THE STATUS, ECOLOGICAL ROLE, AND POTENTIAL FOR REINTRODUCTION OF SPECIES EXTIRPATED FROM THE COLORADO RIVER ECOSYSTEM, GLEN AND GRAND CANYONS, ARIZONA

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EXECUTIVE SUMMARY

The removal of ecologically important foundation taxa (e.g., dominant trees, abundant prey taxa), keystone species (e.g., those that influence trophic structure and composition), or previously abundant species, as well as the substitution of non-native taxa in those roles, affects the structure, composition, function, resilience, and goods and services of ecosystems, such as the Colorado River ecosystem (CRE) affected by Glen Canyon Dam in Glen Canyon National Recreation Area and Grand Canyon National Park, Arizona. The CRE is managed directly by the National Park Service (NPS) and the Secretary of the Interior is advised on dam management by the Adaptive Management Work Group (AMWG). Understanding the distribution and ecological roles of native species no longer present in regulated river ecosystems, such as the CRE, is limited by uncertainties about the pre-dam condition of populations and ecosystem structure; nonetheless, effective ecosystem management and rehabilitation requires accounting for missing species and ecological functions that characterized the natural ecosystem. Decisions about which native species and functions should be and can be restored, and which non-native species can be tolerated, remains the purview of well-informed ecosystem stewards (Schmidt et al. 1998).

Like other great NPS ecosystems, the CRE has lost native species despite the highly protected status of its lands (Newmark 1995; Stevens et al. 2001). Most species-based management attention is focused on federally listed species, as well as on economically important taxa. However, federally endangered species do not necessarily serve as adequate ecological "umbrellas", protecting other species or ecosystems (Angelstam and Roberge 2004), particularly in complex landscapes like the canyons of the Colorado River (Stevens et al. 2001). Extirpated species that are not federally listed may have important ecological roles, and their loss may greatly compromise ecosystem function. Also, little scientific attention has been paid to the distribution and status of rare and endemic taxa in the CRE, particularly invertebrates, for which few status or life history data exist. Ecosystem integrity can be jeopardized by insensitive resource management practices: focus on single-species management can trade off conservation of other non-listed species, and non-listed species and important ecosystem functions may disappear without notice (Simberloff 1998, Stevens et al. 2001), Stevens and Polhemus 2008). Goal 3 of the Glen Canyon Dam AMWG is to "Restore populations of extirpated species, as feasible and advisable" to the CRE; however, the AMWG has not made recent progress on that goal. Achieving that goal requires a review of information on the distribution, status, ecological role(s), and potential for reintroduction of extirpated species and other taxa of management concern in the CRE.

We describe distribution, ecological role(s), status, potential for reintroduction, and the quality of information available on missing or imperiled CRE species. We present a list of the federal- and state-listed and non-listed species known to have been extirpated, those apparently nearing extirpation, and those for which insufficient data exist to determine present status in the CRE. Preliminary analysis of those data suggest that at least 34 species of plants and animals may have been extirpated from the CRE or may be seriously declining there since the closure of Glen Canyon Dam in 1963, and the status of at least 10 other species in the CRE is uncertain. The list includes at least: 2 plants, 5 invertebrates, 5 fish, 2 amphibians, 1 reptile, 8 birds, and 11 mammal species. Of these, only one invertebrate, 4 of the 5 fish, and 5 bird species are or recently have been federally listed. The amount and quality of ecological and monitoring attention is relatively great for endangered CRE humpback chub (*Gila cypha*), Kanab ambersnail (*Oxyloma haydeni kanabensis*), and southwestern willow flycatcher (*Empidonax trailii extimus*) in the CRE. Some ecological, but inadequate monitoring data, are available for bald eagle (*Haliaeetus leucocephalus)*, peregrine falcon (*Falco peregrinus*), and California condor (*Gymnogyps californianus*), but erratically occurring listed species (e.g., brown pelican, *Pelecanus occidentalis*), and the ecology and fate of non-listed declining or extirpated species have largely been ignored.

We discuss strategies for filling information gaps about these species, how to evaluate the potential for reintroduction of extirpated species, and the compliance requirements of AMWG cooperating agencies that may be needed to partner in reintroduction efforts, specifically those of the National Park Service, the Fish and Wildlife Service, and the Arizona Game and Fish Department. We present this information as background for a draft motion to the AMWG and the Secretary of the Interior at the springtime 2009 AMWG:

> In recognition of GCDAMP Goal 3 and towards management of the Colorado River through an ecosystem approach, AMWG establishes the Species of Concern Ad Hoc Group, co-led by Grand Canyon Wildlands Council, NPS, and FWS, and charges it to produce a report by May 1, 2011 that contains the following with regard to extirpated species and other species of management concern in the CRE:
>
> - a review of information about and assessment of the status, habitat needs, and ecosystem roles of the species, and
> - recommendations on options and costs for improved stewardship of the species, including the potential for re-establishment / reintroduction.
>
> AMWG further allocates $50,000 to support development of the report.

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INTRODUCTION

Impacts of Native Species Loss on Ecosystems

The loss of native species is one of the three largest human impacts on natural ecosystems. The removal of ecologically important foundation taxa (e.g., dominant trees, abundant prey taxa) or keystone species (e.g., those that influence trophic structure and composition), and the substitution of non-native taxa in those roles in altered habitats, affects ecosystem structure, composition, function, and resilience, as well as the goods and services provided by those ecosystems. Understanding the distribution and ecological roles of native species no longer present in altered ecosystems such as the Colorado River ecosystem (CRE) on the southern Colorado Plateau is fraught with uncertainties because information on the pristine condition of those ecosystems often is limited. Nonetheless, ecosystem management and restoration planning requires accounting for missing species and functions that characterized the natural ecosystem. Decisions about which native species and functions should be and can be restored, and which non-native species can be tolerated, remains the purview of well-informed ecosystem stewards (Schmidt et al. 1998).

As has occurred in many of the nation's great landscape parks, a rather substantial number of native populations have been extirpated or appear to be at risk in the CRE (Minckley 1991, Newmark 1995, Stevens et al. 2001, Stevens and Gold 2002, L. Stevens unpublished data, NPS files). Much ecological attention has been paid to dwindling populations of endangered CRE big river fish, particularly humpback chub (HBC; *Gila cypha*; Minckley 1991, Valdez and Ryel 1997, Stone and Gorman 1999) and birds (e.g., southwestern willow flycatcher – SWFL, *Empidonax trailii extimus*; summarized in Paxton et al. 2007), but the ecological role and distribution of other endangered species that commonly occur in or near the river corridor (e.g., California condor, *Gymnogyps californicus*; Mexican spotted owl, *Strix occidentalis lucida*), as well as non-listed declining or extirpated species, is less well known. Federally endangered species do not necessarily serve as adequate ecological "umbrellas", protecting other species or ecosystems (Angelstam and Roberge 2004), particularly in complex landscapes like the canyons of the Colorado River. For example, HBC is used as a focal species for rive ecosystem management, but it is a sedentary, tributary-spawning species in GRCA that does not well represent other more highly migratory fish species, such as razorback sucker (RBS; *Xyrauchen texanus*) or Colorado pikeminnow (CP; *Pychocheilus lucius*) or any terrestrial species (e.g., SWWL; Stevens et al. 2001).

Extirpated species that are not federally listed may have had important ecological roles, and their loss may greatly compromise ecosystem function, as discussed by Soulé et al. (2005). Because of the important role of ecologically strongly interacting species on ecosystem function, and because the legal framework has not caught up with recent advances in ecosystem and conservation ecology, those authors recommend that natural resource managers…"adhere to a doctrine of 'best conservation practices based on the best science,' applying a more rigorous standard for the management of relatively interactive species than may be mandated by older statutes and effected by current practice and convention." In addition, little scientific attention has been paid to the distribution and conservation of rare and endemic taxa in Grand Canyon, particularly invertebrates, for which few status or life history data exist, and which are jeopardized by insensitive land management practices. For example, Stevens and Polhemus (2008) reported that 52.6% of aquatic Heteroptera species in the Grand Canyon region were found at 3 or fewer sites, and more than 25% were found only at single localities; many of those localities were springs that are threatened by regional groundwater pumping.

A more complete review of information on the distribution, status, ecological role(s), and potential for reintroduction of extirpated species and other taxa of management concern is needed to better understand and manage the CRE as an ecosystem. In this paper, we present a preliminary list of the CRE species known to have been extirpated, those apparently nearing extirpation, and those for which insufficient data exist to determine their status. We describe the distribution, ecological role(s), status, and potential for reintroduction, and the quality of information available on these species. We integrate missing taxa into a conceptual trophic diagram of the CRE, discuss advantages and challenges associated with developing a more complete understanding of the status of extirpated or declining taxa and the potential for reintroduction of extirpated species, and briefly review the compliance requirements of participating agencies associated with reintroduction efforts. We see this information as essential to the process of adaptive management moving towards a more comprehensive ecosystem management perspective.

METHODS

Study Area and Administrative Context

The CRE is managed under two administrative processes. The National Park Service manages natural and cultural resources, pursuant to Grand Canyon National Park enabling legislation (1919), the National Park Service (NPS) Organic Act (1916), and subsequent legislation including the 1992 Grand Canyon Protection Act. Glen Canyon Dam management is overseen by the Bureau of Reclamation's Adaptive Management Work Group (AMWG; a Federal Advisory Committee composed of representatives from all major stakeholder groups; Stevens and Gold 2002, Melis and Lovich 2005), and by the Colorado River Annual Operating Plan, both of which provide advice to the Secretary of the Interior, who serves as the Water Master of the Colorado River. Goal 3 of the Glen Canyon Dam Adaptive Management Program is to "Restore populations of extirpated species, as feasible and advisable." To date, this is the only AMWG goal that has received neither attention nor funding.

The CRE under the purview of the AMWG extends from the lowermost portion of Lake Powell and Glen Canyon Dam a distance of 447 km downstream through Grand Canyon to the boundary of Lake Mead National Recreation Area (LAME) at about Colorado River Mile 278 (Fig. 1). The CRE includes the shorelines and lower portions of tributaries within the 100-yr flood stage, and also extends up the lower Little Colorado River.

Information Sources

The focus of this document are the species of plants and animals that have been extirpated or become extinct in the CRE following closure of Glen Canyon Dam in 1963, as well as those that are failing to recruit or for which too few data are available to assess present status. We consulted with the published and government literature on the biota of the CRE, and used our published and unpublished data and analyses of those biota. Grand Canyon Wildlands Council, Inc. (GCWC; 2009) produced a draft regional conservation area plan, and we drew on some of the information in that plan to frame this discussion. In addition, we compiled information on other species of management concern, including federally listed, extinct, and exotic taxa. The latter taxa often are implicated in the loss or declining status of native species, and so are relevant to this discussion. We also discuss managing agency mandates and compliance requirements, elements that must be included in any reintroduction planning, and

generally describe the planning process and elements necessary to implement population restoration actions.

RESULTS

Extirpated Species in the CRE

At least 34 species of plants and animals appear to have been extirpated from the CRE since the designation of Grand Canyon National Park in 1919, or may have seriously declined there since the closure of Glen Canyon Dam in 1963 (Table 1, Fig. 2). The status of at least 10 other species in the CRE is uncertain because of limited data and information is lacking on many rare species of plants, invertebrates, and birds. Extirpated or highly a-risk species include at least 2 plant, 5 invertebrate, 5 fish, 2 amphibian, 1 reptile, 8 bird, and 11 mammal species. Of these taxa, 1 invertebrate (Kanab ambersnail, KAS, *Oxyloma haydeni kanabensis*), 4 fish, and 3 birds are presently federally listed as endangered (23.5%); however, only 2 species (5.9%) are intensively monitored by the AMWG program (HBC, KAS), while SWWF, peregrine falcon, Mexican spotted owl (*Strix occidentalis lucida*), and California condor are monitored in GRCA but the results of that monitoring activity is not incorporated into AMWG considerations of CRE management. Several federally endangered species have been extirpated from large portions of their historic ranges including all of the CRE, most notably the native fishes. The 2 leopard frog species (*Rana* spp.), as well as bald eagle (*Halaieetus leucocephalus*), and yellow-billed cuckoo (*Coccyzus americanus*) are federally or state threatened (8.8%). Thus, 10 (29.4%) of at least 34 extirpated or at-risk species are federally listed and therefore have some form of legal protection, whereas at least 24 (70.6%) of the extirpated or at-risk CRE species are not strongly legally protected, and have not attracted the management attention of CRE stewards. Several missing or declining species that are not federally listed as endangered (e.g., Colorado River otter) normally play important roles in river ecosystem function (GCWC 2005). In the following section, we describe each of the following groups of extirpated or at-risk CRE species: federally endangered taxa, federal- or state-listed threatened taxa, and non-listed taxa.

Extirpated or At-risk Endangered Species

Kanab Ambersnail: KAS population occurs naturally only at Vaseys Paradise Springs in the Colorado River in GRCA, where it remains the focus of considerable taxonomic and ecological debate (Spamer and Bogan 1993). Although this taxon likely will be synonymized with *O. h. haydeni* on the basis of genetic analyses, it remains an endangered species, a highly restricted population, and therefore of concern in CRE management. The AGFD, NPS, FWS, and Upper Colorado River Basin Office of the Bureau of Reclamation partnered beginning in 1996 to translocate populations of KAS into remote, off-river tributaries in Grand Canyon, and the population in Royal Arch Creek has persisted. This effort alleviates a FWS Reasonable and Prudent Measure in Biological Opinions in 1996 and 1997 to find or create at least one off-river population of KAS (summarized by Sorensen 2005).

Humpback Chub: HBC has received most of the species management attention in the AMWG program because Grand Canyon supports the largest and most stable remaining breeding population of this endangered minnow species in the vicinity of the Little Colorado River (LCR). Intensive monitoring and non-native trout control programs (Coggins et al. 2006, Grand Canyon Monitoring and Research Center 2008) have provided better insight into long-term population trends, and *in situ* population augmentation in a reach of the Little Colorado River upstream from

the previously known range of HBC has been successfully undertaken by the U.S. Fish and Wildlife Service, adding to the in-LCR population (Sponholtz and Stone, unpublished 2004). Translocation efforts are underway bvy the NPS and collaborators at the time of this writing to stock HBC into Shinumo Creek in central Grand Canyon, a tributary population that may help ensure in-Canyon persistence of the species (GCWC 2008).

***Razorback Sucker (RBS; Xyrauchen texanus*):** RBS were previously widely distributed and highly migratory in the Colorado River, but have been extirpated from the CRE (Dowling et al. 1996, Mueller et al. 2000). RBS presently are being raised and restocked into lower Colorado River reservoirs, including golf course ponds. Restoration potential downstream from Grand Canyon appears to be relatively easy, although long-term persistence of this species may require continued stocking if non-native predator control efforts are not successful. Concurrence on the priority of RBS reintroduction among the NPS and Glen Canyon Dam Adaptive Management Workgroup stakeholders has not been seriously undertaken.

***Colorado Pikeminnow (CPM; Ptychocheilus lucius*):** CPM were the largest native predatory fish in the pre-dam Colorado River that apparently underwent annual migrations through much of the Colorado River (Sigler and Sigler 1996). Breeding populations are now restricted to the upper Colorado River basin. It is a large, ichthyvorous species, and restoration of its population may negatively affect endangered HBC populations. Therefore, CPM restoration in the CRE will much dialogue among the fish managing agencies involved in CRE management, particularly the NPS, Arizona Game and Fish Department (AGFD), and the U.S. Fish and Wildlife Service (FWS). Interactions among HBC and CPM have not been studied in detail.

***Bonytail Chub (BTC; Gila elegans)*:** BTC were previously known from near Glen Canyon Dam and Lake Mead, but due to recruitment failure, the natural population in the lower Colorado River appears to be approaching functional extinction. Restoration or reintroduction of BTC generally has not been considered because of the great potential for hybridization within the genus *Gila*. Douglas and Douglas (2006) analyzed *Gila* genetics, concluding that the Grand Canyon population was distinct, but showed some intergradation with other *Gila* species. Therefore, introduction of other *Gila* species into Grand Canyon is contraindicated, as it is likely to threaten the integrity of the Grand Canyon HBC population.

***California Condor (Gynogyps californianus)*:** Although external to the AMWG program, reintroduction of endangered California condor into the Grand Canyon region has been remarkably successful, and several GRCA nests have successfully fledged young (Alagona 2004). Occupation and use of the CRE by condors is opportunistic, however, external restoration efforts have restored an important top scavenger into the river ecosystem. Management of condor-human interactions has proven challenging because condors are naturally attracted to mammal activity.

Southwestern Willow Flycatcher: SWFL has been extirpated from its historic range in Grand Canyon, as a result of both extra-CRE factors and increased brown-headed cowbird (*Molothrus ater*) populations (Brown et al. 1992; review in Paxton et al. 2007). Although SWFL occupies earlier successional stages of riparian habitat, effective conservation of SWFL could provide effective umbrella coverage of the more than two dozen other neotropical migrant birds that nest

in the Grand Canyon riparian zone. Many of those neotropical species also are negatively affected by cowbird brood parasitism. While the loss of SWFL from Grand Canyon has increased protection of early seral riparian habitat, it has not encouraged ecosystem managers to reduce cowbird populations, an action likely needed to protect the many other neotropical migrant bird species in the CRE.

Mexican Spotted Owl (MSOW; Strix occidentalis lucida): MSOW occasional occur in the CRE, coming down from their normal ranges at the back of nearly every large tributary in central Grand Canyon. MSOW have been observed and photographed at the mouths of tributaries such as Shinumo Creek and National Canyon (LES files). Although apparently incidental in the CRE, the high density of riparian rodents may attract this species; however, the extent of their occurrence in the CRE is largely unknown.

Other Incidentally-Occurring Listed Species: Several other listed species occur or may occur on an accidental basis in the CRE, including: endangered brown pelican (BRPE; *Pelicanus occidentalis*) and formerly proposed mountain plover (*Charadrius montanus*). The occurrence of these species is poorly known, but persistent records at least of BRPE indicate that it occurs accidentally in Glen and Marble canyons (Brown et al. 1987; Stevens et al. 1997a).

Extirpated State or Federal Threatened Species

Relict Leopard Frog (RLF, Rana onca): A single population of relict leopard frog (*Rana onca*) has been detected in lower Grand Canyon at Surprise Canyon (Colorado River Mile 248R; Brennon and Holycross 2005). This population has been documented within the 100-year flood stage of the Colorado River, but has not been detected there in recent surveys.

Northern Leopard Frog (NLF, Rana pipiens): Northern leopard frog (*Rana pipiens*) occurred at Cardenas Creek (Colorado River Mile 71L; Tompko 1976 in Miller et al. 1981) and at -9 Mile Marsh upstream from Lees Ferry (Brennon and Holycross 2005). It has apparently been extirpated from Cardenas Marsh, and its status at -9 Mile Marsh is uncertain. A population also was detected at Hidden Sloughs (-6.5R) in the early 1990's but was suspected to have been introduced there, and has not persisted (LES unpublished data).

***Bald Eagle (BAEA; Haliaeetus leucocephalus)*:** Although now downlisted from the endangered species list, BAEA are still protected under the 1940 Bald Eagle Protection Act, and therefore continue to be a species of management concern in the CRE. Wintering BAEA colonized Grand Canyon in large numbers beginning after 1982, and were regularly reported until the mid-1990' (Brown et al. 1989), and were affected by human disturbance and dam operations (Brown and Stevens 1997, Brown et al 1998). Recent CRE monitoring data on CRE bald eagles over the past decade are not known to us.

***Peregrine Falcon (PEFA; Falco peregrinus)*:** Although now delisted from the ESA, peregrine falcon has become a common top predator in the CRE (Brown et al. 1992, Stevens et al. 2009). Its population is being monitored by the National Park Service, but population trends, if any, are not clear.

Yellow-billed Cuckoo (YBCU; Coccyzus americanus): Listed as a federally threatened species, YBCU requires gallery riparian forest, and therefore it is a species not well-protected by protection of endangered SWFL, which requires relatively early seral successional riparian vegetation (Layman and Halterman 1987, Brown et al. 1987). It was known only in the CRE from a few reports in the Lees Ferry area.

***Plains Gray Wolf* (*Canis lupus youngi*):** Wolves were extirpated from the region by 1945 (Rasmussen 1941, Hoffmeister 1986); however, John D. Lee reported seeing wolves on the south (left) bank of the river at Lees Ferry early in his tenure as ferryman there (Brooks and Cleland 2004). Wolf restoration is being discussed in the region; however, the subspecies often suggested for restoration is the Mexican wolf (*C. l. baileyi*). Hoffmeister (1986) explicitly states that this subspecies did not occur on either the south or north rims of Grand Canyon. Introduction of Mexican wolf north of the Colorado River may threaten the genetic integrity of the plains gray wolf farther north, and is contraindicated.

Extirpated or At-risk, Non-endangered Species

Extirpated species that are not federally listed make up the majority of those lost or presently at-risk from the CRE in post-dam time. The following list is not exhaustive, but represents a number of ecologically important taxa that have not previously been recognized as at-risk in the CRE.

Plants: Although no native plant species has been fully extirpated from the CRE to our knowledge, the persistence of Goodding's willow trees (*Salix gooddingii*) in the CRE is unlikely. No recruitment has been detected in recent decades, and the burgeoning beaver (*Castor canadensis*) population in the mainstream has removed most of the pre-dam trees (Mast and Waring1997, Mortenson et al. 2008). A recent survey by Grand Canyon GCWC (2009) indicates that Goodding's willow have been eliminated from 8 of 17 (47.1%) sites between Lees Ferry and Diamond Creek where the tree occurred prior to the closure of Glen Canyon Dam. At most sites, trees were felled by beaver and continued beaver attack removed resprouting stems until the trees perished.

Fremont cottonwood (*Populus fremontii*) was relatively rare in the pre-dam CRE, but with documented individuals occurring at Lees Ferry and near Mile193L (Clover and Jotter 1944, Turner and Karpiscak 1980). This species shares a similar fate with Goodding's willow and cottonwood recruitment requirements are similar to those of the willow. Although more cottonwood seedling are detected along the river, establishment is failing because, like Goodding's willow and coyote willow (*Salix exigua*), virtually all individuals that recruit or become established are attacked or removed by beaver. All three of these Salicaceae species are renowned as ecologically important species in southwestern rivers, diversifying canopy and subcanopy structure and supporting high concentrations of neotropical migrant birds. The disappearance or absence of these species exerts strong influences on CRE riparian invertebrate and neotropical bird assemblage composition.

Honey mesquite (*Prosopis glandulosa* var. *torreyana*) is abundant on pre-dam terraces in from Mile 39 to 140 and from Mile 160 to Lake Mead, were it makes up a large portion of the now relict pre-dam riparian vegetation zone (Carothers et al. 1979, Anderson and Ruffner 1989). While the species has colonized the lower riparian zone in post-dam time, recruitment in the upper riparian zone (where it has historically has been the dominant species downstream from

Colorado River Mile 39) appears to be failing. A recently initiated study by GCMRC may soon reveal more about its recruitment status and process.

Like the other dominant riparian tree species mentioned above, netleaf hackberry (*Celtis laevigata* var. *reticulata*) does not appear to be recruiting successfully in Grand Canyon. Individual stems of this clonal species in the CRE may date back to 1776 (Salzer et al. 1996); however, most existing clones appear to be decadent and few if any seedlings have been reported in post-dam time. This species appears to be rather tightly restricted to the 2-year flood return stage for the pre-dam river, and does not appear to be colonizing the lower riparian zone. Therefore may be of interest for monitoring and potential restoration.

Numerous other non-listed native plants are rare in the CRE riparian zone, including many first-records for the state of Arizona (e.g., Ayers and Stevens 1994, Ayers et al. 1994); however, a determination of which of those species may be of conservation concern will require a detailed analysis that is beyond the scope of this review.

Invertebrates: Several previously documented or reported butterfly species now are either extremely rare or have been extirpated from the CRE, including: viceroy butterfly (*Limenitis archippus*; Garth 1950, L.E. Stevens unpublished data), and dark buckeye (*Junonia genoveva nigrosuffusa;* L.E. Stevens unpublished data).

Vertebrates: Non-listed extirpated, seriously declining, or rare and apparently at-risk vertebrate species in the CRE include many species, of which several ecologically important taxa are described here.

1) The only population of zebra-tailed lizard (ZTL; *Callisaurus draconoides*; Stevens et al. 2001, Brennon and Holycross 2005) in the CRE was apparently extirpated in 1983 when river-runner trucks conducting take-outs were redirected onto the upper dunes at Diamond Creek. ZTL still occur farther up the Peach Springs Wash drainage, and a population could relatively easily be reintroduced to the mouth of Diamond Creek.

2) Western blind snake (*Leptotyphlops humilis*) is only known from 3 records in the CRE (Stevens 1983, Brennon and Holycross 2005). All records of this species are from the CRE riparian zone, usually in sand dune habitats. The status of this species is unknown.

3) Muskrat (*Ondatra zibitheca*; Hoffmeister 1986; Stevens 1983; Stevens et al. 2001; NPS files) have been reported several times from the post-dam Colorado River corridor in Grand Canyon, and a skull was reported from Tapeats Creek in the 1990's. Additional evidence of this species' presence was detected after 2000 near Mile 77R. This is presently at least a rare species in the CRE, if it still exists there.

4) Colorado River otter (*Lontra canadensis sonora*; Hoffmeister 1986; GCWC 2005; NPS files) is probably extince. Although several reports of otter in the CRE exist from prior to 2000, repeated searches over 20 yr have failed to document live individuals. If a resident population of Colorado River otter still exists, the introduction of other otter subspecies in upper Colorado River drainages and the Verde River has likely sealed its fate because of hybridization (Stevens et al. 2001). GCWC (2005) conducted an analysis of the potential for otter reintroduction into GRCA to restore the missing ecological role of this top mammalian fish predator in the CRE;

however, interagency concerns over potential impact on HBC have been voiced and need to be resolved for otter reintroduction to be conducted.

5) Badger (*Taxodea taxa*) (Stevens unpublished data) were last reported to us in the winter of 1991 by N. Kline at Hidden Sloughs (Colorado River Mile -6.5R). Similarly, the status of other carnivore species, such as spotted skunk (*Spilogale gracilis*), bobcat (*Lynx rufus*), and mountain lion (*Felis concolor*), and as well as other carnivores, is poorly known and not regularly monitored if at all.

7) In addition, the population status of other rare, native CRE species remains uncertain, with many species known in GRCA from only 1-3 specimens or observations each.

6) The native status of painted turtle (*Chrysemys picta*), now an extremely rare species, is uncertain: photographs and verbal accounts demonstrate that it occurred in Glen Canyon and possibly Lees Ferry on the mainstream Colorado River prior to 1960 (T. Nichols and S. Johnson, pers. commun.), where it has been extirpated; however, those observations may have involved feral animals. Similarly, Gambel's quail (*Callipepla gambelii*) were detected up until the early 1990's along the lower CRE (Brown et al. 1987, L.E. Stevens field notes), but have not been reported recently. This species also may have been introduced into the CRE, but more information would be useful, as it was previously abundant on the South Rim (Brown et al. 1987).

8) Although not federally listed except as a migratory bird species, white pelican (*Pelecanus erythrorhynchos*) regularly passes through Grand Canyon during the migratory period (April and October; Stevens et al. 1997a). Single birds or small flocks are regularly reported, and flocks in excess of 200 birds have been sighted (LaRue et al. 2001). Although not presently listed, concern about range connectivity for this species may result in increased conservation status in the future (e.g., Anderson and King 2005).

DISCUSSION

Trophic Status of Extirpated Species

The CRE is a complex suite of wide or narrow reaches that cycles and changes across time and in response to flow regime (Fig. 2). Analysis of the trophic status of extirpated and at-risk species in the CRE reveals that species that have recently been the focus of most management attention (i.e., KAS, HBC, and SWFL) occupy lower and middle trophic positions. While this suite of focal species represents aquatic, wetland, and riparian habitats, much variation in species presence and role within those habitats, limits the usefulness of the monitored species in understanding ecosystem change. In addition, the top predators in the CRE have not received sufficient conceptual or monitoring attention, and trophic linkage above the level of fish remains poorly understood. Therefore, additional attention to the conceptual ecosystem model for the CRE is warranted. The recent effort by GCMRC to update the Walters et al. (2000) conceptual ecosystem model may improve understanding of which species and processes are most appropriate for monitoring.

Setting Restoration Priorities

The relatively high uncertainties and costs associated with restoration of extirpated species require that ecosystem stewards formulate prioritization strategies. Such an effort requires adequate information on administrative context and responsibilities (including compliance framework and costs), as well as basic information on extirpated species' ecological roles, life histories, available and appropriate stock, reintroduction timing, and monitoring. While missing listed species have traditionally been considered as the highest priority for reintroduction and population restoration, the question of whether, how and when to restore other extirpated or at-risk endangered or non-listed species remains unaddressed. Major information gaps exist with regards to peer-reviewed information on the distribution and present status of some listed extirpated or at-risk species, as well as many species of the non-listed taxa. For example, the importance and phenological timing of imprinting on spawning habitat stream waters among young native fishes remains an important but largely unaddressed issue that is highly relevant to fish translocation and reintroduction efforts. Such information may play an important role in the planning and implementation of population reintroduction and restoration actions.

Species Translocation or Reintroduction in the Grand Canyon Region

Reintroduction of native species, and the establishment and translocation of both native and non-native species has a lengthy history in the Grand Canyon region. Federal management of the North Rim early in the 20th Century involved widespread elimination of upland predators, actions that may have had large impacts on ecosystem structure (Rasmussen 1941). Economically important native and non-native taxa have been widely and successfully introduced into the Grand Canyon region, including: non-native tamarisk, Russian olive, and other invasive plant species were intentionally introduced into the Colorado River basin for erosion control and ornamental purposes, and are now widely established; rainbow and brown trout were released by the NPS shortly after the establishment of Grand Canyon National Park (GRCA), and at least 17 other non-native fish species have become established; wild turkey and bighorn sheep have been introduced onto the Arizona Strip since the 1940's; pronghorn were unsuccessfully introduced onto the Tonto Platform in Grand Canyon in the 1940's (Brown et al. 1987; Lavender 1976); Rocky Mountain elk were introduced into northern Arizona, following decimation of native (and now extinct) Merriam's elk (Hoffmeister 1986); large quantities of many non-Grand Canyon aquatic invertebrate species were released by the Arizona Game and Fish Department (AGFD) into the tailwaters of the newly constructed Glen Canyon Dam in the mid-late 1960's; and buffalo x cattle hybrids ("beefalo") recently have been allowed to invade North Rim habitats. Most of Grand Canyon's ecosystems have been affected by these introductions or translocations.

Restoration or augmentation of ecological functions provided by some native predators and scavengers also has been undertaken: pesticide control and the release of numerous peregrine falcons (*Falco peregrinus anatum*) into Colorado in the early 1980's has led to Grand Canyon having the largest breeding population of this previously federally listed top predator of any single land management area in the lower 48 states (Brown et al. 1992; Stevens et al. in press). Eastern river otters (*Lontra canadensis* ssp.) have been translocated into the upper Colorado River and Verde River drainage in Arizona, restoring their contribution to ecosystem function (GCWC 200_). Restoration of endangered California condor (*Gymnogyps californianus*) generally has been successful; however, Meretsky et al. (2000a) question cast doubt on the success of California condor reintroduction because of susceptibility of these birds to lead poisoning, an issue that has lead to a proposed ban on lead shot. Endangered Kanab

ambersnail were introduced into upper Royal Arch Creek in 1997 and subsequently by AGFD and the NPS, to ensure the existence of a refuge population if dam operations negatively affected snail habitat, and that translocation has been successful up to the present time.

Fish Range Restoration

The natural ranges of all Grand Canyon native fish has contracted in post-dam time, and HBC is absent from the upstream reaches where it was formerly abundant. In pre-dam time the mouths of low-gradient tributaries, such as the Paria and Little Colorado Rivers, ponded for several to many kilometers, creating large, shallow, clear-water nursery habitats, in which most native fish species occurred. This has been corroborated by discussion with S. Johnson and others who were pre-dam residents of Lees Ferry. As a boy, he reported hunting and fishing through the lower Paria River drainage, and catching all of big river native fish species there in considerable abundance when the Paria River ponded because of mainstream early summer flooding. Conversations with the late Wendell Minckley also confirmed that HBC were abundant at the mouth of the Paria River immediately following closure of Glen Canyon Dam.

Based on these discussions, GCWC has proposed but not yet found funding for the construction, stocking, and monitoring of fish rearing ponds in the gravel pits near the mouth of the Paria River. Such an action would restore ponded tributary mouth habitat, a habitat type that has been lost from the post-dam Grand Canyon because of flood control. Such a facility could be used to restore the ranges of at least HBC and RBS, and perhaps CPM. Such a recommendation has been positively received by the Tehnical Work Group of the AMWG, as it would: 1) return those species to a historically important tributary and mainstream reach within their natural range; 2) be an efficient, cost-effective, and convenient process from a logistical and monitoring standpoint; and 3) serve as an important field experimental site at which to learn more about *in situ* fish population restoration. However, no action has yet been taken on this topic.

Exotic Species

The total number of non-native taxa in the CRE likely exceeds 300 species (see Table 2 and references therein). The list of non-native species is strongly dominated by more than 200 species of plants, several of which strongly preempt colonization space, increase fire frequency, and affect food resources and pollinator populations (e.g., *Tamarix* spp., *Bromus* spp.). Several dozen non-native inverterate taxa have been detected in the CRE, including: important fish parasites (e.g., Asian tapeworm, *Bothriocephalus acheilognathi; and* anchorworm, *Lernaea cyprinacea*; Hoffnagle and Cole 1999); important food species for fish (e.g., *Gammarus lacustris*) and birds (e.g., tamarisk leafhopper, *Opsius stactogalus*); nuisance species (e.g., New Zealand mudsnail, *Potomopyrgus antipodarum*); and non-native predators (e.g., *Procambarus* or *Orconectes* crayfish in lower Grand Canyon, *Anatis lecontei* ladybird beetle). Among CRE vertebrates, approximately 19 non-native fish species have been detected in the Colorado River in recent decades, with salmonids reportedly responsible for declines in native fish (Marsh and Douglas 1997).

Non-native species and some native populations that have proliferated in post-dam time strongly affect ecosystem form and function in the CRE. Interactions among these species must be considered in planning the restoration of native populations. Several examples obtain:

1) Non-native rainbow trout (RBT) removal around the Little Colorado River confluence may be partially responsible for stabilizing the previously declining breeding population of endangered HBC.
2) Translocation of HBC into Shinumo Creek (CR Mi. 109R) is being undertaken following extensive attempts at the removal of RBT; however, robust populations of native fish co-exist with RBT in that stream, suggesting that native and nonnative species can coexist in some settings (GCWC 2008).
3) Large Goodding's willow trees commonly co-occur with non-native tamarisk, and the willow has largely been lost to beaver foraging (the beaver population in Grand Canyon is likely much larger than in pre-dam time; Mortenson et al. 2008). Therefore, successful restoration of Goodding's willow stands requires both elimination of tamarisk and protection of plantings from beaver.
4) WIFL in the CRE preferentially nest in non-native tamarisk, a common phenomenon throughout Arizona. In part, the extirpation of this species from Grand Canyon was attributable to brood parasitism by native brown-headed cowbird (*Molothrus ater*) brood parasitism. Does WIFL restoration require maintenance of suitable stands of tamarisk from which cowbirds are excluded?
5) The upstream movement of non-native crayfish (*Procambarus, Oronectes*) from Lake Mead, and the potential for downstream dispersal from Glen Canyon and headwater tributaries south of Grand Canyon is one of the most serious threats to Grand Canyon's >4 dozen perennial tributaries. These are some of the West's only remaining largely pristine streams, and are important natural laboratories and sentinel sites for understanding stream-riparian ecosystem ecology and restoration.
6) Introduction of *Dressina* mussels in the lower Colorado River almost certainly will be followed by invasion into upper basin streams and reservoirs. The impacts of this mussel on the CRE and Grand Canyon tributaries are unknown, but may strongly affect river ecosystem structure and function.

Thus, consideration of potentially complex interactions among native and non-native species is required when planning species restoration actions in the CRE.

Reintroduction Planning, Compliance, and Implementation

Reintroduction of one or more extirpated CRE species requires several phases of effort, including: a) developing an administrative context; b) compiling relevant information, stock assessment, and prioritization, c)compliance, e) implementation, and f) monitoring and feedback.

a) Administrative oversight for reintroduction is complex. The National Park Service has direct oversight of natural and cultural resource management of the CRE (U.S. Department of the Interior 2006: 45); however, several agencies advise and assist the NPS on management of Grand Canyon plant and wildlife species, including: individual National Park Service units; the U.S. Fish and Wildlife Service; several Native American Indian tribes; the Bureau of Reclamation; the U.S. Geological Survey, the State of Arizona, particularly the Arizona Game and Fish Department; and various other cooperating stakeholders in the Glen Canyon Dam Adaptive Management Work Group (AMWG). Each of these entities has its own mission, and differences in management focus are the norm, making reintroduction of some extirpated species more difficult. While the administrative context for reintroduction of extirpated species is

explicit in the policies of the National Park Service and in the AMWG (Goal 3), neither organization has undertaken or strongly recommended a reintroduction effort in recent time. Therefore, the first step in reintroduction is to have clearly defined interagency agreement on the effort.

b) The second step in a reintroduction program is to fund compilation of information on the ecology, life history, diseases and parasites, status of remaining populations as potential stock, reasons for extirpation, trophic role(s), relationships to other species, and other information on the known extirpated species in the CRE. This information needs to be evaluated in a matrix approach to allow the CRE managing agencies to clearly prioritize which species should be reintroduced first, and where such reintroduction efforts should be conducted. The prioritization process should include consideration of all aspects of reintroduction, including: legal and managerial justification, availability and genetic suitability of stock, potential socio-ecosystem effects, reintroduction planning, risk and contingency planning, logistics, monitoring, reporting, feedback related to improvement of techniques, and project costs.

c) More detailed stock assessment is needed to guarantee, to the greatest extent possible, that the reintroduced stock is the most fit and genetically the most capable of surviving the translocation process and proliferating in the renewed landscape. Also, it is important to determine the level of population take that an existing native species can withstand and still remain functional.

d) Compliance requirements for species translocation, augmentation, or reintroduction differ and overlap to various extents among the several stakeholders with wildlife management responsibilities in the CRE. NPS compliance requirements for such activities include attention to autecological (stock source), synecological, cultural, other tribal, recreational, natural quiet, and other resource impacts, in accordance with National Environmental Policy Act and the Code of Federal Regulations. U.S. Fish and Wildlife Service reintroduction requirements involve consideration of Section 7 of the 1973 Endangered Species Act (as amended). Wildlife reintroduction actions by the AGFD involve their 12-step program. All of these agencies generally have interacted in proposing and accomplishing previous translocation, augmentation, or reintroduction projects in the region (e.g., KAS, California condor).

CONCLUSIONS

Ecosystem management requires adequate understanding of the ecological role of and potential for restoration of, extirpated species and processes. Understanding the feasibility and advisability of restoration of extirpated species is mandated through Goal 3 of the AMWG mission, and also is mandated by the wildlife managing agency stakeholders, most notably the National Park Service. In the above paper, we discuss filling information gaps about missing species and the compliance requirements of AMWG cooperating agencies that may be needed to partner in reintroduction efforts, specifically those of the National Park Service, the Fish and Wildlife Service, and the Arizona Game and Fish Department. AMWG is uniquely poised to undertake the technical and social mechanisms needed to address Goal 3. Evaluation of the potential for reintroduction of extirpated species will require more thorough conceptual ecosystem modeling and discussion among well-informed ecosystem stewards, and partnerships among AMWG stakeholders. We present the above information as background for a draft motion

to the AMWG and the Secretary of the Interior on AMWG Goal 3, to be discussed and refined at the springtime 2009 AMWG meeting:

"In recognition of GCDAMP Goal 3 and towards management of the Colorado River through an ecosystem approach, AMWG recommends that the Secretary of the Interior direct GCMRC to work with the TWG to review information and assess the status, habitat needs, ecosystem roles, and recommend options for improved stewardship, including re-establishment / reintroduction, of extirpated species and other species of management concern in the CRE. AMWG requests this information by the end of FY 2011."

We further recommend that AMWG direct that this more thorough examination be conducted for $50,000. A more thorough examination of the status and ecological roles of extirpated and at-risk species in the CRE will greatly improve the scientific understanding and integrated adaptive management of this globally recognized ecosystem.

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Table 1: List of extirpated and at-risk species in the CRE, and rare species of unknown status and/or nativity.

Common Name	Species Name	Status in CRE	Ecological Role	Quality of Information Confirming Status in CRE	References
Northern Leopard Frog (NLF)	*Rana pipiens*	Extirpated	Predator	High	Tompko 1976
Relict Leopard Frog (RLF)	*Rana yavapaiensis*	Extirpated	Predator	High	LES files, USGS files
Yellow-billed Cuckoo (YBCU)	*Coccyzus americanus*	Extirpated	Insectivore	Moderate	Brown et al. 1987, LaRue et al. 2001
SW Willow Flycatcher (SWWF)	*Empidonax trailii extimus*	Extirpated	Insectivore	High	Brown et al. 1987, LaRue et al. 2002
Bald Eagle (BAEA)	*Haliaeetus leucocephalus*	Not monitored	Predator, scavenger	High	Brown et al. 1987, 1998; Brown and Stevens 1997
Prairie Falcon (PRFA)	*Falco mexicanus*	Not monitored	Top predator	Low	Stevens et al. in press, NPS files
Peregrine Falcon (PEFA)	*Falco peregrinus*				
California Condor (CACO)	*Gymnogypes californianus*	Reintroduced	Scavenger	High	Brown et al. 1987, LaRue et al. 2001; NPS and Peregrine Fund files
Wild Turkey (WITU)	*Meleagris gallopavo* *	Occasional colonist	Herbivore/ omnivore	Moderate	Brown et al. 1987, LaRue et al. 2001
Mexican Spotted Owl (MXSO)	*Strix occidentalis lucida*	Occasional in lower tributaries	Predator	Moderate	Brown et al. 1987, LaRue et al. 2001
Waterbirds ~ 70 species, including Brown Pelican	All	Unknown	Herbivores, predators	Moderate	Brown et al. 1987, Stevens et al. 1997; LaRue et al. 2001; NPS files
A Chironomid Midge (MEST)	Metrocnemis stevensi	Undetermined	Herbivore	Medium	Sublette et al. 1998
Humpback Chub (HBC)	*Gila cypha*	Stablized popuulation	Mid-trophic predator	High	Minckley 1991
Bonytail Chub (BTC)	*Gila elegans*	Extirpated	Mid-trophic predator	Moderate	Minckley 1991

Roundtail Chub (RTC)	*Gila robusta*	Extirpated	Mid-trophic predator	Moderate	Minckley 1991
Colorado Pikeminnow (CPM)	*Ptychocheilus lucius*	Extirpated	Top predator	High	Minckley 1991
Razorback Sucker (RBS)	*Xyrauchen texanus*	Extirpated	Detritivore	High	Minckley 1991
Kanab Ambersnail (KAS)	*Oxyloma haydeni kanabensis*	ES; to be delisted?	Decomposer, parasite host	High	Spamer and Bogan 1994, AGFD 2009
Vulcan's Well waterbug (BEFL)	*Belostoma* nr. *flumineum*	Undetermined	Predator	Medium	Stevens and Polhemus 2008
A Saldid Shorebug (MIQU)	*Micracanthia quadrimaculata*	Undetermined	Predator	Medium	Stevens and Polhemus 2008
Many species	---	Undetermined	Many	Variable	Blinn and Cole 1991, Stevens et al. 1998
Viceroy Butterfly (VBF)	Limenitis archippus	Extirpated?	Herbivore, pollinator	Medium	LES files
Bats ~ 20 species	All	Unknown	Insectivores and frugivores	Low	Hoffmeister 1986, NPS files
Feral Ass (FEAS)	*Equus asinus*	Nearly extirpated	Herbivore	High	Carothers et al. 1979
Mountain lion (MtnL)	*Felis concolor*	Undetermined	Predator	Moderate	Hoffmeister 1986, Stevens 1983, NPS files
Colorado River Otter (CRO)	*Lontra canadensis sonora*	Extinct?	Predator	Moderate-high	Hoffmeister 1986; GCWC 2005; NPS files
Bobcat (Bobc)	*Lynx rufus*	Undetermined	Predator	Low	Hoffmeister 1986, Stevens 1983, NPS files
Muskrat (MR)	*Ondatra zibethica*	Undetermined	Herbivore	Moderate	Hoffmeister 1986, Stevens 1983, NPS files
Northern Grasshopper Mouse (NGM)	*Onychomys leucogaster*	Undetermined	Predator	Low	Hoffmeister 1986, Stevens 1983, NPS files
Deer Mouse (DM)	*Peromyscus maniculatus*	Undetermined	Omnivore	Low	Hoffmeister 1986, Stevens 1983, NPS files
Western Harvest Mouse (WHM)	*Rheithrodontomys megalotis*	Undetermined	Herbivore	Low	Hoffmeister 1986, Stevens 1983, NPS files
Spotted skunk (SpSk)	*Spilogale spilogale*	Undetermined	Predator	Low	Hoffmeister 1986, Stevens 1983, NPS files

Badger (BDGR)	*Taxodea taxa*	Unknown	Predator	Low	LES files
Fremont Cottonwood (POFR)	*Populus fremontii*	Declining?	Cornerstone	Low	Turner and Karpiscak 1980
Goodding's Willow (SAGO)	*Salix gooddingii*	Declining	Bird, beaver, insect habitat	Medium	Clover and Jotter 1944, Phllips et al. 1987, LES files
Zebra-tailed Lizard (ZTL)	*Callisaurus draconoides*	Extirpated	Terr. predator	High	Tompko 1976, Miller et al. 1982, LES files
Species of Unknown	**Status or Nativity**				
Painted Turtle (PT)	*Chrysemys picta*	Native, Extirpated?	Predator	Low	T. Nichols photos, S. Johnson pers. comm.
Brown Pelican (BRPE)	*Pelicanus occidentalis*	Rare migrant	Predator	Low	Brown et al. 1987
Turkey Vulture (TUVU)	*Cathartes aura*	Not monitored	Scavenger	Low	Brown et al. 1987
Mountain Plover (MOPL)	*Charadrius montanus*	Rare migrant, at best	Predator	Low	Brown et al. 1987, LaRue et al. 2001
Gambel's Quail (GAQU)	*Calipepla gambelii*	Missing in lower GC	Herbivore	Low	Brown et al. 1987, LES unpublished data
Roadrunner (RR)	*Geococcyx californianus*	Undetermined	Predator	Low	Brown et al. 1987. LES unpublished data
Arizona Wetsalts Tiger Beetle (CIHA)	*Cicindela haemorrhagica arizonae*	Undetermined	Predator	Medium	Stevens and Huber 2004
LCR Hairy-necked Tiger Beetle (CIHC)	*Cicindela hirticollis coloradula*	Undetermined	Predator	Medium	Stevens and Huber 2004, Pearson et al. 2006
Gray Wolf (GW)	*Canis lupus youngi*	Extirpated	Terr. predator	Low	J.D. Lee diary, Rasmussen 1941, Hoffmeister 1986
Netleaf Hackberry (CELA)	*Celtis laevigata var. reticulata*	Declining?	Cornerstone	Low	Salzer et al. 1996

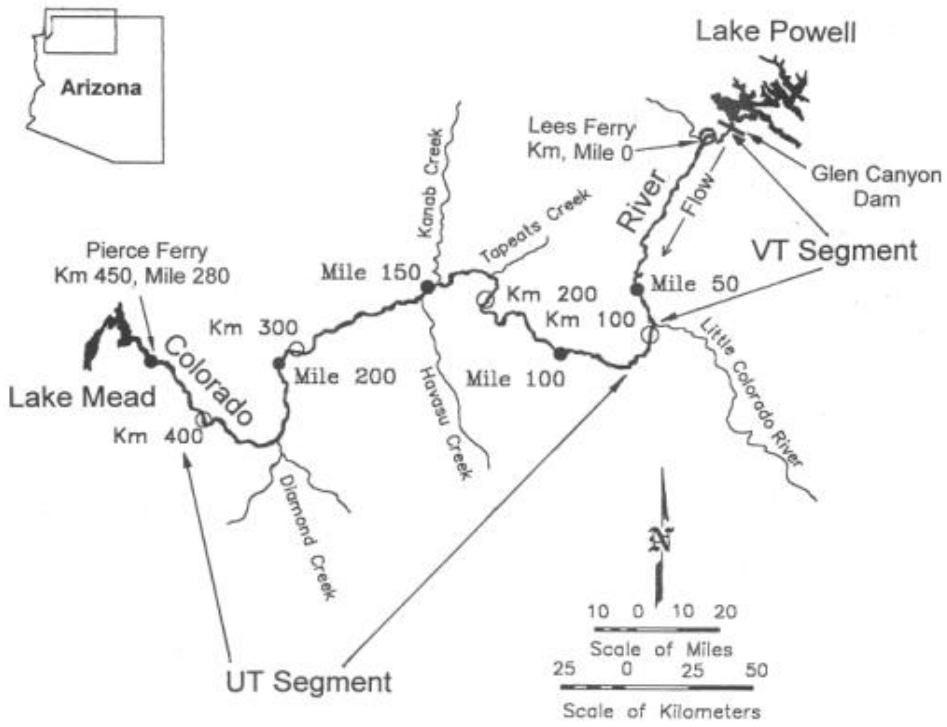

Fig. 1: Map of the Colorado River ecosystem between Glen Canyon Dam and Lake Mead, Arizona.

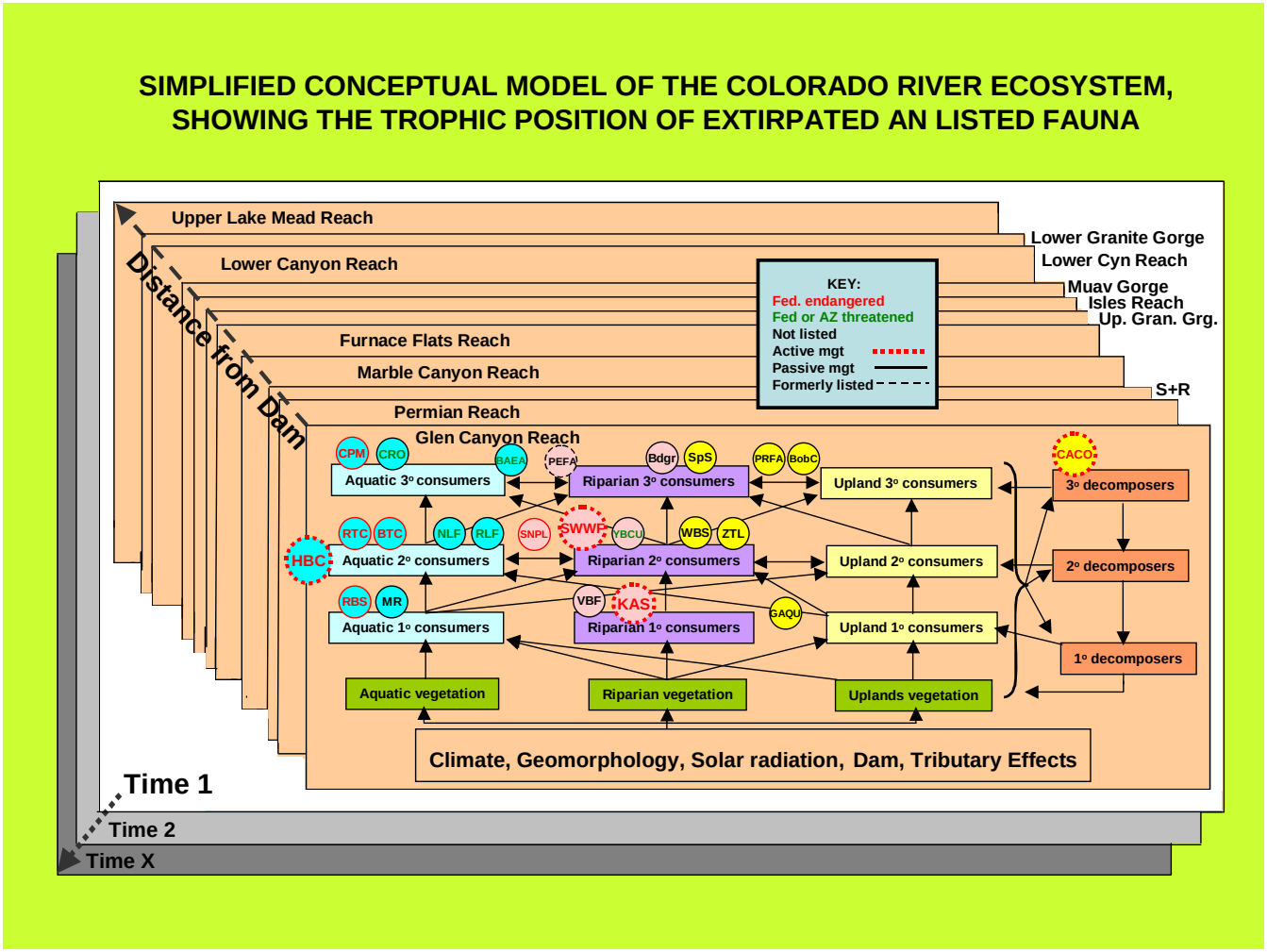

Fig. 2: The Colorado River ecosystem, depicting four trophic levels affected by the dam and physical factors, through the geomorphic reaches of the river and over time. The relationships of some extirpated and at-risk species are depicted within their trophic levels as circles. Abbreviations for species are found in Table 1. Most management attention is focused on CACO, HBC, KAS, and SWWL (large circles), but other endangered (red text), threatened (blue text), and non-federally listed (black text) species also occurred in the CRE or appear to be at-risk of extirpation there.