the populations are part of the same stock.

Another possible outcome is that either performance or fitness will improve over the multiple generations. This is a rarely observed outcome. Such *hybrid vigor* is generally a compensation for past inbreeding events. Where observed, hybrid vigor usually lasts for one generation only. Subsequent generations of mixing lose any vigor effects and may in fact experience lowered performance or fitness. Furthermore, in cases where growth rate or size is increased, it is often at the expense of reproductive fitness[86].

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[83] In other cases divergence may result from chance factors unrelated to environmental conditions (*genetic drift*).

[84] *Adaptation* is an inherited change (ultimately due to a genetic mutation) within a population. Some changes that occur, such as learned behaviors, represent *acclimation* to environmental conditions and are not passed on to offspring.

[85] Here, fitness refers to survival and reproductive success (in the Darwinian sense) not physical robustness or muscularity. The two may be positively correlated, but are not necessarily so. For further exploration of the issues associated with stock transfers, see Waples, R. S. 1995. Genetic effects of stock transfers. In Philipp et al. (Editors). Proceedings of the World Fisheries Congress, vol. 3. Protection of Aquatic Biodiversity. Oxford and IBH Publishing.

[86] There is a trade-off between somatic growth and reproductive function; i.e., there is no free lunch. It is uncommon for both to occur simultaneously as a hybrid vigor effect of crossing lines.

The third kind of outcome is when offspring experience lower performance or fitness. This is commonly referred to as an *outbreeding depression*. Outbreeding depression is presumably caused by the jumbling of genes when divergent stocks interbreed. An individual's genes are not floating freely in the body or in cells, they are packaged on chromosomes. Furthermore, most traits important to reproductive function are complex and are encoded by many genes. In a way, individual genes interact with others to behave as "super-genes" and become co-adapted (that is, selection has operated more at the genome level rather than the individual gene level). Through the simple reshuffling process experienced in producing sex-cells, these super-genes can become mismatched and convey a less than optimal set of reproductive functions. If severe enough, then sterility or inviability of offspring can result. This outcome of mixing is *prima facie* evidence that the populations are divergent lineages.

The importance of preventing the intentional or inadvertent mixing of geographically separated populations (especially in the absence of empirical information of the effects of interbreeding) is rooted in the risks of creating an outbreeding depression and of losing genetic diversity among populations. A primary difficulty with managing fish populations in this regard is that an effect may not be noticed for a couple of generations after the secondary contact and measuring the effect in the wild requires a conscientious and systematic effort.

Note that the same processes that occur with between-species interactions also occur with within-species interactions. The exact threshold of genetic divergence that conveys the status of species remains elusive (mostly because it is not an appropriate way of looking at the question)[87]. We currently tend to define species, at least nominally, based on multiple lines of evidence (morphology, distribution, behavior, genetic characters, etc.). In fact, current thinking in evolutionary biology suggests that the amount of genetic (or more correctly evolutionary) divergence between groups we call "species" and the divergence of those groups we call "populations" differs in degree, not in kind. Therefore, the idea that an outbreeding depression effect is observed at the population or the species level is likely a reflection of the degree of genetic divergence. In fact, the biological concept of species (that is, reproductive isolation between groups) is nothing more than an extreme example of an outbreeding depression model. According to the biological species school of thought, species that have evolved allopatrically (in the different places) are less likely to have premating "mechanisms" in place to avoid interbreedings that lead to outbreeding depressions. Therefore, just as stocks from different geographic areas should be kept isolated, so too should exogenous species that are capable of interbreeding with local residents.

[87] Mayr, E. 1982. A History of Biological Thought. Harvard University Press. Cambridge, MA) provides a history of species concepts. See also Avise, J. 1994. Markers, Natural History, and Evolution. University of Georgia Press. Athens, Georgia, for a discussion of the various species concepts.

Appendix III: Factors in Population Declines

A number of biological, chemical, and physical changes to an ecosystem can act as stresses often cited in association with a species' endangerment or decline.

Habitat loss is often cited as the primary reason why a species faces extinction. Because most fish require a suite of related living spaces at different times in their lives (or to serve different roles such as foraging, spawning, or sheltering habitats), seemingly trivial changes in habitat can have profound effects on wild species if no accommodation or compensation is provided. There are a wide variety of activities that can change the character of habitats, including channelization, bank destabilization and erosion, denuding of riparian buffers, flooding, siltation, de-watering, salination, acidification, and others. The rates at which habitat changes occur and the resiliency of aquatic systems to persistent changes are important variables as to whether species will decline over the long term. Unfortunately, determining the impacts of any individual change in habitat is often very difficult because the local effects may be small. However, when viewed at a larger scale (e.g., ecosystems or landscapes), the cumulative effects of many small changes become more noticeable.

Because of the enormity of cost and effort for such undertakings, studies of such cumulative impacts are conducted far too infrequently. Smaller studies, manageable within existing budgets or infrastructure, are more commonly used. Unfortunately, these smaller studies often fail to provide us with a suitable information-base from which to make rational decisions.

Another of the causes for decline of species in aquatic ecosystems is overharvest, that is, removal of individuals at a rate greater than can be replaced through recruitment (reproduction). Essentially, harvest is a source of *mortality* for fish or a form of human *predation* on fish populations. We most often think about overharvest in conjunction with commercial fisherman, but we now know that it is possible to overharvest a system even with the relatively inefficient methods of recreational angling if sufficient fishing pressure is applied. Even so-called "no-harvest" or catch-and-release fishing contributes to mortality due to handling or metabolic stress, hook woundings, and disturbance to spawning behavior. The variables that influence overharvest are total harvest, fishing effort (time spent fishing with a particular kind of gear), catch per effort (efficiency), where effort is concentrated or diffused, size and distribution of the population being fished, the relationships of "source" and "sink" populations, and other vital statistics used to study population dynamics.

A third cause for the decline of species biological interference, of which we will discuss three forms. All three are associated with a shift in trophic structure of the system.

First are ecological effects, such as predation or competition. Generally (but not always), these are associated with the introduction of a non-native species. Whether accidental or intentional, these introduced species generally prove detrimental to one or more of the native species in the system. Sometimes this is the intended outcome. For example, biological control (i.e., predation) of “pest” species is a common rationale for introduction. However, the removal of the pest needs to be considered in context of its value (either aesthetic or functional) to the ecosystem. And the longer term effects of an invasion of one species, becoming an invasion of two species.

Another kind of ecological (i.e., competition) effect can be due to an introduction of a species or population with similar ecological requirements or characteristics, (i.e., *niches)*. Where food, shelter, or other important resources are limiting, the effects of introduction are varied depending on life history characteristics of the residents and invaders (but can include a physical displacement and elimination of residents or high mortality of the introduced group). The bottom line is that rarely can two groups successfully occupy the same niche at the same time[88].

A second kind of impact is genetic interference due to interbreeding or population bottlenecks. It is important to recognize that biodiversity at the genetic level is organized in a hierarchical manner. It is also important to recognize that genetic biodiversity serves a function and is determined through the processes guiding biological evolution. If we examine a species of trout, for example, we can estimate the composition of genetic diversity, that is “how much” and “what kind” of variation is observed at the present time within the species as a whole. Once we know the composition component of diversity, we can look to see whether the diversity has any *structure*, that is, how the variation is distributed within and across watersheds, within and across seasons or years, in relation to behaviors and life-histories, or associated with physical or morphological variation. Next, we can investigate whether the compositional or structural diversity serves a function, and what processes are guiding them. Therefore, when discussing and examining genetic diversity it is vital to define specifically the context and kind of diversity.

As a general rule, populations with low levels of genetic diversity among individuals *within* the group suffer a greater risk of extinction than do similar populations possessing greater levels of within-group genetic diversity. It is vital to recognize the need to avoid the urge to haphazardly mix populations for the sake of increasing this *within* population component. This generality applies even if numbers of individuals is presently large because an invariant group lacks the ability to adapt to changing environmental conditions. The analogy commonly employed to this situation is a “lottery”. If the winning number in a lottery is the same each round and, therefore predictable, it is best to have lots of replicate tickets with that winning number (equate this to stable environmental conditions). However, if the winning number changes each round and, therefore unpredictable, it is

[88] Courtney (1995) describes why the “vacant niche” concept, commonly used to justify introduction of exogenous species or populations, is fallacious. Courtney, W. R. 1995. The case for caution with fish introductions. American Fisheries Society 15:413-424.

best to have lots of different numbers on tickets with few or no replicates (equate this to a constantly changing environment).

Within-population diversity is reduced in two primary ways: through genetic bottlenecks and through inbreeding. A genetic bottleneck occurs when the genetic diversity within populations is diminished. The narrower the bottleneck, the lower the chances that diversity will be retained in subsequent generations. Often a reduction in population size is related to the size of the bottleneck, but a variety of breeding processes too can cause bottlenecks in otherwise large populations. The variable exhibiting the greatest influence on size of a bottleneck is related to fecundity (i.e., number of potential offspring an individual can have over its life time). The greater the fecundity, the greater the chance for bottlenecks to occur in spite of large population sizes (most fish species, including trout and salmon, have large fecundities). Inbreeding and inbreeding depression are consequences of non-random matings among related individuals at a rate greater than would be observed in large population. The chances for relatives to mate in small populations is greater than for larger populations, although it can occur.

The structure of genetic diversity among-groups can be altered (and integrity compromised) through the mixing of populations (see Appendix II). Outbreeding effects can be created when formerly isolated populations or species come together and breed. One extreme outcome of such outbreedings is the inviability of the hybrid offspring. However, more subtle effects can also occur where the hybrid offspring are viable but less reproductively successful (i.e., have lower Darwinian fitness) than the offspring from matings within the former isolates. Even if the hybrid offspring are equally or more fit than their non-hybrid cousins, the unique combination of genes (often referred to as gene pool integrity) in the former isolates can be disrupted, the effects of which may not surface for a couple generations.

A third kind of impact is the direct and indirect effects of diseases. Diseases can directly harm individuals or populations through epidemic (i.e., local) or pandemic (i.e., widespread) occurrences by increasing the mortality rates. Diseases can also cause harm more indirectly through bottleneck effects when populations crash (see description above), leading to what has been called an “extinction vortex.” In principle, an extinction vortex is a feedback loop that ratchets inward until extinction is inevitable. For example, small populations are more likely to lose genetic variation than are large populations. Populations with low genetic variation are at greater risk of failing to adapt to changing environments that diverse populations leading to smaller populations sizes, which leads to greater losses of genetic diversity, and so on until the population disappears.

There are other links among ecology, genetics, and disease. The ability to fight off infection is related to immune function, for which genetic diversity is important for producing a broad spectrum of cellular and systemic defenses. A population that goes through a single narrow or several bottlenecks risks losing genetic diversity for genes responsible for immune function as well as for other kinds of genes.

There is an enormous literature base regarding the co-evolution of hosts and parasites. A review of this literature strongly suggests that a strain of disease resistant trout is not probable. The basis of this conclusion emerges from what we know about the host-parasite relationship, one best described as an "evolutionary arms race." A host can theoretically acquire a random mutation (albeit rare) that conveys some resistance or immunity to a novel parasite. This is not the most common outcome because parasites, too, experience random mutations, some of which can convey a mechanism to circumvent the acquired resistance in the host. Such back and forth of acquired random mutations for resistance and over-ride is where the "arms race" concept comes from. In fact, most of the work that has been done with these kinds of systems to date observe or predict that the parasites usually "win" the arms race. The reason for this is that generation time for parasites is considerably less than that for the host. The victory is not one where the parasite overwhelms the host population. It is not considered a stable strategy for a parasite to "kill" its host (at least not before it can reproduce and transfer the parasite to another individual). Ultimately, the chances are not great that natural or even artificial selection will create resistant forms or strains for introduction (i.e., the "hopeful immunity" approach).

In general, the planet is inundated with a wide range and number of disease-causing agents that seem not to be lethal most of the time (planetary biomass of non-disease agents is quite high). But, *exotic* disease agents can cause a high rate of problems because pathogen and host evolved in isolation of each other. This means that the pathogen-host pairs have yet to reach an equilibrium in terms of virulence and resistance (and the "arms-race"). It is also important to remember that stress from other ecological and genetic sources (such as dietary deficiencies, fatigue, injury, chemicals, and historical losses of diversity) contributes to the expression of diseases in both natural and wild settings.

APPENDIX IV: FISH MANAGEMENT POLICY IN COLORADO

(Editor's Note: Since this document was completed, Colorado has adopted a new statewide fisheries policy, which supersedes many of the following policies and which places a greater emphasis on wild and native trout resources.)

General Aquatic Resource Management Authority

In Colorado, the General Assembly has established general guidelines for wildlife and fisheries management in statute. Beyond defining basic principles, the legislature generally defers to the Colorado Wildlife Commission (Commission) in setting wildlife policy for the state and to the Colorado Division of Wildlife (CDOW) for executing those policies.

The goals for wildlife management in Colorado are described in law:

> It is the policy of the state of Colorado that the wildlife and their environment are to be protected, preserved, enhanced, and managed for the use, benefit, and enjoyment of the people of this state and its visitors. It is further declared to be the policy of this state that there shall be provided a comprehensive program designed to offer the greatest possible variety of wildlife-related recreational opportunity to the people of this state and its visitors and that, to carry out such program and policy, there shall be a continuous operation of planning, acquisition, and development of wildlife habitats and facilities for wildlife-related opportunities. (§33-1-101)

From this basis in statute comes what is sometimes referred to as the CDOW's "dual mission": to protect and manage wildlife and to provide recreational opportunities.

Rather than attempting to address more specific issues of wildlife policy itself, the General Assembly established the Commission to oversee the CDOW and its programs for wildlife management and outdoor recreation (§33-1-103,104). The Commission is expected to represent all geographic regions of the state as well as the full range of interests in wildlife management. The Commission is comprised of eight member Commissioners. Of the eight members, one (but not more than two) must be from each of five regions in the state to ensure regional equity. Similarly, one Commissioner is to represent each of the following interests: livestock, agriculture, sporting, wildlife organizations, and county commissioners. The remaining three Commissioners are at-large. Appointments are made for 4-year terms by the governor, and confirmed by the state Senate. The group is expected to be non-partisan, and no more than 4 members may belong to the same political party. The Commissioners elect from their ranks a Chair, a Vice Chair, and a Secretary tasked with conducting meetings and serving as chief spokespersons. The Commission has been given broad authority to regulate the taking of wildlife, to set seasons, to control transport and release of wildlife, and to capture and propagate wildlife for stocking (§33-1-104, 106).

The CDOW is staffed by professional fish managers, planners, and administrators charged with the daily conduct of fisheries management. The CDOW is under the direction of a Director, who serves essentially as the chief executive of the agency. Within the CDOW, specific divisions involved with aquatic resource management include a Hatchery Section (responsible for fish culture operations); an Aquatics Section (responsible for fish management and research activities); and a Habitat Section (responsible for CDOW involvement with in-stream flow programs, land use planning, and other activities that impact on wildlife habitat). The CDOW is also divided into three geographic regions: Western (Colorado River drainages), Northeastern (Platte River drainages), and Southeastern (Arkansas and Rio Grande River drainages).

While the General Assembly generally defers to the CDOW in the details of wildlife management, there are some instances where additional direction was established directly within state statute. Current legislative direction relating to fisheries falls under four major categories: endangered species management, license fees, protection of fishing waters, and fish health.

Endangered species and biodiversity – Colorado adopted an endangered species law (most recently revised in 1984) to protect indigenous wildlife that is threatened or endangered. The General Assembly directed that such species "be accorded protection in order to maintain and enhance their numbers to the extent possible" (§33-2-102). The law directs the CDOW to take appropriate *positive* actions to manage and enhance at-risk wildlife (here, meaning to increase the numbers and range of representative populations), but lacks the enforcement authority of its federal counterpart[89]. Specifically, Colorado law has a "listing" process and limitations on the "taking" of listed wildlife; however, the law requires no formal recovery plan or identification of critical habitat(s).

Licenses – The General Assembly has set upper limits on the level at which fees can be imposed for different kinds of licenses (§33-4-102). The fee structure is revisited with the legislature as needed to offset programmatic investments or to better reflect the costs and benefits of providing wildlife management services.

Fishing waters – State agencies are required to protect and preserve fishing waters of the state:

> It is declared to be the policy of this state that its fish and wildlife resources, and particularly the fishing waters within the state, are to be protected and preserved from the actions of any state agency to the end that they be available for all time and without change in their natural

[89] George, S. 1996. Saving Biodiversity: a status report on state laws, policies, and programs. 218 pp. Available from Defenders of Wildlife, Washington, DC or the Center for Wildlife Law , Albuquerque, NM.

existing state, except as may be necessary and appropriate after due consideration of all factors involved (§33-5-101).

State agencies that are considering construction or "development" which would alter natural streams are required to notify or consult with the Commission beforehand; the Commission can then make suggestions for changes in the construction plan to protect the fishing waters. If the agencies can not reach suitable agreement on the plan, they can elevate the issue to the governor for arbitration. The consultation process is limited in that it applies only to state construction, not to other kinds of state agency actions or to private sector activities[90].

Fish health – One area where the Commission shares authority for wildlife management with other state entities is fish health. The legislature (in 1991) established a board to review any regulations relating to fish health prior to consideration by the Commission. The fish health board has five members: two from the private aquaculture industry, one from the Colorado Department of Agriculture, one from the CDOW, and one from the U.S. Fish and Wildlife Service (§33-5.5-101). If the board votes to approve a regulation, it is forwarded to the Commission with their recommendation. Regulations that the board opposes can be forwarded to the Commission only if the Director of the CDOW determines that a situation exists which threatens to have serious impacts on existing aquatic populations (§33-5.5-102).

Fisheries Management Policies

Fish stocking decisions are guided by five Commission policies (D-1, D-2, D-4, D-6, D-9) and an administrative directive issued by the director (F-1). The policies are generally complementary, but there are some inconsistent messages.

Management of aquatic wildlife (D-1, 1975) – The Commission established a goal to "provide optimum fishing recreation . . . within the limits of the resource and available funding." The policy called for efforts to: (1) maintain water quality and quantity; (2) provide information to the public; (3) design regulations that allow for the greatest possible use of the resource while restricting use when it adversely affects the resource; (4) carry out fish propagation in the most efficient manner possible; (5) stock in waters where a fishery would not otherwise exist or where the existing wild fishery would not support "adequate fishing recreation"; (6) negotiate agreements with land management agencies and individuals to protect/improve habitat; and (7) conduct research including population inventory, creel census, and habitat study. The policy called for care in making new introductions of non-native species:

[90]The CDOW also has a memorandum of understanding with the state Division of Water Resources calling for consultation on activities which may harm wildlife values. However, the recent destruction of the fishery in Phantom Canyon (North Fork Poudre River) due to massive sediment releases from Halligan Reservoir suggests that this consultation does not take place consistently.

> Non-native (exotic) fish species will be introduced *only* when sufficient investigations are conducted to insure that the species will not have an adverse effect on the habitat occupied by native fish species; when it is ecologically suitable for the environment; when they will be contained within the boundaries of the state; and when there exists a justifiable biological or social need for the species.

Fish stocking (D-2, 1975) – The Commission reiterated its intent to "provide anglers in Colorado with the best fishing opportunity possible" and noted the need for stocking if "all waters are to be utilized to an optimum extent for fishing recreation purposes." The Commission added specific guidance for fish stocking activities. (1) Waters which demonstrate acceptable production and growth without stocking or with sub-catchable stocking should not be stocked with catchable fish. (2) Catchable plants should be made when the largest return to creel will result. (3) Catchable fish will be stocked only in waters with public access; streams will not be stocked with catchables within 1/2 mile of areas closed to the public. (4) Exotic fish will not be stocked without prior written approval of the state fish administrator for fish management.

High lake management (D-3, 1975) – This policy addressed management of high elevation lakes, both natural and man-made, where water levels do not fluctuate greatly (i.e., *not* water supply reservoirs). The Commission called for: (1) opposition to watershed uses which will accelerate erosion and waste accumulation; (2) use of buffer zones to protect the lakes and natural plant and animal communities; (3) opposition to water diversion which would modify the lakes; (4) fishery management "designed to satisfy species use requirements in relationship to the productive capacity of the lake;" (5) management primarily as natural systems, where maximum fish production is *not* achieved at the expense of the ecosystem; and (6) stocking as needed to provide "optimum fishing recreational opportunities." The policy reemphasized the use of stocking in providing "optimum" fishing recreation, but also elevated ecosystem protection as a primary consideration in stocking decisions.

Fish management and stocking (F-1, 1976) – The Director issued this guidance for fish management decisions. It states that the "primary functions of Fish Management are to provide optimum fishing recreation . . . and to maintain aquatic wildlife for consumptive and non-consumptive use within the limits of the resource and available funds." Much of the directive reiterates the Commission policies adopted in 1975. Some additional guidance was added, however. The directive requires fish stocking to be justifiable under one or more of the following conditions: natural reproduction or year-round survival is inadequate; growth potential is such that more poundage of fish can be returned than the weight of fish originally planted; a reasonable percentage of fish planted is returned to creel; put-and-take stocking may be used to supplement wild populations; put-and-grow stocking may be used to provide a fishery where otherwise one might not exist. The directive specifically endorses put-and-take stocking into waters containing or capable of supporting wild fish.

The F-1 directive requires that the annual fish stocking schedule be submitted to the Director for review and approval. The policy also encourages stocking of catchables during the time of greatest fishing effort and the use of frequent smaller plants to spread each allotment of fish among more anglers over the year. The directive reiterates Commission direction limiting stocking in areas without public access. It further limits stocking to areas with habitat condition suitable to fish survival. For catchables, waters must have a 40% return to creel if they are to be stocked[91].

The F-1 directive also instructs fish managers to "utilize healthy sources of fish and fish eggs in an effort to control and prevent the spread of infectious fish diseases." It calls for caution in transferring fish between fish culture units so as to avoid parasite and disease problems.

Wild trout and gold medal waters (D-6, 1992) – In this policy, the Commission formally recognized its responsibility to preserve and protect native and to maintain desirable, yet non-native populations of wild trout. The focus of the policy is on designating and managing relatively large, accessible wild trout waters. While recognizing that many small tributary streams and high likes support wild trout, the Commission felt that they did not receive enough angling pressure to require specific management.

The policy states that the CDOW *may* designate waters that meet any one of the following criteria: (1) the water supports a self-sustaining native cutthroat trout population; (2) for streams, the water supports a naturally reproducing trout population with a minimum standing stock of 40 pounds per acre (or less, if it provides essential spawning and nursery habitat for an adjoining water); (3) for lakes, the water supports over 40 pounds per acre and the fishery can be sustained through natural recruitment. Wild trout designation can be withdrawn if the population can no longer maintain itself, or if socio-economic conditions or land use changes result in withdrawal being in the best interest of the state.

For lakes and streams designated as wild trout waters, the policy offers specific management guidelines. First, it calls for habitat protection and enhancement through cooperation with land managers. If human activities result in loss or degradation of a wild trout water, compensatory mitigation will be requested. Special regulations (size, species, bag limits; tackle restrictions; season closures; etc.) may be recommended to protect and perpetuate the wild population. Finally, the CDOW will not stock hatchery-reared fish in designated waters except to restore or reestablish a wild population (e.g., native trout recovery, or in response to an environmental catastrophe). Where stocking takes place, the structure of genetic diversity will not be altered, only trout from wild broodstocks will be used, and only fry or fingerling trout will be planted.

The Commission also set guidelines for designated "gold medal" waters. To be eligible for gold medal listing, a water must consistently maintain a standing stock of 60 pounds per acre, with a minimum average of 12 trout per acre that are 14" or longer. Gold medal

[91] The Commission later adopted a 70% return to creel objective in its Long Range Plan.

habitats are to be protected in cooperation with land managers. Compensatory mitigation will be requested when they are degraded. Regulations will be used to maintain or enhance larger trout while striving for a catch rate of one trout per hour. Fingerling or fry size fish may be stocked to achieve and maintain the gold medal status.

Whirling disease (D-9, 1996) – In response to broad public concern about stocking of fish exposed to whirling disease, the Commission issued this policy outlining how WD+ fish could be used. The policy states that the primary objective of fish stocking should be "the continued protection of the health of the aquatic resources of the state when the stocking of fish exposed to the WD parasite is considered." The policy precludes stocking of WD+ fish in "protected" habitats, which include: all native cutthroat trout recovery and management waters; waters in wilderness and wilderness study areas, national parks, and primitive areas; waters set aside for salmonid spawning habitats; and all coldwater streams with few exceptions. WD+ fish *can* be stocked into positive standing waters or low-risk habitats that are deemed "not to present a further threat to the expansion of the parasite." The policy (and associated regulation) distinguishes between two kinds of waters receiving WD+ fish. "Restricted habitats" are those where the CDOW should minimize its contribution to the parasite load by using only "lightly-infected" fish[92], while unrestricted habitats can be stocked with fish regardless of their parasite load. Commission regulations specifically identify some coldwater streams as "restricted habitats" under the (sections of the Arkansas, Colorado, Conejos, East, Gunnison, Poudre, Rio Grande, South Platte, and Taylor rivers). Within these guidelines, the Director is given responsibility for developing the list of waters which are protected habitat, restricted habitat, or unrestricted habitat[93].

Management Principles

In 1991, the Commission approved a series of management principles[94] regarding topics ranging from outreach to habitat protection to human use of wildlife resources. Several principles have relevance for fish management and stocking programs. These include:

- The Division "will aggressively support and encourage" hunting, fishing, and viewing activities compatible with sound management.
- The Division should work to obtain decisions from public and private land and water managers that will benefit wildlife habitats. Land managers will be advised of possible problems and alternatives.
- The Division should protect habitat through easements, leases, and acquisitions, with a focus on blocks of habitat large enough to preserve ecological communities.

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[92] "Lightly infected fish" are those reared at hatcheries with an estimated average parasite load of less than 10,000 spores per fish.

[93] In February 1997, the CDOW issued its first map and listing of habitat designations under this policy. Most of western Colorado was designated as protected habitat.

[94] These can be found as an appendix to the CDOW's 1994 Long Range Plan.

However, the principles which bear most directly on propagation and stocking deal with human use of wildlife and wildlife abundance. In these principles, the Commission focused on managing recreation in a manner that preserves wildlife resources:

> Recreational hunting, fishing, trapping, and viewing wildlife are important parts of Colorado's outdoor heritage and economic future. We . . . will plan and conduct programs that protect those qualities and diversity of opportunities. However, the primary consideration in any wildlife management decision will be to maintain healthy wildlife resources.

Whereas previous policies placed great emphasis on providing "optimum" recreation, these principles made it clear that the emphasis was now to be directed at the resource itself. However, this principle was not applied wholly to fisheries resources. The Commission specifically exempts fish stocking from its guidance for other wildlife stocking programs:

> We will generally stock wildlife only to bypass problems which limit reproduction, assist the natural expansion of a species/subspecies into available habitat, or to reestablish extirpated populations of native species … Stocking of wildlife for immediate harvest is not consistent with other wildlife management activities because it does not make use of habitat productivity … [this] may cause people to infer that we do not believe ecological limits are important. Normally, we will not use this technique. *Stocking of catchable fish is a traditional exception to this policy because many of Colorado's accessible waters cannot sustain natural sport fisheries which are acceptable to the public*. However, we will not use this approach in waters which can be managed to provide public sport fishing satisfaction without stocking or by stocking sub-catchable fish. [emphasis added]

The Commission did seek to take some steps to reduce the use of catchable trout, precluding stocking of catchable fish in waters which could be effectively managed through other means.

Long Range Plan

The long-range plan is the CDOW's highest-level planning document. The 1994 edition opens by restating the agency's mission: "to perpetuate the wildlife resources of the state and provide people the opportunity to enjoy them." It then provides direction to guide activities under that mission over a 15 year period. It offers a general sense of how the CDOW will contend with emerging challenges, particularly the tremendous increase in Colorado's human population, and the attendant problems associated with equitable allocation of limited, and perhaps dwindling, resources to this growing population base.

However, it does not address how it will meet those challenges with any level of specificity. The 1994 plan is much more general than the previous (1988) plan.

The plan states that the CDOW's "foremost aim" will be to protect and enhance the viability of all Colorado's wildlife species. The plan further states that "the Division will provide quality opportunities for hunting, fishing, wildlife viewing, and other forms of wildlife recreation and enjoyment, consistent with the goal of protecting the wildlife resource." The implication is that long-term and sustainable resource management will be paramount, and that recreational opportunity will ensue if that task is done well. In protecting wildlife, the Commission recognized the central role of habitat protection: "since habitat loss, degradation and fragmentation are the greatest threats to the viability of wildlife, the Division will emphasize habitat protection strategies." However, the Plan later states that "by far the majority of the Division's resources will continue to be used to provide hunting and fishing opportunities." This makes it rather unclear how habitat protection will be emphasized, since prioritization must be reflected in resource allocation.

The 1994 Long Range Plan includes several goal statements which concern fishery management and stocking:

GOAL 1 – "define and identify high priority habitats in the state." The plan calls for prioritizing habitat inventory needs, collecting and sharing data on wildlife habitats, and identifying high priority habitats and strategies to protect and enhance them.

GOAL 3 – "protect, enhance, and restore aquatic and terrestrial habitats for all wildlife species in Colorado." The plan suggests the use of easements, leases, cooperative agreements, and acquisition to protect habitats on private lands. It also calls on the Division to serve as an advocate for wildlife with land use decision-makers and regulatory agencies.

GOAL 4 – "monitor the status of Colorado's wildlife species." The plan calls for a monitoring system to characterize viability by 1999, and for the status and critical trends of all species determined by 2009.

GOAL 5 – "protect wildlife species that may be at risk of becoming threatened or endangered." The plan directs the CDOW to identify species of special concern by 1996 and to develop management plans for those species in a timely manner. By 1998, all species of concern are to be inventoried.

GOAL 12 – "increase participation in fishing as the state's population grows and simultaneously increase the level of angler satisfaction." The plan highlights four areas of activity under this goal: expanding access, improving the state's fishery database, protecting and improving high priority aquatic habitats, and stocking fish "as appropriate to maintain angler satisfaction." This statement represents a philosophical shift from the Commission's position in the 1988 plan ("increase hatchery production"). While the plan recognizes the value of stocking as a management tool, it does not specifically endorse current or expanded production and stocking as did the previous plan.

However, the goal to "increase participation" is not applied solely to underutilized fisheries (i.e., those with sufficient natural productivity to support greater levels of fishing than they now receive). It can be argued that this objective provides an incentive to manage some waters to provide harvest beyond their natural capacity, through increased stocking.