The Effect of Controlled Floods on the Lower Aquatic Communities in the Grand Canyon

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ABSTRACT

Glen Canyon Dam on the Colorado River has induced many changes in the physical and biological processes in the river. For the past decade, managers have tried to restore some of the important biological processes in the canyon by instituting an adaptive management strategy of controlled periods of high release from Glen Canyon Dam. These "controlled floods" are a large perturbation to the river system and have radical effects on the all of the organisms associated with it. This paper discusses the effect of the controlled floods on the aquatic food base, which includes algae, plants, zooplankton and macroinvertebrates. The Grand Canyon is also home to one of two remaining populations of the endangered Kanab Ambersnail. The controlled flooding has potentially detrimental consequences for their continued persistence as their habitat is within the high water zone. Additionally, the invasive New Zealand Mud Snail has recently colonized the tail waters of Glen Canyon Dam. This snail's presence is altering the entire food web in the Grand Canyon and could further imperil the status of the native fish in the river, most of which are threatened or endangered.

Introduction

Regulated rivers exhibit profound changes in the physical processes that govern their structure and function. These changes alter the complex biological communities associated with rivers, especially by changes in the number and type of species present. The lowest levels of the food web are made up of primary producers, detritus and lower faunal organisms such as zooplankton and micro- and macro-invertebrates (Shannon et al. 2001). The primary producers in a system are organisms such as algae, cyanobacteria, diatoms, and macrophytes (large vascular plants) that transform solar energy into stored starch that is available to other organisms as food. Detritus consists of organic material derived from decomposing plants, animals and fish wastes. The animal portion of the food base consists of aquatic insects, zooplankton, aquatic worms, and mollusks that colonize and eat the primary producers. The aquatic food base is the fundamental resource that supports all of the vertebrate forms of wildlife within the system (Shannon et al. 2001). Nearly all of the wildlife in the Grand Canyon is either directly or indirectly linked to the aquatic food base including both native and non-native fish, insectivorous birds and bats, reptiles, waterfowl and a multitude of animals that feed on fish such as the Bald Eagles, Western Grebes, Kingfishers (Carothers and Brown 1991, Stevens et al. 1997a, Shannon et al. 2001). In this paper I will discuss how the aquatic food base responds to controlled flooding and is changing over time, the impact of the controlled floods on the endangered Kanab ambersnail, and the recent invasion of the Grand Canyon by the New Zealand mudsnail.

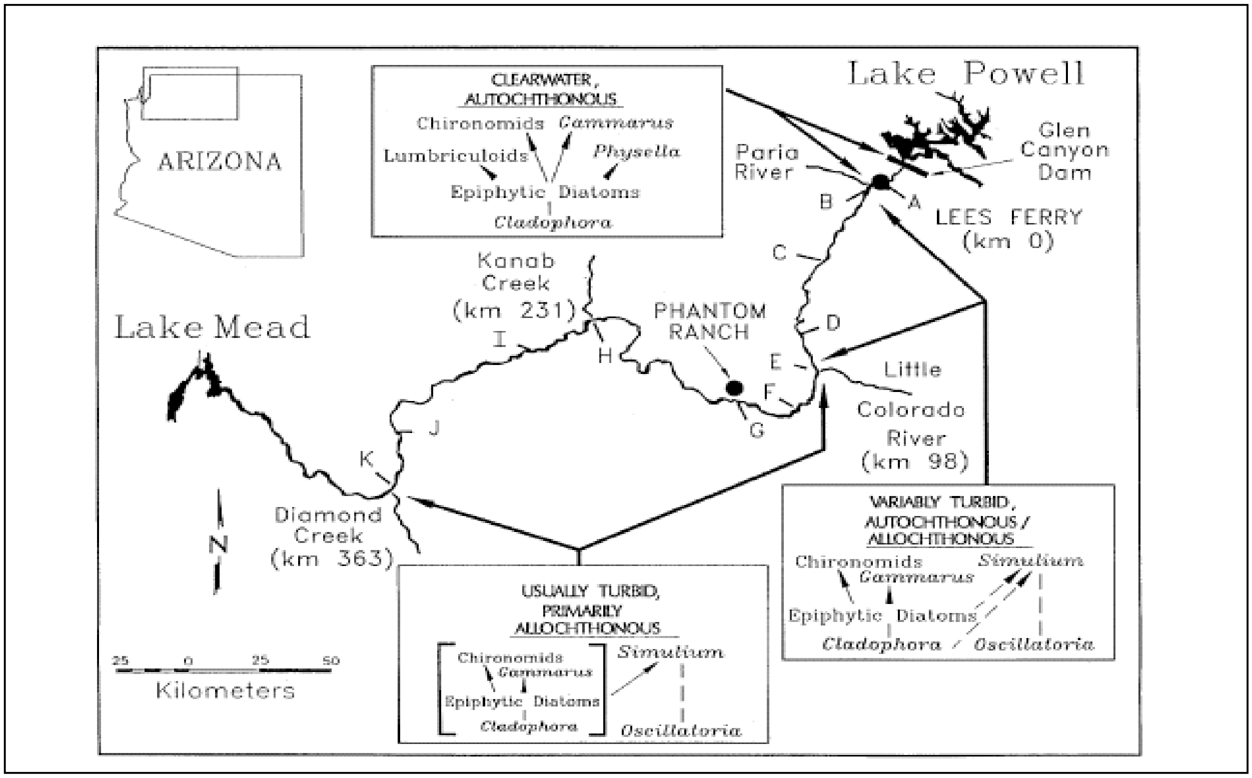
The Aquatic Food Base

Glen Canyon Dam on the Colorado River was put into place in 1963. Prior to that time, the Colorado River was a warm, sediment rich system that had large variation in flow throughout the year, ranging from a trickle in the dry months to extremely high flows as snow melted in the upper basin during spring and early summer (Shannon et al 2001, Blinn et al. 1998, Schmidt et al. 1998). Violent summer monsoons caused flooding in tributary streams, and many tons of sediment entered the river as sudden rains scoured the sparsely vegetated soft sandstone rock that makes up the Colorado plateau. The high amount of sediment in the river caused it to become turbid. High turbidity prevents energy from the sun from penetrating the water; so fewer plants and other primary producers were historically present in the river. Glen Canyon Dam drastically changed nearly all of the fundamental processes that formed and maintained the river and its associated biota. Sediment became trapped behind Glen Canyon Dam so that the tail-waters below the dam run clear. Water released from the dam comes from the layer of cold, dense water near the bottom of the reservoir (hypolimnion) and maintains a much colder average temperature than the river had in the past. Changes in water temperature and clarity led to related changes in the aquatic food base.

The Colorado River historically received most of its organic inputs from sources exterior to the river such as riparian trees, vegetation and debris washed into tributary streams. This is termed allochthonous material. When organic matter is produced within the stream itself, via algae and aquatic plants, it is termed autochthonous. There remains a large discrepancy in the scientific literature regarding the historic food base in the lower Colorado River. McDonald and Dobson (1960) reported a “sparse and depauperate” community of aquatic insects in the Glen Canyon area with 20 species reported. Persons et al. (1985) maintained this assumption and suggested that the post-dam species assemblages and densities were virtually unchanged from those in the pre-dam Colorado mainstem. Creel censuses and limnological studies performed by the Arizona Game and Fish Department from 1963 to 1972 indicated a highly disturbed system that possessed low densities of macroinvertebrates limited to *Helisoma* sp. (black snail) and chironomids (Stone 1964). This led Arizona Game and Fish Department to introduce an assortment of invertebrate species to the tailwater between 1966-1969 including the amphipod, *Gammarus lacustris*, chironomid species and snails. Most of the introductions failed however, the Gammarus and chironomids became the dominant food base taxa for trout in the tailwater.

More recent studies question the contention that the pre-dam Colorado supported so few insect taxa. Stanford and Ward (1986) and Haden et al. (2003) argue that the upper Colorado River and the Green River in Canyonlands National Park provide the best example of historic conditions in the Grand Canyon because they retain many of the distinct properties associated with free flowing desert rivers. The Green and Colorado Rivers are warm in the summer, sediment laden, and dependent on allochthonous carbon sources for their primary productivity. The species assemblage found by Haden et al. (2003) in Canyonlands National Park reflects such characteristics by the feeding guilds that are present in the macroinvertebrate population. Multi-species feeding guilds (determined by how and what an organism eats), rather than the presence of individual species, have long been used to indicate stream function (Cummins 1974; Wallace and Webster 1996; Covich et al. 1999). The aquatic insect assemblage in Canyonlands National park is large (49 taxa from 13 orders), diverse and dominated by filterer and collector organisms such as Ephemeroptera (mayflies) and Trichoptera (caddis flies) that make their living by filtering bits of detritus and coarse particulate organic matter out of the water column (Haden et al. 2003). It is particularly significant that such a high diversity of Ephemeroptera, Plecoptera and Trichoptera were found in the upper watershed, as these species are often very sensitive to sedimentation and their presence is used as an indicator of good water quality (Cummins 1974). The fact that the hydrograph and sediment loads through Canyonlands National Park are virtually unchanged from historic data indicates that the pre-dam food base was likely far richer and more abundant than previously thought.

Figure 1. Map of the Colorado River through Grand Canyon National Park. Boxes show river ecosystem energy shifting from autochthonous sources in the Clearwater segment to largely allochthonous sources in the turbid downstream reaches. Dashed lines without arrows in the boxes indicate weak trophic linkages. (Stevens et al. 1998).



The 26-km reach from Lee's Ferry to the mouth of its first major tributary, the Paria River has been transformed into a very different system by the presence of Glen Canyon Dam. This stretch of the river has very high aquatic plant productivity due to the newfound clarity of the water, its consistent temperature and the nutrient-rich inputs from Lake Powell reservoir. A cold, clear stream with a stable substrate is the ideal condition for the prolific growth of algae (Blinn et al. 1998). The system along this reach is dominated by the alga species, *Cladophora glomerata* (Shannon et al. 2001) but densities of aquatic macrophytes such as *Chara contraria*, *Potamogeton pectinatus*, and *Elodea* species have been increasing since 1993 (McKinney et al. 1996, 1997). This thick carpet of vegetation on the scoured river bottom is the basis of an entirely new food web at the base of Glen Canyon Dam. Cladophora hosts epiphytic diatoms that are the preferred food for many macroinvertebrates (Blinn and Cole 1991; Shannon et al. 1994). This clear water habitat has created a community of aquatic organisms that would ordinarily be found in nearctic regions and cannot tolerate sediment laden water as was historically present (See Table 1). Caddisfly and stonefly shredders presumably present in the pre-dam Colorado are absent in the tail waters of the Glen Canyon Dam, largely due to the low input of allochthonous carbon (Pomeroy et al. 2000).

Grazers that feed on the plentiful algae, epiphytic diatoms and macrophytes dominate the new species assemblage. These plants are plentiful in the reach at Lee's Ferry because of increased clarity in the water, consistent temperatures and lack of sediment scour (Stevens et al. 1997b, Shannon et al. 2001, Haden et al. 2003). While the aquatic food base is very different than it once was, most native fish are opportunistic omnivores and consume the new species when they are present (Minckley 1991). The first major tributary below Glen Canyon dam is the Paria River. It dumps large inputs of sediment into the Colorado and a resulting decrease in turbidity-intolerant species occurs (Stevens et al. 1998). Below the Paria, the food base consists mainly of ooze-dwelling oligochaetes as well as dipterans and physid snails in the backwaters and the bulk of the food base likely comes from tributary inputs (Stevens et al. 1998, Brouder et al. 1999).

Members of the Colorado River Food Base below Glen Canyon Dam

Figure 2. Cladophora covered rocks

http://www.dees.dri.edu/Projects/Trbm/cladophora.jpg

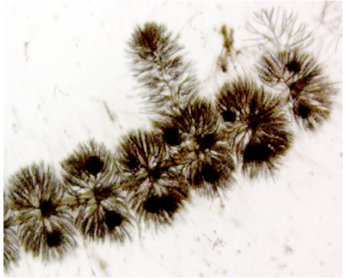


Figure 3. Batrachospermum sp.

www.stcsc.edu/ecology/algae/Algae.htm

Figure 4. Cladophora glomerata
www.stcsc.edu/ecology/algae/Algae.htm

Figure 5. Macrophyte: Elodea spp.

Image from:
www.biofil.pl/Rosliny/

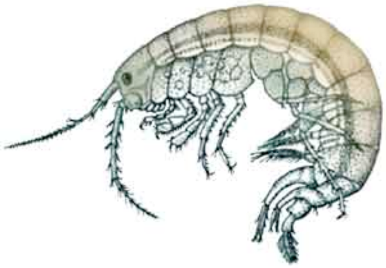


Figure 6. Introduced arthropod, *Gammarus lacustris*

Image from: www.zooexcurs.narod.ru/arthropoda/crustacea3.htm

Figure 7. Rhyacophila larvae (Caddisfly)

Image from: www.ariverneversleeps.com/.../nature.shtml

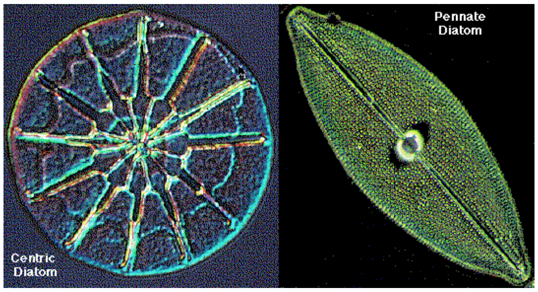


Figure 8. Diatoms

Image from: www.tidepool.st.usm.edu/ crswr/diatoms.html

Figure 9. Ephemeroptera. Leptophlebiidae

Image from: ceratium.ietc.wwu.edu/.../ Image000001/web.jpg

Table 1. Post-Dam Tail water Aquatic Food Base Species Assemblage (Shannon et al. 2001, Haden et al. 1999)

Primary Producers	**Macroinvertebrates**	
Algae: Epiphytic diatoms	**Insects** Diptera (flies): *Bibiocephala grandis* *Wiedemannia* spp. *Simulium arcticum* Complex (black flies) Chironomidae (midges) *Cricotopus annulator* Ceraptogonidae	**Oligochaetes** Lumbricidae Lumbiculidae Naididae Tubificidae
Chlorophyta: *Cladophora glomerata* *Mougeotia spp.* *Oedogonium spp.* *Spirogyra spp.* *Stigeoclonium spp.*	Trichoptera (Caddis Flies): *Hydroptila arctia* *Rhyacophila* spp. Hydropsyche oslari Limnephilidae	**Amphipods** *Gammarus lacustris*
Rhodophyta: *Batrachospermum* spp. *Rhodochorton* spp.	Ephemeroptera (Mayflies): *Baetis* spp. *Heptagenia elgantula* *Traverella albertana*	**Mollusks** Physid spp. New Zealand Mud Snails Lymnaeid spp.
Cyanobacteria: *Oscillatoria spp.* *Tolypothrix* spp. **Macrophytes**: *Chara contraria* *Potamogeton pectinatus* *Elodea* sp.		**Zooplankton** Copepoda: Calanoida Cyclopoida Harpacticoida Cladocera Ostracoda

The 1996 Test Flood

In 1996, after years of planning, land managers in the Grand Canyon permitted a controlled flood event in the Canyon to attempt to rebuild beaches, rehabilitate habitat and recreate pre-dam conditions. The response of the aquatic food base was of particular interest to researchers because it determines the food available for higher organisms such as endangered native fish, and would show how the altered food base responds to the systemic perturbations that the flood experiment sought to mimic. Macro-invertebrates and zooplankton exhibit a flight response to disturbance that is termed "drift response." When an environmental perturbation occurs, they allow themselves to be taken by the current to a more favorable location. While individuals generally have high mortality in flood events, riverine species are evolved to cope with such disturbances and have life history traits such as broad geographical ranges, rapid reproduction rates, and large numbers of offspring that allow them to recolonize an area within a few months of the event (Meffe and Minckley 1987, Shannon et al. 1996, Brouder et al. 1999).

Food Base Response

Biologists studying the food base response to the controlled flood sampled organic drift (detritus, particulate plant and animal matter and flotsam) intensively before, during and after the flood event. Shannon et al. (2001) categorized drift into three size classes, as that generally determines the species guild that will consume it: coarse particulate organic matter (CPOM) > 1mm, fine particulate organic matter (FPOM) <1 mm, and Flotsam (> 0.1 m). Researchers found the peak biomass of organic drift (*Cladophora glomerata*, miscellaneous algae, macrophytes and bryophytes (known as MAMB) and detritus) occurred as flow was first ramped up during the rising limb of the hydrograph (Shannon et al. 2001). Drifting miscellaneous macroinvertebrates, composed primarily of tubeficid worms and aquatic diptera followed the same pattern. The presence of the tubeficids indicates the movement and disturbance of sediment in the bedload of the river. The entire food base community (plant and animal) experienced reduced density immediately following the flood, with an estimated 90% of the benthos removed within the first 24 hours of the test flood (Shannon et al. 2001). Scour and entrainment of primary and secondary producers occurred throughout the canyon, though taxa associated with fine sediments such as macrophytes and aquatic worms were more susceptible to the perturbation than those associated with armored cobble habitats (Shannon et al. 2001).

Figure 10. High water during the 1996 Control flood. GCMRC

Figure 11. Chironomid Larvae.

Image from **www.biologica.bc.ca/ photos/pic09_ksamples.html**

Figure 12. Tubeficid worm

Image from www.biologica.bc.ca/ photos/pic09_ksamples.html

Table 2. Material found in CPOM, FPOM and Flotsam based on Shannon et al. 2001

CPOM	FPOM	Flotsam
G. lacustris Chironimid larvae Simuliids larvae Miscellaneous invertebrates (lumbriculids, tubificids, physids, trichopterans, terrestrial insects and unidentifiable insects) *C. glomerata* Miscellaneous algae/macrophytes Detritus	Zooplankton: (Copepoda) Calanoida, Cyclopoida, Harpacticoida Cladocera Ostracoda Miscellaneous Zooplankton Small chironomidae Oligochaeta Tardigrada	Woody detritus Aggregate clumps of macrophytes/algae

Recovery

The recovery of the aquatic food base to the 1996 test flood occurred with astonishing alacrity. In the months that followed the test flood, almost no sediment entered the system from tributary streams so water clarity was very high. The clarity of the water and the steady flows that followed the test flood likely contributed to the rapid recovery of the food base communities as much, if not more than the flood event itself (Shannon et al. 2001). Cobble substrates had complete recovery of the phytobenthos (aquatic plant community) in as little as a month. Macroinvertebrate recovery was similarly swift and all species either recovered or exceeded their pre-flood biomass within two months (Shannon et al. 2001). Shannon et al. (2001) reported, “collections for primary consumers during a post-flood trip of June of 1996 included some of the highest biomass values and most diverse fauna ever recorded during a six year monitoring program (Blinn et al. 1994, Shannon et al. 1996, Stevens et al. 1997b)." McKinney et al. (1999) noted that the controlled flood had limited impact but no apparent benefits to the aquatic communities of the Grand Canyon.

Brouder et al. (1999) examined the changes in sediment composition and the associated benthic invertebrates in backwaters. Backwaters are of particular interest because they are often warmer and slower than the main channel, accumulate the fine silts preferred by many invertebrates, and collect detritus that the invertebrates feed on. These factors also make them important habitat for fish. One of the main goals of the test flood was to rework the backwaters by flushing silt out, adding sand and rejuvenating the sandbars. While the floods achieved this goal, the beneficial results were temporary because the regulated discharges from the dam that followed were at a level that contributes to rapid erosion of sand bars. The scouring action is detrimental to the benthic invertebrates in the short term because fine silt and ooze are the preferred habitat of many species, particularly oligochaetes (worms). Their recolonization rate may have been hindered by the changes in sediment composition undergone by the backwaters. However, the detrimental effects of the flood on the backwater invertebrate communities were fairly short lived; complete recovery of invertebrate biomass and density took only a few months. Invertebrate species are adapted to periodic disturbance exhibit low resistance but high resilience to controlled flooding (Brouder et al. 1999).

Figure 13. Spatial and temporal distribution of biotic variables through the study area in 1991. (A) Total mean *Cladophora glomerata* AFDM in gC/m ^{2}; (B) total mean *Oscillatoria* spp. AFDM; (C) mean total aquatic macroinvertebrate AFDM; and (D) total mean detrital AFDM (Stevens et al. 1998).

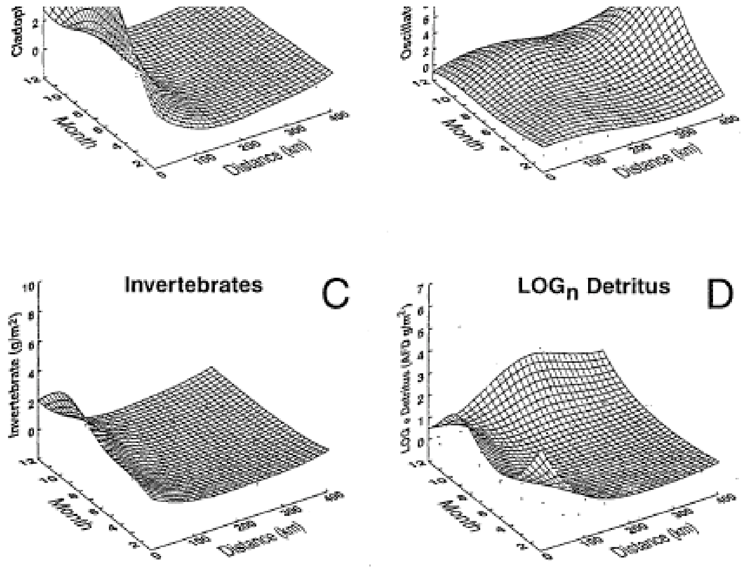


Figure 3. Spatial and temporal distribution of biotic variables through the study area in 1991: (A) total mean *Cladophora glomerata* AFDM (gC/m^2); (B) total mean *Oscillatoria* spp. AFDM; (C) mean total aquatic macroinvertebrate AFDM; and (D) total mean detrital AFDM

Analysis

The controlled flooding regime that has been practiced on the Grand Canyon since 1996 is initially very detrimental to the aquatic food base, but its affects are quickly ameliorated by the species' life-history traits that allow them to withstand and recolonize after spates of perturbation. The alteration of the historic food base in the Grand Canyon may result in diminished ability to endure flooding as later studies (Shannon et al. 2003) indicate decreased recruitment in the year following the 2001 test flood. All of the taxa that contribute to the aquatic food base (with the exception of the cyanobacterium *Oscillatoria*) showed dramatically decreased populations between 2001 and 2002. *Gammarus lacustris*, the introduced amphipod, and chironomidae larvae showed reductions in biomass of 90% and 35% respectively (Shannon et al. 2003). It is difficult to determine a precise causal relationship for this decrease, but researchers were surprised at the low biomass of the phyto-benthic community because continuous low flows and high water clarity generally increase primary production in the stream. It is difficult to assess the success of the test flood regime because the management of flow regime and uncontrollable conditions in a given year make it difficult to correlate results to a specific cause. Management of the river flow before and after the flood has as much, if not more, impact on the benthic community's recovery as the flood event itself.

There are benefits of the controlled flooding on invertebrate populations that could outweigh the drawbacks of reduced populations immediately following the flood event. Periods of high flow may indirectly increase populations of macroinvertebrates that were historically found in the Grand Canyon by entrainment of allochthonous material such as terrestrial leaf litter, woody debris and vegetation. This type of material, largely eliminated from the system by the presence of Glen Canyon Dam, provides crucial food sources for invertebrates in turbid desert streams (Haden et al. 1999, Haden et al. 2003). The absence of such material from the current system is probably largely responsible for the decreased biodiversity and density of invertebrates on the sections of the Colorado below the confluence of the Paria River. The decrease in light penetration lowers primary production and favors the growth of the less nutritious cyanobacteria, *Oscillatoria* spp. in the lower reaches (Blinn et al. 1999). *Oscillatoria* is shown to support ten-fold fewer invertebrates than *Cladophora*, making the input of allochthonous carbon vital to support the benthic community and food base for imperiled native fish. However, one potential concern is that the prevalent non-native *Tamarix ramosissima* that has become the dominant vegetation is an inferior food source for invertebrates. This is due to its high tannin content and faster decomposition rate than native cottonwoods and willows (Bailey et al. 2001). Bailey et al. (2001) demonstrated that tamarisk leaf litter supported fewer than half the number species and a quarter of the overall abundance of macroinvertebrates as cottonwood leaf litter in the same stream. While the quality of tamarisk is less than that of native vegetation, any allochthonous inputs would benefit the carbon-starved lower Colorado. If the test flood has a negative effect on the tamarisk population and favored native vegetation within the Grand Canyon, it would likely benefit the macroinvertebrate food base. Another threat to the aquatic food base is the presence of the invasive New Zealand Mudsnail, which will be discussed later in this paper.

Kanab ambersnail

The Kanab ambersnail (KAS),*Oxyloma haydeni kanabensis*, is a federally endangered, endemic snail that occurs in only two locations in the world. One of those locations is at a spring called Vasey's Paradise that flows into the Colorado River and is well within reach of high water. The snails are a relict species from the cooler, wetter Pleistocene era and are dependent on perennially wet soil surfaces and decaying plant litter of springs and seepages near sandstone or limestone cliffs (USFWS 1995). KAS require monkeyflower (*Mimulus spp.*), cattails (*Typha spp.*) or watercress (*Nasturtium spp.*), as their primary habitat. Historically, annual floods scoured all vegetation below the 90,000 cfs mark. The vegetation at Vasey's Paradise has increased by about 40% at its lower stage elevation since the completion of Glen Canyon Dam, thus artificially allowing the KAS to greatly expand the area it occupies. Federal law prohibits the "taking" or killing of endangered organisms and thus the controlled floods undertaken by the USGS are potentially in direct opposition to the law.

Figure 14. Kanab Ambersnail

Image from: www.arizonaguide.com/ gallery_popup~gallery_id...

Figure 15. Vasey's Paradise

Image from: www.kaibab.org/ tr971/gcr1035m.htm

While the KAS has survived and recovered from countless flood events in the canyon in the pre-dam era, the test flood was of sufficient magnitude to substantially alter the habitat at Vasey's Paradise and negatively affect the population. The U.S. Fish and Wildlife Service's (USFWS) biological opinion on the effects of dam operations on endangered species established that a permissible level of impact to the snail and its habitat was the destruction of 10% or less. Impacts larger than 10% of the habitat required a formal consultation between the Bureau of Reclamation and the USFWS as well as the cessation of operations causing the damage. The controlled floods stood to alter as much as 17% of the habitat and while the USFWS acknowledged the potential overall benefits of the flood, protecting the KAS from harm was paramount. They determined that 90% of the KAS population must be removed from the potential flood zone. This required almost complete destruction of the vegetation that the snails depended on, an effort that would save the snails but destroy their critical habitat. At the last minute, USFWS amended their requirements to have 75% of the snails removed from 50% of the worst-case inundation zone (Meretsky et al. 2000). The researchers removed approximately 1,275 KAS to higher ground for the duration of the flood. In order to comply with the requirements of the KAS's recovery plan, the USFWS determined that future floods must be restricted to less than 45,000 cfs and higher flows were to be avoided (GCMRC 1999).

In the 2001 controlled flood, USFWS actually dug up patches of monkey flower and put them on pallets located above the high water mark, thus hopefully removing more snails from the threat of high water than the 1996 flood while conserving the vegetation critical to the snail's survival. While extensive measures were taken to insure that the snail was not unduly harmed by the control flood, the quandary of the KAS occurring in only a single, vulnerable location forced managers search for another solution. USFWS initiated studies on potential sites of suitable habitat where wild populations of KAS could be established throughout the Canyon, thus relieving the burden of Vasey's Paradise being their only habitat. The National Park service introduced small populations of KAS in three suitable locations above the flood line, including Elves Chasm and Indian Creek. The snails are persisting and reproducing in the release area and some are migrating into adjacent suitable habitat (Sorensen 2004).

Analysis

The impacts of the test floods on the KAS are potentially severe if radical measures to remove the snails to higher ground for the duration of the flood are not taken. While temporary removal of a portion of the population is technically feasible and has been done several times, it is not a sustainable management method and it is extremely labor intensive to hand pick thousands of snails from the poison ivy-filled vegetation at Vasey's Paradise. Additionally, the process is very destructive to the snail's habitat, though any vegetation within the high water zone gets scoured away during the flood. The fact that the population has maintained itself at Vasey's Paradise through many floods of far higher magnitude than the moderate releases permitted for the test floods indicates that the KAS is somewhat resilient to environmental perturbation and its population is sufficiently high at Vasey's Paradise to recover from minor floods. The establishment of viable wild populations in locations out of the flood zone will relieve some of the concern about KAS mortality during controlled floods. Continued monitoring and removal of individuals at Vasey's Paradise during floods may be required until those other populations become stable enough to augment the current population. The fact that the snail is hermaphroditic and fecund helps it to recover quickly after perturbations. Ultimately, the presence of the KAS should not hinder the continued rehabilitation of riverine processes attempted with the controlled flood releases and conversely, the controlled floods will not excessively damage the snail's population.

New Zealand Mudsnail

The New Zealand mudsnail (NZMS), *Potamopyrgus antipodarum*, is an invasive gastropod that has invaded many of the large drainages in the western United States (Shannon 2002, Shannon et al. 2003). The USFWS has listed the NZMS as an aquatic pest species under the Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990. The NZMS was first established in the Colorado River in 1995, but was misidentified until 2002. It is thought that the NZMS was introduced via gear from recreational fishermen at Lee's Ferry. The NZMS concerns managers because it competes directly with the important food base species in the tailwater. Chironomids and *Gammarus lacustris* have provided an adequate food base for native fish and introduced trout in the tailwater, but in recent years there have been drastic shifts in the aquatic food base at Lee's Ferry. The dominant keystone alga, *Cladophora glomerata*, has been

Figure 16. New Zealand Mudsnail

Image from: http:// wildlife.state.co.us/aquatic/ nuisances/hitchhikers/NewZealandMudsnail.asp

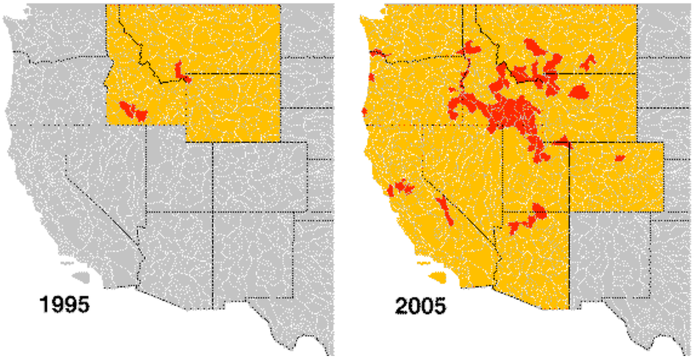


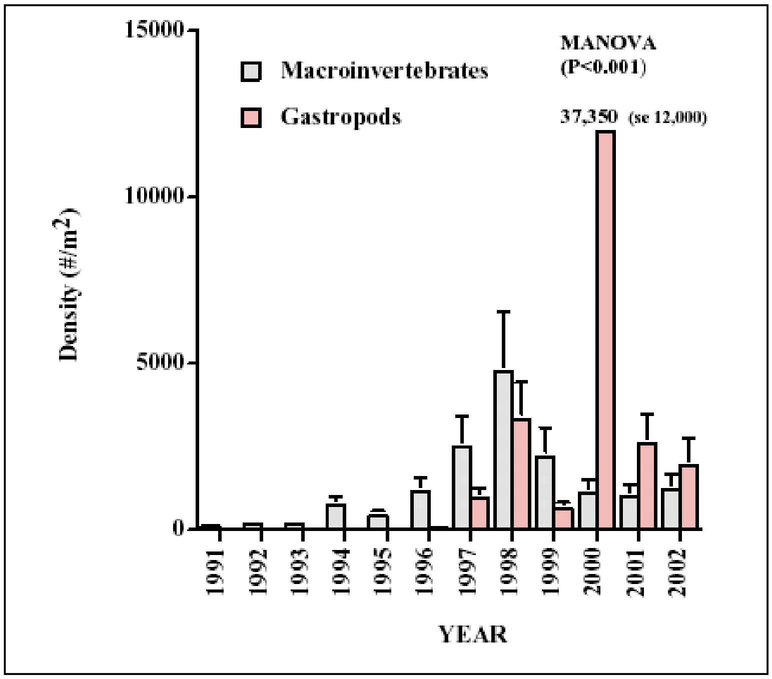
Figure 17. Changes in the NZMS distribution in the western U.S.A. from 1995 to 2005.

Image from: http://www.esg.montana.edu/aim/mollusca/nzms/

replaced by less nutrient-dependent filamentous algae. This is likely due to changes in the nutrient load of Lake Powell, but may also be related to the NZMS invasion (Shannon et al. 2003). The other species of algae are less nutritious and support fewer macroinvertebrates and diatoms, which has led to major decreases in important food base species (Blinn et al. 1999).

The NZMS's morphology and life-history traits enable it to enter and dominate low gradient streams, particularly in disturbed ecosystems such as the Grand Canyon. It is a small, hardy snail that can live out of water for up to a month. It has an operculum that allows the snail to seal itself in its shell for long periods of time and it has been observed to not only pass through the gut of a fish intact, but to give birth immediately afterward with no ill affect (Haynes et al. 1985). The NZMS is a threat to native fish fauna for several reasons: 1) They have low value as a food species and thusly are a trophic "dead end," severing the important link that invertebrates form between primary producers and secondary consumers (Shannon et al. 2003). 2) The snails compete directly with important food species for food resources and consume the majority of the epiphytic diatom assemblage 3) They are asexual, meaning that they do not need a mate to produce offspring, and they are extremely fecund; one NZMS can give birth to as many as one million progeny a year. NZMS has been observed in every habitat type in the Grand Canyon and makes up anywhere from 20%-100% of the invertebrate biomass in cobbled areas. They are able to move rapidly into pristine habitats and are thought to diminish their functionality through interference competition and their low food value (Shannon et al 2003). While the detrimental effect of the NZMS is poorly understood, it is thought that they contribute to the "sub-lethal but negative impact" on native fish (Shannon et al. 2003). Trout populations at Lee's Ferry have already shown evidence of NZMS impacts. Recruitment is high, but the fish are not growing well, a symptom commonly expected with NZMS invasions (Anderson 2002).

Figure 18: From Kloeppel and Shannon 2003. Demonstrating that NZMS is the dominant macroinvertebrate in the Grand Canyon



Analysis

The recent invasion by the NZMS may have already created negative impacts on both the aquatic food base and the declining populations of the endangered humpback chub (*Gila cypha*). Shannon et al. (2003) report that the NZMS prefers habitats with constant temperatures, flows and high primary productivity. Because of this, the controlled floods may help to reduce populations in the mainstem and reduce the invasions of tributaries. However, all of the test floods that have occurred on the Colorado River have taken place since the NZMS first arrived and the population has steadily increased since that time. This indicates that the NZMS is resistant to high flow events and that current flood levels (< 45,000 cfs) are unlikely to adequately reduce the population. Invasions from the NZMS have occurred throughout western watersheds and managers across the country are grappling with the difficult question of how best to rid them of this pestilential invader.

Conclusion

The test floods introduced to the Grand Canyon are an attempt to resurrect the important physical processes that have shaped the river for millennia. While the floods themselves have a detrimental short-term effect on most of the invertebrates and aquatic plant communities, they are not detrimental to them in the long term. Most of the species in the aquatic food base have evolved in dynamic river systems that are prone to periodic disturbance and can fully recover within months of such an event. It is not clear how or if flood timing will affect invertebrate recovery because of the diversity of life history strategies, life expectancy, reproductive timing and habitat susceptibility that occur within the food base, but we do know that invertebrates are better able to withstand disturbance that is predictable in its timing and intensity (Poff 1992, Haden et al. 2003). The test flood regime could be very important to recover some important Canyon resources such as sand bars and backwater habitat.

The Kanab ambersnail is a species that will not benefit from the test floods, in fact they have benefited from the lack of floods that allowed a significant expansion of their habitat. However, management precautions can be taken to avoid damaging their population unduly. Fall and winter flooding may be more harmful to KAS as they go dormant at that time and are more difficult to locate and remove from senescent vegetation and leaf litter than when they are active. Now that U.S. Fish and Wildlife Service is establishing additional wild populations of the snail out of the flood zone, it is less likely that the KAS's presence will be a hindrance to further managed floods. It is critical that care is taken to protect the snails in Vasey's Paradise, as their range is so limited and the introduced populations are not well established yet. A miscalculation in the high water line could prove extremely detrimental to the Vasey's Paradise KAS population.

It is imperative that managers initiate further studies of the New Zealand mudsnail's impact on the ecosystem. The NZMS is a dangerous invader whose presence is altering the lower trophic levels of the food web and contributing to the precipitous decline of the endangered humpback chub and other native fishes. While the food base in the Colorado River is quite different than it once was, it has provided an adequate food source to both native and non-native fish. The NZMS's presence may reduce the aquatic food base and lead to further declines in the already impacted aquatic community. It is unclear how the controlled floods impact NZMS populations, but under the experimental regime of the last ten years they have grown and spread downstream from Lee's Ferry. We must also consider the possibility that controlled floods are possible vectors for snails to colonize new areas. It is uncertain as to what extent the presence of the NZMS has on the aquatic food base. However, preliminary studies on the Colorado River, and evidence in other rivers indicate that the food base declines in the snail's presence.

In all, there is good potential for the controlled floods to be a positive impact on the Colorado River ecosystem despite of its short-term negative effects. In heavily managed rivers such as the Colorado River, it can be very difficult to understand the vast scope of ecosystem impacts and responses, but ultimately, we are trying to make the best management choices to rehabilitate important ecosystem components. The prevalence of invasive species throughout the Grand Canyon confounds our understanding of the controlled flood impacts and the system's recovery. The ultimate goal is to make the whole system healthier and preserve the critical natural resources in Grand Canyon National Park. Our knowledge of the Grand Canyon ecosystem is still limited, therefore using our best knowledge and learning as we go is a vital tool for future management decisions.

Figure 17. The Grand Canyon

Image from: http://www.mongabay.com/external/grand_canyon_trouble.htm

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